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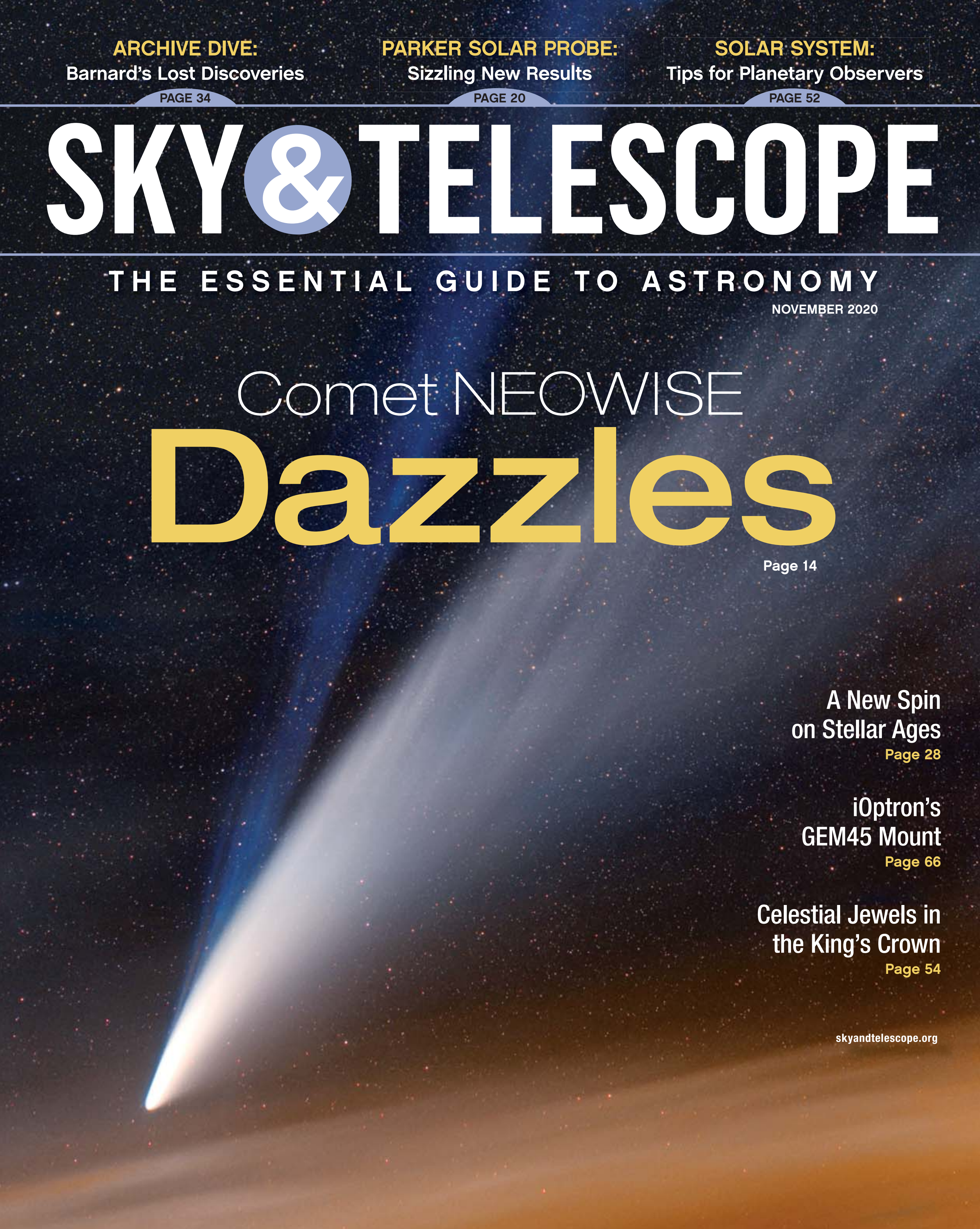
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

NOVEMBER 2020



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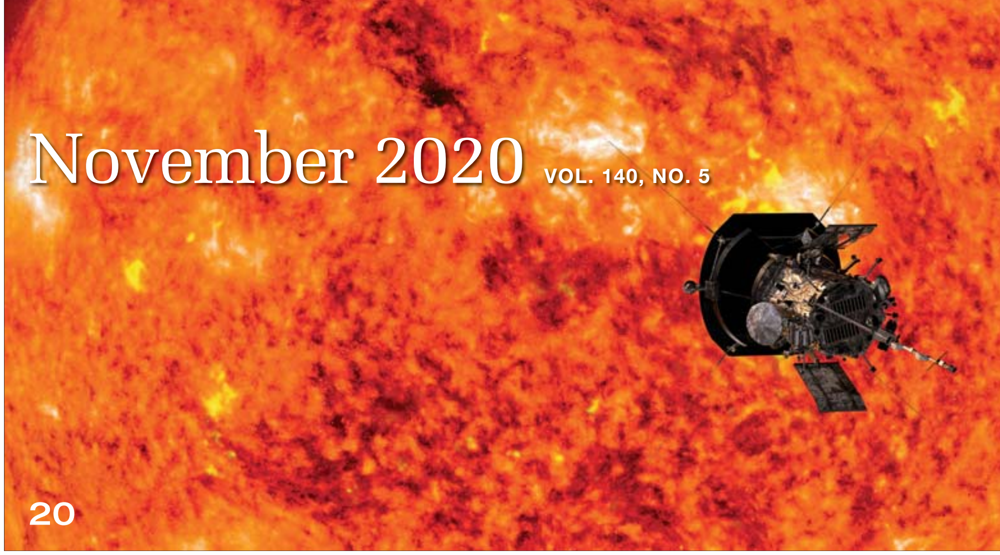
THE ESSENTIAL GUIDE TO ASTRONOMY

November 2020 VOL. 140, NO. 5



NASA / JOHNS HOPKINS APL / STEVE GRIBBEN

ON THE COVER

Comet NEOWISE displays complex ion and dust tail patterns.
PHOTO: GERALD RHEMANN

ONLINE

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New to astronomy? From learning the night sky to tips on buying your first telescope, here's everything you need to jump into the fun.
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Cozying Up to Our Star

WHEN IT COMES TO interactions with the Sun, survival depends on getting close but not too close. We owe our very existence to this sweet spot, with Earth basking in our solar system's Goldilocks zone: neither too hot nor too cold but "just right" for life to thrive.

Comet NEOWISE, which we parade on our cover and in Associate Editor Sean Walker's photo essay on page 14, demonstrated this maxim to a T. Comets that swing too near the Sun can split and fizzle, as Comet ATLAS did earlier this year. Others that keep our star too much at arm's length can slip by without becoming visually stunning. But Comet NEOWISE got it just right.

When it was discovered on March 27th, the comet was about magnitude 18. By the time it emerged from its nearest brush with the Sun on July 3rd, it had attained a mag of 0.5 to 1, easily visible to the naked eye. As our selection of images reveals, thousands of observers across the world enjoyed this comet, the brightest viewable from the Northern Hemisphere since the mid-1990s' Comet Hale-Bopp.

Getting it just right: a Parker Solar Probe image of Comet NEOWISE, taken on July 5th, just after perihelion

NASA / JOHNS HOPKINS APL / NAVAL RESEARCH LAB / PARKER SOLAR PROBE / BRENDAN GALLAGHER

Comet Biela, by contrast, might be one of those icy visitors that, like Icarus, flew too close to the Sun. I say "might," because, as David Nakamoto explains in his story on page 58, the fate of this comet (first identified in 1826) remains unclear. Did it fragment into multiple pieces like Comet Shoemaker-Levy 9 famously did in the 1990s? If so, does any large chunk of it survive to this day?

Even if the comet itself no longer exists, the meteor shower associated with it might. In 1872, dust particles from Comet Biela put on one of history's best meteor displays. In subsequent decades, this shower waned in intensity. But as Joe Rao notes in his sidebar on page 63, astronomers recently detected a major uptick in the comet's shower, with exciting possibilities for 2023 in particular.

Nothing takes the Goldilocks concept to such exacting extremes as the Parker Solar Probe, however. As News Editor Monica Young describes starting on page 20, this highly engineered spacecraft will journey right up to our star. If the Earth-Sun distance were the 100 yards of an American football field, the probe's upcoming nearest approaches would have it straddling the 4-yard line.

Young will explain *why* we're sending this car-size spacecraft into the Sun's very atmosphere, but consider for a moment one extraordinary fact about *how*: The Sun-facing surface of the probe's heat shield will reach temperatures of up to 1,370°C (2,500°F) on closest approach. Yet the instruments behind the shield will remain at 29°C (85°F)! Human ingenuity, it seems, knows no bounds, especially when it comes to getting things just right.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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SHARE YOUR UNIVERSE

Fond Remembrances of Fantastic Comets

Ken Hewitt-White's article, "Celebrating Hale-Bopp" (*S&T:* July 2020, p. 30), reminded me of one of the highlights of my career as an airline pilot. We had a smooth ride on a flight to Seattle with an aviation-safety inspector in the jumpseat and Comet Hale-Bopp directly ahead. I knew a lunar eclipse was in progress behind us and requested a 90° left turn for 15 miles followed by a 180° right turn to get back on course. The controller cleared our request and asked why. "Well, we've got quite a sight for the passengers!" we replied. We had the flight attendants turn out the lights and told everyone that a lunar eclipse was happening to the left and Hale-Bopp was visible on the right. We turned around and switched the view after a couple of minutes. Other flights behind us started making the same request. Judging by the reaction at the gate, we created several dozen new stargazers that evening.

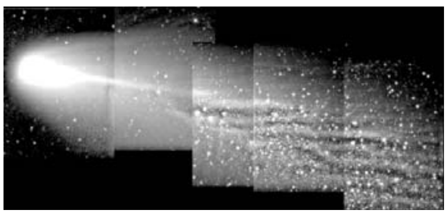
Gordon Strader
Nampa, Idaho

I enjoyed Ken Hewitt-White's article. It brought back many great memories. I observed Comets Bennett (C/1969 Y1), West (C/1975 V1), and Hyakutake (C/1996 B2), but Comet Hale-Bopp (C/1995 O1) is the one I remember as the best comet of my life.

At that time, CCD astrophotography was coming into its own. My good friend Jim Edlin built me a camera based on *The CCD Camera Cookbook* by Richard Berry and colleagues. We had some great times with that camera, but one night stands out.

I don't remember the date, but we spent all night in my observatory photographing Comet Hale-Bopp as it climbed into the northeastern sky. I used an 80-mm Orion ED refractor and took short integrations moving down the tail. Later, I combined the images together. That image was at the top of the *Camera Cookbook* homepage for awhile.

James Hannon
Terryville, Connecticut



▲ James Hannon captured this image of Comet Hale-Bopp using a homemade CCD camera from his backyard observatory.

◀ Comet Hale-Bopp put on an incredible show for skywatchers in 1997. This image of Adam Horne watching Hale-Bopp through binoculars appeared in the July 1997 issue of *S&T*.

JOHNNY HORNE

A Simple Solution

I read Jerry Olton's article "Finder Finders" (*S&T:* June 2020, p. 72) with interest and thought that I should share how I aim my 8-inch Newtonian. I look at a bright star with one eye looking directly at the sky and the other peering through the finderscope. Then I move the telescope until the image in the finder coincides with the view in the other eye. I'm grateful to the vendor who sold me the telescope for giving me this tip, when I wanted a red-dot finder. He lost a sale but won a loyal customer.

Peter Morris
Harare, Zimbabwe

Trifid Nebula's True Colors

In "A Tourist's Guide to the Summer Highlights" (*S&T:* July 2020, p. 60), Jerry Oltion comments that, to his eye, the emission portion of the Trifid Nebula (M20) appears bluish and the reflecting portion appears reddish — opposite what images show. I've noted the same thing using a 14.5-inch Newtonian under dark skies. I thought the emission portion appeared blue because it was brighter.

I've also called experienced observers over to see the seemingly reversed colors and had them disagree.

In contrast, I've also seen M20 under exceptional skies at Arches National Park with a 70-mm refractor. Both components appeared nearly equal in brightness, and both looked white.

Andrew Jaffe
Portsmouth, New Hampshire

A History of Stardust

I applaud Brian Ventrudo's article "Stellar Archaeology" (*S&T:* June 2020, p. 58). He clearly and concisely explains how the study of observable ancient Population II stars allows astronomers to estimate the history of the earliest stars, Population III, which are so far unobservable. His explanation of the origins and history of metals that make up younger stars, including our own Sun, is fascinating.

Jay Bruesch
Excelsior, Minnesota

I was puzzled by the diagram "Origins of the Elements" on page 64 of Brian Ventrudo's article. In particular, I did not understand the inclusion of elements with atomic numbers greater than iron produced by "Dying low-mass stars." I can't see how these stars could produce an appreciable amount of heavy elements. It wouldn't be by fusion, since the fusion of elements heavy enough to make these atoms is endothermic. Nor could it be by a neutron absorption process of lighter elements since, as far as I know, neutrons are not produced in large amounts during the death of low-mass stars. Could you please explain?

Paul White
Portsmouth, Rhode Island

Camille Carlisle replies: *Great question. Low-mass stars do create heavy elements through neutron capture, in a gentler process than fusion called the s-process (s is for slow). As the star ages, reactions in the star create free neutrons, and these combine with heavy atoms left over from previous generations of stars. When this reaction creates unstable nuclei, the neutrons decay into protons, creating heavier elements. Margaret Burbidge and colleagues wrote the seminal work that first described the formation of heavy nuclei in 1957:* **https://is.gd/Margaret_Burbidge**.

The periodic table we published is a reproduction of the one published by Jennifer Johnson in the research journal Science *last year:* **https://is.gd/Nucleosynthesis**.

Io Epiphany

My daughter gave me a gift subscription to *Sky & Telescope* in 2018. I have some basic equipment but don't consider myself an amateur astronomer. Much of what I read in *S&T* flies past me as Halley's Comet did the year she was born, but Ashley Davies' article "Io, the Volcanic Rosetta Stone" (*S&T:* July 2020, p. 14) was so wonderfully written and illustrated that I finally understood a few of the basic tenets of tidal heating. Congratulations and thank you for this revelation of outer-space phenomena and for bringing an aging adult wonders of science and physics that were largely unknown back in my day, when we had nine planets. I'm hoping to stick around long enough to make up for a good portion of what I've missed, proudly wearing my "Never Underestimate an Old Man Who Loves Astronomy" T-shirt.

John P. Junke, Sr.
Walla Walla, Washington

Across an Eclipse

The photograph of an airplane crossing the partially eclipsed Sun below Howard Ritter's letter (*S&T:* Aug. 2020, p. 6) is an illustration of a phenomenon I have seen many times since becoming a solar observer in 1979.

I mentioned one of these sightings while giving a talk on solar observing to the Memphis Astronomical Society several years ago. My friend Richard Moore immediately declared it the "Plane of the Ecliptic."

Bill Wilson
Memphis, Tennessee

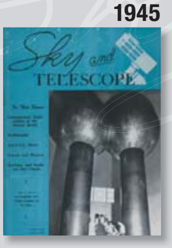
FOR THE RECORD

● In the "Path of Pluto" chart (*S&T:* July 2020, p. 49), SAO 188414 was mislabeled as SAO 1888414.

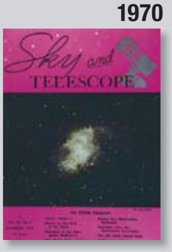
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1945



1970



1995

◖ November 1945

Radar's Novelty "War-inspired advances in electronics promise to [be of value to] astronomers.

"Radar-tracking equipment may ultimately perform highly accurate parallax work in the solar system. The time interval required for a radio pulse to be reflected back from a distant object tells the distance . . . and the accuracy in distance attainable promises to be of the order of a fraction of a mile! Moreover, as the character of the echo depends on the nature of the reflecting surface, radio ranging might eventually answer such questions as, for example, whether or not there are oceans on Venus."

The first hint that Venus is too hellishly hot for oceans came in the 1950s, not from radar, but from the planet's emission at radio wavelengths. Crude radar mapping of the cloud-veiled surface from Earth began in the 1960s, but it vastly improved later, close up, with the Soviet Venera and American Magellan orbiters.

◖ November 1970

Nonrandomness? "[Typically, meteor-shower watchers] see some meteors coming in quick succession, others separated by long intervals. . . . The existence of bunchiness cannot be accepted as real unless it meets a suitable statistical test, such as the following.

"At Running Springs, California, John Rabold and David Gilmore used a tape recorder and WWV signals to obtain the arrival times of Perseids to the nearest second on the morning of August 12th. Let us take their data for the two-hour period beginning at 9:00:00 UT, during which 155 Perseids were recorded. We divide this period into 120 consecutive intervals of 60 seconds each, and count how many intervals contain 0 meteors, 1 meteor, 2 meteors, and so on. [An accompanying table compares these to] the Poisson distribution formula . . . The agreement between the observed and predicted values . . . is so close that we can infer a random distribution of arrival times, at least for this sample of 155 Perseids."

Editor Joseph Ashbrook often engaged readers in useful observing projects, then demonstrated their scientific value.

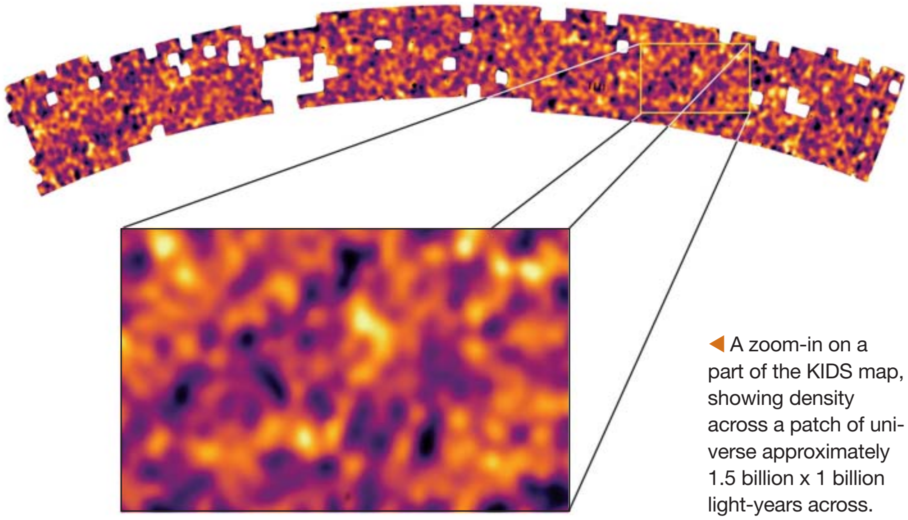
◖ November 1995

Space Voids "Bubbles, supershells, and chimneys — vast regions nearly empty of interstellar gas — can be found in many galaxies [including the Milky Way.

"In fact,] data obtained at ultraviolet wavelengths suggest that our solar system may enjoy a chimney of its own. Spectral studies of the yellow giant star 31 Comae with the Extreme Ultraviolet Explorer satellite show remarkably little absorption of the star's emission by ionized magnesium and atomic hydrogen. A typical swath of the interstellar medium contains enough of these two gases to create strong absorption lines in a star's spectrum. This suggests, noted Thomas R. Ayres (University of Colorado) and his colleagues, that we may be looking out a 'hole,' or chimney, when viewing perpendicular to the galactic plane."

COSMOLOGY

Unexpectedly Smooth Universe Points to New Physics



◀ A zoom-in on a part of the KIDS map, showing density across a patch of universe approximately 1.5 billion x 1 billion light-years across.

THE UNIVERSE APPEARS TO be smoother than expected.

The latest data release from the Kilo-Degree Survey (KIDS) confirms earlier indications that the current distribution of gravitating matter is less clumpy than predicted by the standard cosmological model.

Using the 256-megapixel OmegaCAM on the 2.6-meter VLT Survey Telescope at Cerro Paranal in Chile, the KIDS collaboration has studied 31 million galaxies in two large swaths of sky totaling 1,006 square degrees. Intervening matter (both visible and dark) slightly bends the light from these galaxies via weak gravitational lensing, producing tiny distortions in their shapes (*S&T:* Sept. 2016, p. 34). Precise analysis of this cosmic shear reveals the distribution of matter.

The standard cosmological model predicts that galaxies and galaxy clusters should group together a certain amount in the present-day universe. However, analysis of the KIDS map yields a measurement of this clustering, termed S_8, 8.3% smaller than expected. Researchers posted five studies on the KIDS results July 30th on the arXiv preprint server.

There's only a 1 in 1,000 chance that the findings are from scientists looking at a unusual part of the universe, according to team member Benjamin Joachimi (University College London).

The issue with S_8 might be related to the ongoing Hubble constant controversy (see below), says KIDS project lead Koen Kuijken (Leiden Observatory, The Netherlands). But it's too early to say if either really points to a fundamental problem with the standard cosmological model. "Maybe it's just a matter of relatively small modifications."

"If the anomaly in S_8 and the Hubble constant stands the test of time, then both may imply new physics," counters theorist Abraham Loeb (Harvard University). "So far, however, I have not seen an elegant theoretical idea that can account for the Hubble tension, let alone the anomaly in S_8."

■ GOVERT SCHILLING

COSMOLOGY

New 3D Map of the Universe Heightens Debate

THE SLOAN DIGITAL SKY SURVEY (SDSS) has released a new map of the universe, a comprehensive look at the universe's evolution over the past 11 billion years. The results heightened ongoing tension over the current expansion rate of the universe.

In 23 papers posted July 19th to the arXiv preprint server, astronomers amass conclusions from the Extended Baryon Oscillation Spectroscopic Survey (EBOSS), which cataloged almost 1 million spectra of galaxies and quasars in a search for a signature from the universe's earliest years.

When the cosmos was still hot, light was entangled with matter. As plasma gravitated toward areas of higher density, photons rebelled, pushing the charged particles outward again. The resulting push and pull sent the primordial plasma sloshing. As the cosmos cooled, matter went from charged to neutral, freeing the photons now seen as the cosmic microwave background (CMB). But the sloshing left its imprint on the distribution of matter (*S&T:* Apr. 2016, p. 22). That imprint remains on the very largest cosmic scales: When SDSS astronomers tabulated the distances between millions of galaxies, they found that galaxies are slightly more likely to be separated from their nearest neighbor by 490,000 light-years.

Astronomers can use this characteristic separation as a *standard ruler* to gauge the change in the universe's expansion rate over cosmic time.

Using EBOSS data, astronomers measured how fast the universe is expanding now, represented by the controversial *Hubble constant*, finding a value between 67.4 and 69.0 km/s/Mpc. The Hubble constant decides the fate of the universe and has been a source of ongoing controversy (*S&T:* June 2019, p. 22). The EBOSS result agrees with measurements from the CMB but is lower than what measurements of stars and supernovae in relatively nearby galaxies would suggest.

"If people thought that after more data collecting the discrepancy would just disappear, that hasn't happened," says Adam Riess (Johns Hopkins University), who was not involved in the study. "In fact, its significance has generally been growing."

"I think there is something interesting at play," he adds.

■ MONICA YOUNG

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

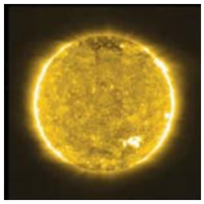
B. GIBLIN / K. KUIJKEN / KIDS TEAM

SUN

Solar Orbiter Takes Closest Images of the Sun

THE EUROPEAN SPACE AGENCY'S Sun-imaging spacecraft has released its first images.

The Solar Orbiter captured the views on May 30th, ahead of full science operations and just before its first perihelion on June 15th. The first pass took the spacecraft to within 77 million km (48 million miles) of the solar surface, or roughly half Earth's distance from the Sun. The Solar Orbiter does not go as near to the Sun as NASA's Parker Solar Probe does (see page 20). However, its greater distance allows multiple cameras to safely peek out from peepholes in the spacecraft's heat shield in order to photograph the Sun and its atmosphere.

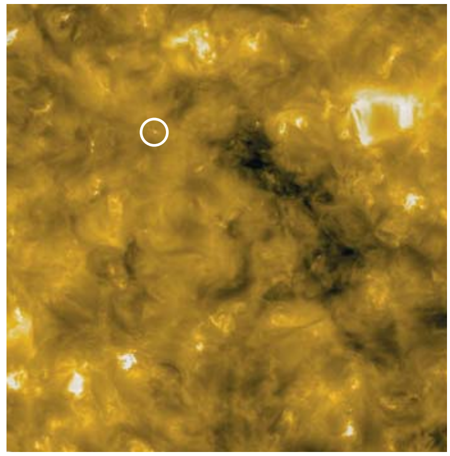


The Solar Orbiter will continue to offer a unique vantage point on solar activity. While other views of the Sun — whether from Earth or from satellites — have come from within the *ecliptic*, the plane in which the planets orbit, the Solar Orbiter will provide the first images of the solar poles. Its increasingly inclined orbit will ultimately take the spacecraft 33° above the equator.

That orbit is still shrinking, too: When science operations begin in March 2022, the Solar Orbiter will fly within ⅓ astronomical unit of the Sun's visible surface and capture images at least twice as sharp as the ones just released. The spacecraft won't start probing the solar poles until 2025, with its best polar views coming after 2027.

■ MONICA YOUNG

See more Solar Orbiter images and results at https://is.gd/SOfirstlight.



▲ The first views taken by the Extreme Ultraviolet Imager show ubiquitous mini-flares, dubbed *campfires* (circle).

SOLAR SYSTEM

Three Mars Missions Launch Successfully

THREE COUNTRIES SENT MISSIONS to the Red Planet this July: United Arab Emirates (July 19th), China (July 23rd), and the United States (July 30th).

The Emirates Mars Mission was the first to go, launching from the Tanegashima Space Center in Japan. The United Arab Emirates funded and built the spacecraft in collaboration with Arizona State University and University of Colorado, Boulder. Both institutions also contributed instruments to the mission. Called Hope, the mission marks the first time a national space agency passed up on a preliminary lunar mission and instead headed to Mars on the first try.

The ambitious Chinese mission, Tianwen 1, contains an orbiter, lander, and rover all in one package. The China National Space Administration provided only sparse information about the mission leading up to and during the launch, but officials lifted the news blackout 36 minutes after launch, confirming that Tianwen 1 had successfully reached a Marsbound trajectory.

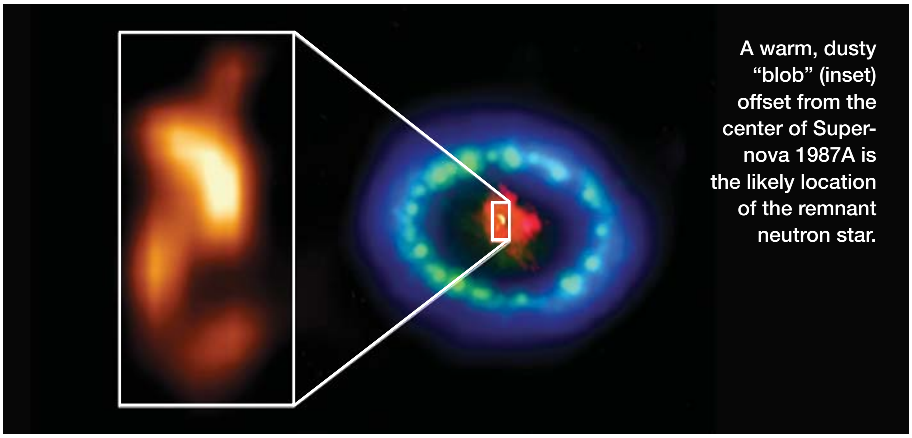
A week later, NASA's Perseverance rover and its helicopter Ingenuity took to the skies, launching from Cape Canaveral Air Force Station in Florida. This was the last mission to take advantage of the current launch window to Mars (*S&T:* July 2020, p. 22). The European Space Agency's ExoMars mission and Rosalind Franklin rover will wait for the next window in 2022.

All three missions will take a seven-month journey to Mars, arriving in February 2021. Hope will enter a wide elliptical orbit around the planet, while first Perseverance, and then Tianwen 1, will touch down on the Red Planet.

■ DAVID DICKINSON

▼ Three missions head to Mars for the United Arab Emirates *(left)*, China *(center)*, and the United States *(right)*.

SUN WHOLE DISK AND CLOSE-UP: SOLAR ORBITER / EUI TEAM (ESA & NASA) / CSL / IAS / MPS / PMOD / WRC / ROB / UCL / MSSL (2); UAE HOPE: MHI WEBCAST; TIANWEN 1: CNSA; PERSEVERANCE: NASA / JOEL KOWSKY



A warm, dusty "blob" (inset) offset from the center of Supernova 1987A is the likely location of the remnant neutron star.

SUPERNOVA

Astronomers Find SN 1987A's Neutron Star

SUPERNOVA 1987A WAS one of the most-observed supernovae in history after it exploded in the Large Magellanic Cloud just 168,000 light-years away. Telescopes around the globe and in space captured the blast wave, which illuminated three overlapping rings of material that had likely blown off in the star's final years.

But in the 33 years since, a puzzle has plagued astronomers. Neutrinos received at Earth right after the supernova indicated that the collapsed object ought to be a neutron star. But astronomers couldn't find it. Dust obscures the center of the blast, and some even wondered if the core had collapsed further into a black hole.

Closer study showed the gaseous remains of the star's outer layers to be slightly off-kilter, hinting that whatever compact object had formed in the blast had received a kick away from the explosion's center.

Last year, observations from the Atacama Large Millimeter/submillimeter Array (ALMA) hinted that the search might be at an end. Phil Cigan (Cardiff University, UK) and colleagues reported in the November 20, 2019 *Astrophysical Journal* that they had zeroed in on a blob of dust heated to 33K (–400°F).

Now, in a separate study that will appear in the August 1st *Astrophysical Journal*, Dany Page (National Autonomous University of Mexico) and colleagues demonstrate that — out of a smorgasbord of possible alternatives — the most plausible scenario is one in which an enshrouded neutron star warms the dust. What's more, they showed that the dust blob overlaps the predicted location of the kicked-out stellar core.

If all pans out, NS 1987A will be the youngest neutron star ever observed.

■ MONICA YOUNG

GALAXY

Close Encounters in the Milky Way's Bulge

NEW RESEARCH SHOWS that stellar flybys are common in our galaxy's crowded center. Visits from interlopers could affect how young worlds grow in the Milky Way's bulge.

Moiya McTier (Columbia University) and colleagues conducted simulations of interactions between bulge stars over time, reporting the results in the June *Monthly Notices of the Royal Astronomical Society*. They found that over a billion-year period, roughly 80% of bulge stars would experience close encounters, passing within 1,000 astronomical units (a.u.) of another star. Half of bulge stars would have such an encounter not just once but more than 35 times over the course of a billion years. About a third of bulge stars could have company swing by within 100 a.u., and less than 1 in 5,000 stars entertain a visitor within 10 a.u.

The new study takes into account both the crowded environs at the galactic center and the unusual paths some stars there take.

"Some bulge stars move on elliptical orbits, but some of them also move on box- or X-shaped orbits," McTier says. "Many of them move on rosette orbits that look like what you might draw with a spirograph."

While McTier's work didn't directly measure how strongly stellar visitors affect growing planets, the research provides a foundation for future studies. Close encounters could destabilize planetary orbits, strip planets from their host stars, or even interrupt formation before it can begin. But according to Maxwell Cai (Leiden University, The Netherlands), who was not involved in the study, intruder stars could also *help* growing planets. A stellar visitor's tidal gravitational forces could cause small gravitational changes in the disk of dust and gas circling a newborn star, helping material clump together to make planets.

■ NOLA TAYLOR REDD

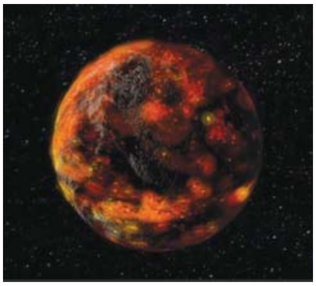
Read more at **https://is.gd/MilkyWayEncounters**.

▼ An artist's impression of the Milky Way's disk and crowded central bulge.

SUPERNOVA 1987A: ALMA / ESO / NAOJ / NRAO / P. CIGAN / R. INDEBETOUW / NRAO / AUI / NSF / B. SAXTON / NASA / ESA; MILKY WAY BULGE: ESO / NASA / JPL-CALTECH / M. KORNMESSER / R. HURT

SOLAR SYSTEM

The Moon Might Be Younger Than We Thought



◀ The newly formed Moon had a magma ocean topped with a thin crust.

THE NEWLY FORMED MOON could have taken up to 10 times longer to solidify than we thought. If so, our satellite might be younger than previously estimated.

Scientists think the Moon formed after a Mars-size body hit the still-forming Earth, launching material into orbit that coalesced into our satellite. It started its days in a molten state, covered by a deep magma ocean that gradually cooled. Since mineral dating of lunar rocks only goes as far back as the moment the minerals formed, scientists need to figure out how much time elapsed before the magma ocean completely solidified to date the Moon.

Maxime Maurice (German Aerospace Center) and collaborators have now simulated the Moon's early evolution and published their findings in the July 10th *Science Advances*.

From all the processes the team considered, two previously overlooked aspects dramatically prolonged the magma ocean's solidification: the insulating effect of the primordial lunar crust and the likelihood that mantle convection started before the magma ocean had completely solidified, bringing heat up from the depths. The two processes make a significant difference to the long-term survival of the magma ocean, says Wim van Westrenen (Vrije Universiteit Amsterdam), who was not involved in the study. Maurice and colleagues think the magma would have taken 150 million to 200 million years to solidify, as opposed to previous estimates of 10 million years.

A longer-lived magma ocean might at first seem to imply an *older* Moon. However, Maurice and colleagues instead suggest that the ocean's slow crystallization would also have altered the ratios of certain isotopes in minerals. These ratios are known as isotopic "clocks" because they change at known rates over time, and they're used to age-date the minerals — and the Moon itself. A more slowly cooling ocean requires that these clocks be recalibrated.

The team thus places the age of the Moon between 4.40 billion and 4.45 billion years, up to 110 million years younger than the commonly accepted age of 4.51 billion years.

The finding opens the door to re-dating many lunar samples and, ultimately, the Moon-forming impact.

■ JAVIER BARBUZANO

MAGMA OCEAN ON MOON: NASA GODDARD SPACE FLIGHT CENTER; STAR WITH TWO PLANETS: ESO / BOHN ET AL.

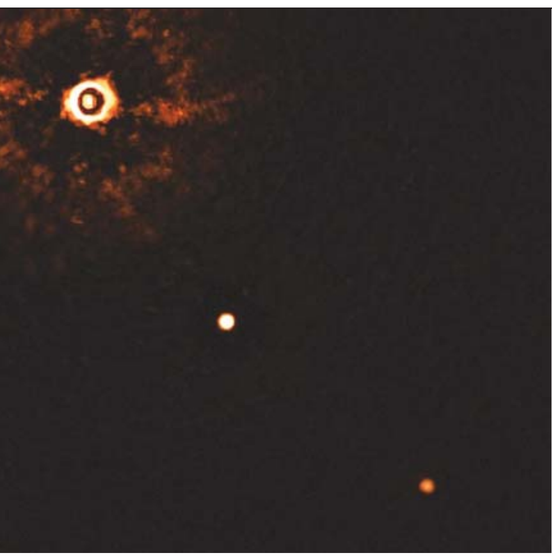
IN BRIEF

Webb Telescope Delayed Again

NASA has delayed the launch of its beleaguered James Webb Space Telescope to October 31, 2021. This represents a seven-month postponement for the already much-delayed mission, which was scheduled to launch next March. The European Space Agency's Ariane 5 rocket will still carry the observatory into space from French Guiana. Thanks to reserves set aside earlier on, officials say the mission will stick to its Congressionally mandated $8.8 billion development budget. That means the mission can continue its development without going back to Congress to ask for additional funding, which it last had to do in 2018 when it was facing a 10-month delay.

The new October 2021 launch date was set to take into account pandemic-related changes, including augmented safety precautions and reduced on-site personnel, as well as technical challenges outlined by the Government Accountability Office last January. Two tests remain that carry some risk, says program director Gregory Robinson (NASA). The first is an acoustics and vibration test of the complete observatory. The other is a second "deploy-and-stow" of the highly complex, seven-layer sunshield, which will keep the instruments cool enough to observe the infrared universe in unprecedented detail. Acoustics and vibration tests are scheduled to finish in October 2020.

■ MONICA YOUNG



A Young Sun and Two Giants

For the first time, astronomers have imaged multiple planets orbiting a young, Sun-like star. The Spectro-Polarimetric High-contrast Exoplanet Research (SPHERE) instrument on the European Southern Observatory's Very Large Telescope (VLT) captured this image of the 17-million-year-old star, dubbed TYC 8998-760-1, and its two giant companions. One of the star's cohorts straddles the planet–brown dwarf divide with a mass 14 times Jupiter's; the other has a mass of six Jupiters. They orbit at 162 and 320 astronomical units, respectively, more than four times farther out from their star than Pluto's average distance from the Sun. In computer simulations published in the July 20th *Astrophysical Journal Letters*, Alexander Bohn (Leiden University, The Netherlands) and colleagues show that circular orbits at these distances are stable, but even mild elongations to the orbits would cause them to be unstable and therefore likely short-lived. So the researchers suggest that the planets probably formed in place, unless there was some very specific (and therefore less likely) scenario that ejected the planets to their far-out orbits.

■ MONICA YOUNG

Comet NEOWISE put on quite a show this summer (see more photos starting on page 14).

ROGER N. CLARK, CLARKVISION.COM

My Virtual Comet Sighting

There's nothing like being there, but these days we can all find a pretty good view.

FEW THINGS STIR THE SOUL like the sight of a comet airbrushed onto a dark starry sky, its ghostly glow intruding on a familiar celestial landscape, its tail blown by unseen winds, reminding us that the heavens are far from static and fully known. The transience is part of the thrill.

Comets travel through time as well as space. Short-period comets, which originate in the Kuiper Belt, beat a slow rhythm through our history. The most famous is 1P/Halley, which has a period of 76 years, roughly equal to the current average human life expectancy (which is twice what it was the last time the comet came around). In 1986, with a group of fellow grad students, I trekked into the Tucson desert, pre-dawn, to observe Halley.

I'm a big fan of long-period comets, which come from much farther out, in the Oort Cloud. These surprise guests fly in fast and show up suddenly, without warning, from any direction on the sky. Sometimes it's only a matter of months between discovery and closest approach. Occasionally they can brighten dramatically, providing delightful views.

My favorite was Comet Hyakutake, the Great Comet of 1996. Known officially as C/1996 B2, it was discovered in January that year and made a close approach to Earth in late March. I was fortunate to be staying in a cabin in Utah, far from any city, and I'll never forget my first glimpse of it as a little phosphorescent smudge near the horizon, at first so subtle I wondered if I wasn't imagining it. Then, as my eyes adjusted, or when I looked through binoculars, the immensity of the tail hit me, an extended object that visibly moved during the course of the evening.

There's no way to predict how many good naked-eye comet viewings any of us will get during our lives. So, any time you have the opportunity to see one, you should seize it.

Having said all this, I have a confession to make: I missed seeing Comet NEOWISE (C/2020 F3) in July. For multiple reasons, including a convalescing dog needing to be carried about, I just couldn't leave the dense, bright city where I live, and a week of thunderstorms put the kibosh on my binocular gazing efforts.

But missing this comet made me appreciate all the more something that has occurred in recent decades. Today we have a truly interconnected global visual system. In the age of the internet and digital cameras, anyone with a web connection can now savor celestial wonders photographed in exquisite detail against a dizzying array of backgrounds. So, I "saw" NEOWISE rising over Joshua Tree National Monument, reflected in a mountain lake, passing above a European cathedral, and even, in time-lapse, rising from the limb of Earth as shot from the International Space Station.

Of course, there's still nothing like being out under a dark, star-speckled sky with good friends, a night breeze, the song of cicadas, and the stunning immediacy of the celestial sphere. But these days, when more of us than ever live in cities and are sometimes stuck there, I'm so grateful for all of the talented astrophotographers and appreciative that our experience of the cosmos has become shared in this way.

■ **DAVID GRINSPOON** is an astrobiologist and author who needs to get out of the house more.

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MiniTrack LX3: Fully mechanical photography mount for cameras up to 3kg (105.8oz) (6.6lbs).

Saslong Night - Sassolungo da Col Raiser (Italy) – Photo: Cristian Fattinnanzi

Wide-field imaging, as depicted above, is possible with ease. The fully mechanical Omegon MiniTrack LX3 mount works just like a clock. No power necessary. No charging. No battery. Simply mount your camera onto the LX3 and wind it up. Easily capture wide-field images of the cosmos on your camera.

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✔ Up to 3kg (105.8oz) (6.6lbs) load capacity

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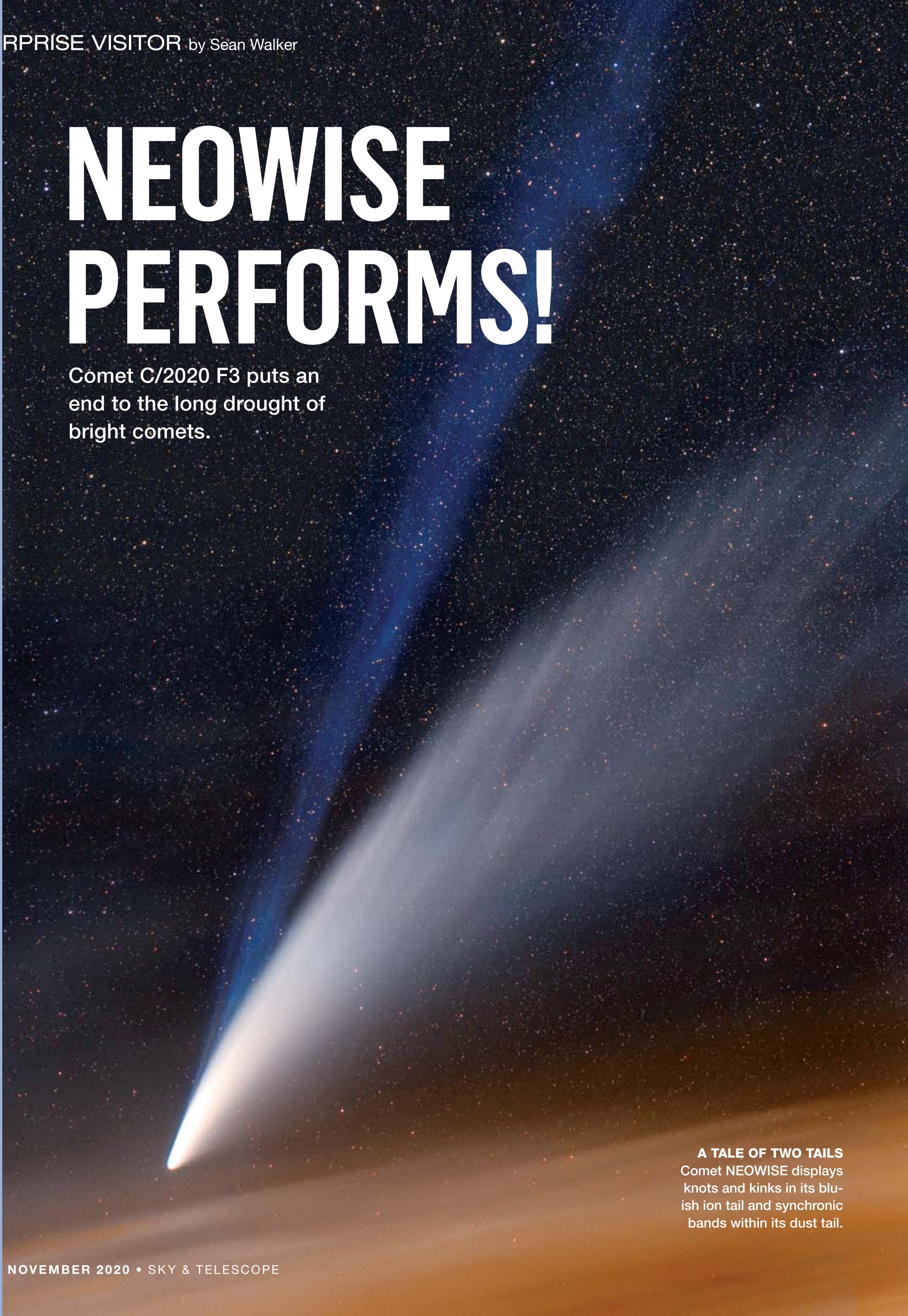
NEOWISE PERFORMS!

Comet C/2020 F3 puts an end to the long drought of bright comets.



A TALE OF TWO TAILS Comet NEOWISE displays knots and kinks in its bluish ion tail and synchronic bands within its dust tail.

GERALD RHEMANN

Beautiful! Finally! It's about time!

That's the consensus amongst observers after Comet NEOWISE blazed forth from perihelion in the predawn skies of early July. Not since Hale-Bopp departed for the outer limits of the Oort Cloud has there been such a widely observed Northern Hemisphere comet.

Comet NEOWISE (C/2020 F3) was discovered on March 27, 2020, during the near-Earth observation extended mission of the Wide-field Infrared Survey Explorer (WISE) space telescope. When first swept up by the spacecraft, the comet was roughly 2 astronomical units (a.u.) from the Sun and just a faint 18th-magnitude puff passing through the telescope's field. Preliminary orbital calculations determined it to be a non-periodic comet, resulting in the designation C/2020 F3.

Observers throughout the Northern Hemisphere awaited news of the comet's solar encounter with bated breath, fearing yet another disappointing breakup. After all, both comets ATLAS (C/2019 Y4) and SWAN (C/2020 F8) promised good shows in late May, only to break apart and fade before reaching perihelion.

Comet aficionados anxiously watched NEOWISE as it passed through the field of the LASCO C3 coronagraph on the SOHO spacecraft days before perihelion, awaiting confirmation that the comet had survived its 44-million-kilometer (27.3-million-mile) brush by the Sun. Fortunately, the third time was the charm. NEOWISE's 5-kilometer nucleus survived its July 3rd pass just 0.29 a.u. from the Sun, an event that altered the comet's orbit to a 6,700-year-long ellipse. Confirmation of the comet's fate came quickly, as several observers picked up its bright magnitude –2 nucleus in morning twilight.

A Brilliant Display

Within days, NEOWISE slowly climbed higher from the horizon, displaying a bright, curved dust tail several degrees long and easy to spot in the brightening twilight.

By the 6th, a faint, bluish ion tail became visible as the comet crept higher by the day. Urban observers were able to spot the comet's 1st-magnitude nucleus wherever a low northeastern horizon permitted. But the best show was yet to come.

The comet's orbit kept it low in the northeast for several more days as it slowly skirted dawn's twilight horizon. Around July 10th, NEOWISE began to be visible in the evening for observers at northerly latitudes and was even circumpolar for comet watchers north of 42° latitude.

At this point, the comet displayed synchronic bands within its dust tail and fast-moving knots and kinks in its growing ion tail. NEOWISE's position in the evening sky permitted long-exposure photographs, showing its bluish ion tail streaming some 20° from the nucleus, as well as a third, reddish sodium tail. This was only the third time such a feature has been seen in a comet.

By mid-July, dust production began to slow, and the comet faded to roughly 2nd magnitude as it crossed the legs of Ursa Major. However, both its bright tails continued to lengthen due to its changing viewing geometry. Photographs of NEOWISE are reminiscent of the V-shape last seen in Comet Hale-Bopp (see the July issue, page 30). Most observers could trace the comet's dust tail to about 5° from moderately dark locations, and even longer when viewed with binoculars.

PHILIPP SALZGEBER

▲ **RED TAIL** Comet NEOWISE briefly displayed a reddish tail made up of sodium atoms, as seen in this deep image taken from Vorarlberg, Austria, on the 10th of July.

Telescopically, the inner coma of NEOWISE displayed interesting detail. Due to its low altitude in the mornings at the start of July, the *false nucleus* (thick atmosphere surrounding the nucleus) appeared distinctly orange, and mid-size instruments revealed several "hoods" of material in the inner coma, expanding outward before being swept into the trailing dust tail. Binoculars and small telescopes showed the dark lane separating the two tails. Over the course of two weeks, the coma turned strikingly greenish and expanded. Bob King observed, "On July 14th through my 10-inch telescope it was a tiny, bright light bulb at the head of the comet's tail, which looked for all the world like streamlined fog."

The Moon entered the evening sky as July came to a close, challenging the fading comet for dominance. August came with the comet still just visible to the naked eye, though greatly diminished.

By the time you read this, the comet will be a faint telescopic object well on its way back to the outer solar system. But its wonderful show reminds us of the surprises the night sky occasionally serves up. We don't know when the next bright icy visitor from the outer reaches of the solar system will blaze into view, but until then, we hope you enjoy this collection of wonderful mementos from NEOWISE's surprise summer appearance.

■ Associate Editor **SEAN WALKER** will drop everything in pursuit of a good view of a bright comet.

MILKY SCOOP
Comet NEOWISE is seen traversing the southern extent of Ursa Major on July 22nd over the cliffs at Dwejra Bay, Malta, looking like an errant scoop of the Milky Way spilling out of the Big Dipper.

CHANGING COMA
These fantastic, high-resolution views of the head of NEOWISE show changes in the coma over a 14-day period. Each image was recorded through a Ceravolo 300-mm f/9 astrograph with an SBIG Aluma 694 camera from Anarchist Mountain in southern British Columbia, Canada. Note the yellowish coma early in the series, which shows multiple shells of dust left in the comet's wake that expand to become the striations seen in the broader dust tail. As dust production slowed, a fuzzy green coma took its place.

July 11

July 13 (morning)

July 18

July 19

LANDSCAPE: JOSEPH CARUANA;
COMA SERIES: DEBRA AND PETER CERAVOLO

PLEIN-AIR PORTRAIT
No camera? No problem! Deirdre Kelleghan sketched NEOWISE in pastels over Clare Island in Ireland on the evening of July 20–21 between 23:45 and 1:15 local time.


July 13 (evening)


July 14


July 15


July 21


July 24


July 25

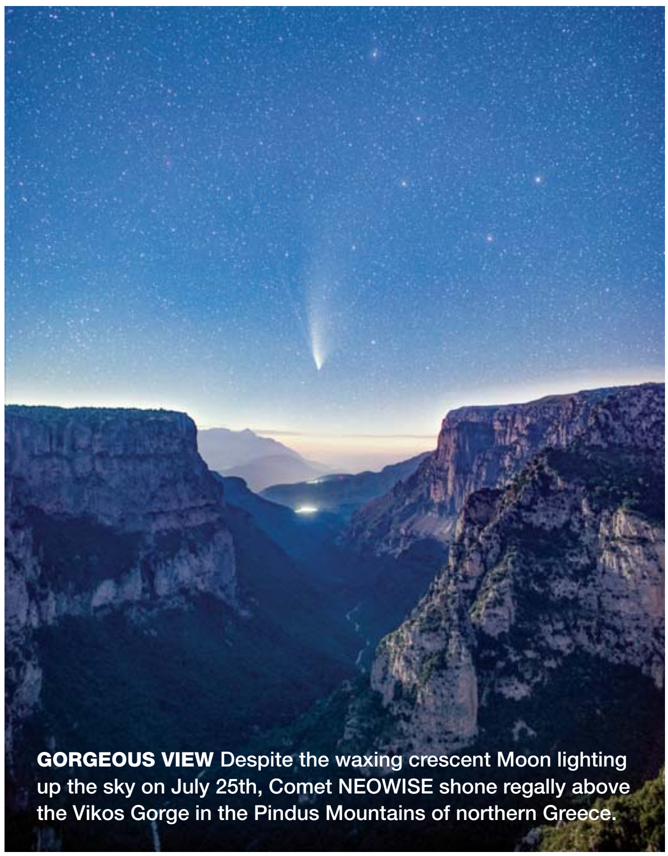
CELESTIAL CROSSING The comet is seen passing over the Mackinac Bridge in this composite image recorded from the shore of Mackinaw City, Michigan, on the morning of July 20th. Read about how this image was taken at **https://is.gd/Mackinac**.

MARYBETH KICZENSKI

BLUE BEACON The comet's ion tail shone steadily through the end of July as NEOWISE passed several galaxies in Coma Berenices.

▲ **REFLECTIVE SCENE** The graceful arc of NEOWISE's dust tail is mirrored in the still waters of a pond located in Likely, California.

▲ **ILLUMINATION COMPETITION** NEOWISE shines brightly above the immense rock formations of Metera, Greece.



GORGEOUS VIEW Despite the waxing crescent Moon lighting up the sky on July 25th, Comet NEOWISE shone regally above the Vikos Gorge in the Pindus Mountains of northern Greece.

CLOCKWISE FROM TOP LEFT: MICHAEL JÄGER; FRANK DIBBELL; CONSTANTINE EMMANOUILIDI (2)

To Touch the Sun

NASA's Parker Solar Probe is on a record-breaking journey to study our nearest star.

The launch of the Delta IV Heavy sounded of fire and thunder. The rocket's vibrations rumbled over the team of scientists and engineers standing miles away in the early hours of August 12, 2018, as they watched the rocket carrying NASA's Parker Solar Probe lumber into the sky.

Team member Kelly Korreck (Center for Astrophysics, Harvard & Smithsonian) was tense. As the head of science operations for one of the mission's instrument suites, she knew what to listen for from pre-launch vibrational testing — when one particular instrument mock-up had begun to rock violently.

"In testing, we heard the Solar Probe Cup rattle, just 'djr-djr-djr' at one point in time when it hit a certain frequency," Korreck says. "As I was listening to the frequency of the rocket taking off, I was listening like, 'Oh here she is, oh my goodness, she's rattling right now, she's rattling!'"

Relief came soon enough. Within 45 minutes, the spacecraft sent a signal indicating it had reached its expected trajectory; over the following weeks, its instruments switched on one by one. "That thing is actually going to go into the atmosphere of a star," Korreck recalls thinking. "It's an amazing feeling."

By the time this issue reaches newsstands, Parker will already have swung around the Sun six times, with another 18 passes planned, gradually approaching the Sun. During its final three orbits — starting December 24, 2024 —the spacecraft will pass within 6.2 million kilometers (3.8 million miles, or about 9 solar radii) of the seething gases in the photosphere. At its closest, Parker will be traveling at 190 km/s (430,000 mph), fast enough to travel from New York to Tokyo in under a minute — and faster than any other mission before it.

Designed, built, and operated by the Johns Hopkins Applied Physics Lab, the spacecraft carries four independently developed instruments to this unexplored territory. Mostly shielded behind 11.4 centimeters (4.5 inches) of carbon composite, the detectors measure electric and magnetic fields, plasma properties, and particle energies, as well as image the corona and solar wind. "The spacecraft itself is just crammed tight," says Russell Howard (Naval Research Laboratory), principal investigator of the WISPR camera.

After decades of studying the Sun from afar, Parker's various detectors are finally giving scientists a close-up look at our star — a chance to "touch" the Sun and pierce its mysteries.

Parker will swim in the hot corona as it's being heated and taste the nascent solar wind as its particles are being accelerated.

▶ **LAUNCH** The United Launch Alliance Delta IV Heavy rocket lifts into the air, carrying the Parker Solar Probe sunward.

PARKER ARTIST'S CONCEPT: NASA / JOHNS HOPKINS APL / STEVE GRIBBEN; LAUNCH: BILL INGALLS / NASA

Inside the Sun's Atmosphere

The notion that a spacecraft can touch a star is poetic — but it's scientifically defined, too.

The churning ball of plasma that is our Sun has no solid surface, but witnesses of total solar eclipses have long seen an edge of sorts. When the Moon blocks the glare of the burning Sun, it reveals the softer glow of the solar corona. The transition from searing ball to glowing halo represents the Sun's visible surface, or *photosphere*. Nevertheless, the Sun's dominance extends well beyond the photosphere and into the diffuse outer atmosphere.

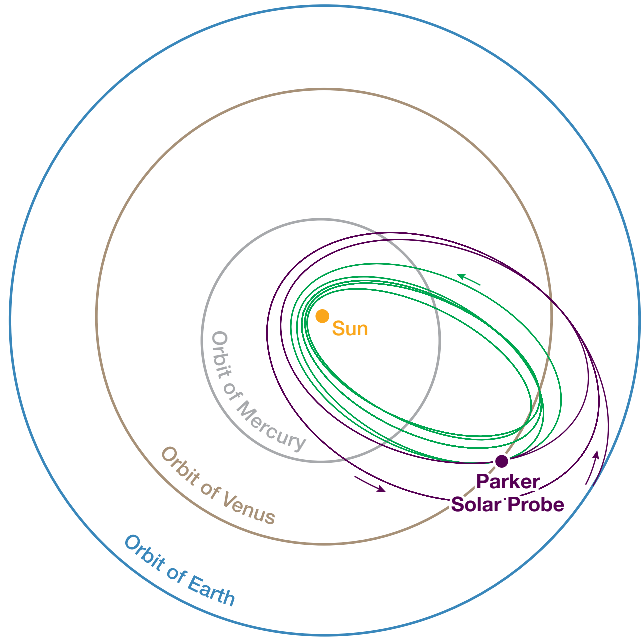
It was observations of the corona during the 1869 total solar eclipse that recorded light emitted by 13-times ionized iron atoms (though it took 73 years to identify them as such). Atoms missing that many electrons can only exist in a plasma heated to millions of degrees, and in 1958 Eugene Parker wrote down the full implications. Such a hot plasma wouldn't stay bound to the Sun, he realized — the charged particles would escape, flowing outward in a supersonic solar wind.

At the time, Parker's idea was so contrary to prevailing ideas that it almost didn't get published. *Astrophysical Journal* editor Subrahmanyan Chandrasekhar didn't like the idea, but he couldn't find anything wrong with Parker's math, so he overruled the scientific reviewers and published the paper. It turned out to be good timing: Just four years later, the Mariner 2 probe confirmed the existence of Parker's theorized solar wind. We now know that the Sun loses the mass of Utah's Great Salt Lake every second.

However, while the existence of the multi-million-degree corona and the speedy solar wind are now well established, their sources have been hotly debated for more than six decades. To understand their origins, astronomers realized, we have to get a lot closer to our star — close enough that the Sun is clearly controlling the physics of what we measure.

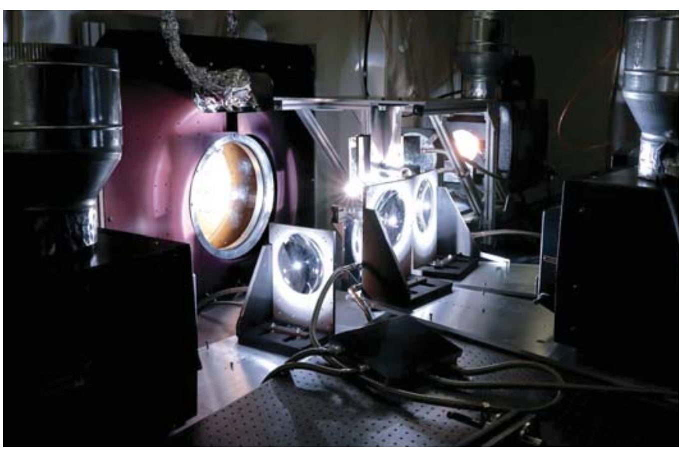
Think of a big prominence rising off the Sun and looping around in the corona, suggests Solar Probe Cup instrument scientist Anthony Case (Center for Astrophysics, Harvard & Smithsonian). As the Sun rotates, the prominence rotates with it — it has to, because the plasma in the prominence follows the magnetic fields that are rooted in the Sun. In a sense, the prominence still "belongs" to the Sun. But at Earth, the magnetized plasma of the solar wind is no longer part of the Sun; it's flowing directly away from it. At some point in between, Case says, there's a transition, one scientists call the *Alfvén radius*.

The Alfvén radius isn't any more solid than the Sun is. Magnetic fields, the density of the solar wind, and other conditions near the Sun are constantly changing. So the boundary between the Sun and its outflowing atmosphere is



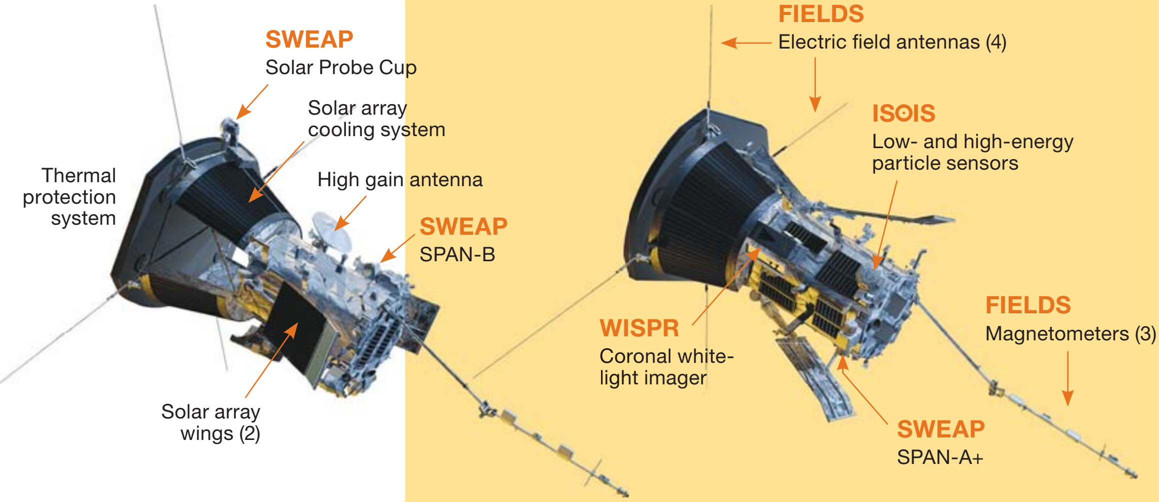
▲ **APPROACH** Parker approaches the Sun over 24 orbits, pictured here. The first perihelion took the spacecraft within 36 times the Sun's radius from the visible surface. The last three perihelia will take Parker within 9 solar radii. Parker's past trajectory and current position are shown in purple; green shows its future path.

▼ **INGENUITY & IMAX** *Left*: The team combined the light from four IMAX-like projectors to simulate the light and heat that would be coming from the Sun. Special lenses of fused silica concentrated and directed the light into a vacuum chamber (the glowing hole seen at left), illuminating the Solar Probe Cup on one side. Particles from an ion gun (wrapped in foil and pointed down at the chamber) simulated the solar wind. *Right*: Instrument scientist Anthony Case prepares the Solar Probe Cup before its integration onto the spacecraft.



PARKER ORBITS: GREGG DINDERMAN / *S&T*; SOURCE: NASA / JOHNS HOPKINS APL; IMAX SETUP: LEVI HUTMACHER / MICHIGAN ENGINEERING, COMMUNICATIONS & MARKETING; SOLAR PROBE CUP: ANDREW WANG / ANDREWTAKESPHOTOS.COM dynamic and bumpy, too. "It's not just plus or minus a mile," Korreck explains. "It's plus or minus a solar radius."

A primary goal for the Parker Solar Probe is to slip inside this boundary, something no spacecraft has ever done. Within the Alfvén radius, Parker will swim in the hot corona as it's being heated and taste the nascent solar wind as its particles are being accelerated.



▲ **ALL ABOARD** These views show the instruments aboard the Parker Solar Probe. The view at right shows the side of the spacecraft that faces the direction of motion.

Taking the Heat

Before Parker can do any of that, though, it must first survive its close approaches to the stellar furnace. The good news is that the environment doesn't feel as hot as one might think. While the temperature of the corona is more than a million degrees, that number describes the motions of the plasma's particles, and they're too sparse to transfer heat to Parker. The heat the probe does feel comes from the sunlight itself. The difference is like sticking your hand in a hot oven rather than in a glass of hot water.

Still, radiational heat at closest approach is 500 times what we receive at Earth. Unshielded, Parker would reach temperatures approaching 1,400°C (2,500°F) — hotter than any lava on Earth. Most of the instruments therefore take their measurements from behind the shelter of a heat shield, a masterpiece of thermal engineering that took more than a decade to create. Two thin layers of a graphite-like carbon material sandwich a thick slice of carbon foam that's so lightweight it's 97% empty. An ultra-white aluminum oxide coating on the shield's sunward-facing side reflects most of the light and

▼ **STANDING TALL** The Parker Solar Probe looks small inside one half of the 19.1-meter-tall (62.7-foot-tall) fairing. Although the probe was small compared to what a Delta IV Heavy usually carries, the rocket provided the necessary lift to bring Parker close to the Sun.

▼ **PARKER'S SUNSCREEN** The heat shield consists of two main components: a light carbon foam that's mostly space and a bright white coating of aluminum oxide. A thin tungsten layer separates the two so that they don't interact.

PARKER INSTRUMENTS: NASA / JOHNS HOPKINS APL (2); HEAT SHIELD: NASA / JOHNS HOPKINS APL / ED WHITMAN; PARKER IN ROCKET FAIRING: NASA / JOHNS HOPKINS APL / ED WHITMAN

To the Sun, Via Venus

▲ **VENUS FLYBY** Seven gravity assists from Venus boost the Parker Solar Probe on its journey toward the Sun.

Approaching the Sun takes more energy than leaving the solar system altogether, as any spacecraft leaving Earth inherits its orbital speed of 30 km/s (66,500 mph). Slowing that momentum counterintuitively takes more energy, says mission designer Yanping Guo (Johns Hopkins University Applied Physics Laboratory). "The launch energy required to reach the Sun is more than 50 times that required to reach Mars and twice that to reach Pluto!"

When mission planning began, the best option for losing so much speed — a swing around Jupiter — was out of the question. A Jupiter flyby usually requires nuclear power, and NASA's limited supply of plutonium-238 was already spoken for by other missions.

For Parker to even begin development, it would need another way to the Sun. Guo realized that seven swings by Venus rather than one by Jupiter could do the trick. It only works because the braking maneuvers around Venus are tightly coupled, so that one flyby sets the spacecraft up for the next one.

The flybys serve as more than a trajectory assist. Inhospitable Venus has been relatively neglected by spacecraft in the last three decades (*S&T:* Sept. 2018, p. 14). Parker gives planetary scientists an opportunity to explore its alien atmosphere as well as the fields induced by the charged plasma that flows around this magnetically dead world.

Shannon Curry (University of California, Berkeley) says the initial results from the first two Venus encounters are promising. "We're finding things that have never been explored outside Earth, not even at Mars," Curry says. "Microscale physics that explain a lot of how things like bow shocks form, how the magnetotail structure works, how magnetic reconnection works."

Previous missions had quantified how much atmosphere typically manages to escape, Curry adds, and Parker's data are now revealing how and why. Scientists can then extrapolate back in time to understand how Venus was able to maintain its thick shroud without a magnetic field to protect it — a question relevant to other worlds such as Titan and even exoplanets.

heat; a fine layer of tungsten keeps the aluminum oxide from interacting with the carbon foam and turning gray.

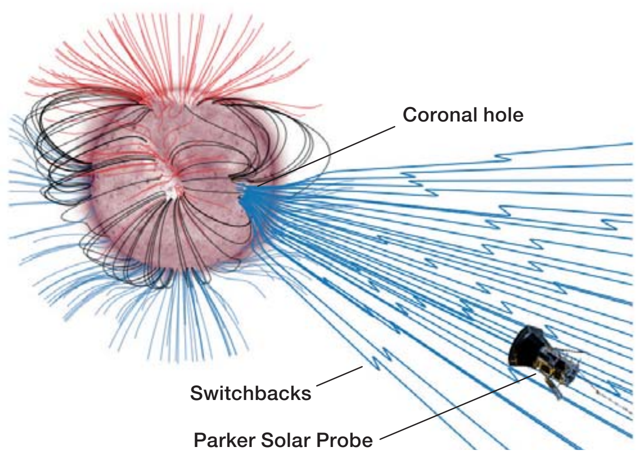
The shield keeps most instruments at roughly room temperature, except for two that extend beyond it. The Solar Probe Cup (SPC), one of the Solar Wind Electrons, Alphas, and Protons (SWEAP) instruments, hangs outside the heat shield to point its particle-collecting receptacle directly toward the Sun. And four whip antennas that help measure the electric field, part of the FIELDS electromagnetic instrument suite, also extend beyond the heat shield.

Developing instruments that could function so close to the Sun took trial and error, sometimes behind a welding curtain. During material tests, the lab smelled like a pan left on the stove too long. The "mistakes" still hang on the wall: deformed plates of stainless steel and unalloyed titanium. At testing temperatures of some 1,600°C, "all steels melt, all aluminum is long gone," says structural engineer Henry Bergner (Center for Astrophysics, Harvard & Smithsonian). The only options remaining are refractory metals, like those used in nuclear reactors or rocket nozzles.

In the end, the team decided on molybdenum alloyed with titanium and zirconium for the bulk of the cup. The team also used lab-made sapphire to insulate the electronics, after figuring out how to grow the crystals in a way that keeps them from cracking at extreme temperatures.

Testing the instrument required some ingenuity. To simulate the light and the heat that the SPC would experience near the Sun, the team concentrated the light of four IMAX-like projectors into a vacuum chamber using special lenses of fused silica. Sometimes the building's air conditioning couldn't keep up.

For the FIELDS instruments, the whip antennas that extend beyond the shield easily withstand the heat. But these



▲ **CORONAL WINDOW** This schematic shows a possible magnetic configuration for the Sun during Parker's first perihelion. The color of the Sun represents extreme ultraviolet emission; white areas on the surface represent regions where magnetic field lines escape into interplanetary space, known as coronal holes. Parker encountered such a region during its first pass around the Sun — along with thousands of magnetic switchbacks.

PARKER'S VENUS FLYBY: NASA / JOHNS HOPKINS APL / STEVE GRIBBEN; MAGNETIC FIELD SCHEMATIC: UNIVERSITY OF CALIFORNIA, BERKELEY; SPACECRAFT IMAGE: NASA / JOHNS HOPKINS APL long, hollow tubes of reactor-grade niobium, which help measure the electric field, still have to connect to a room-temperature spacecraft. Fortunately, the tubes' walls are so thin that they fix their own problem: They barely conduct heat. "Once you put that tube behind any little bit of shadow, it just chokes the heat flow down," explains Stuart Bale (University of California, Berkeley), FIELDS principal investigator.

The other instruments of SWEAP and FIELDS hide in the shadow behind the spacecraft. Their protection from the heat is so effective, they actually need heaters to keep them warm at closest approach.

The solar panels are also behind the heat shield but are, for obvious reasons, partially exposed to the Sun's light. They keep cool with about a gallon of deionized water, which flows through small channels embedded in the panels and then into four radiators. Like our vascular system, the water absorbs heat, then radiates it back into space — keeping the panels efficiently generating energy.

"The spacecraft is like a warm-blooded animal, it regulates its own temperature," says SWEAP principal investigator Justin Kasper (University of Michigan).

Indeed, Parker is one of the most autonomous spacecraft ever launched. Communicating with Earth takes power that's required for instrumentation, so during its searingly close passes by the Sun, the spacecraft flies on its own. "It's quite a bit of the mission that we're not communicating with this thing at all," Bergner says.

A variety of sensors and controls aids Parker in its decision-making. In response to rising heat, the spacecraft can fold back its solar panels, and star trackers and light sensors help the spacecraft keep all its instruments in the heat shield's shadow. "She's an adult," Korreck says. "She's taking care of herself now."

▲ **GOING TO THE SOURCE** An artist's concept shows Parker flying into the solar wind. By sampling the charged particles closer to where they are first accelerated, the mission hopes to understand their origin.

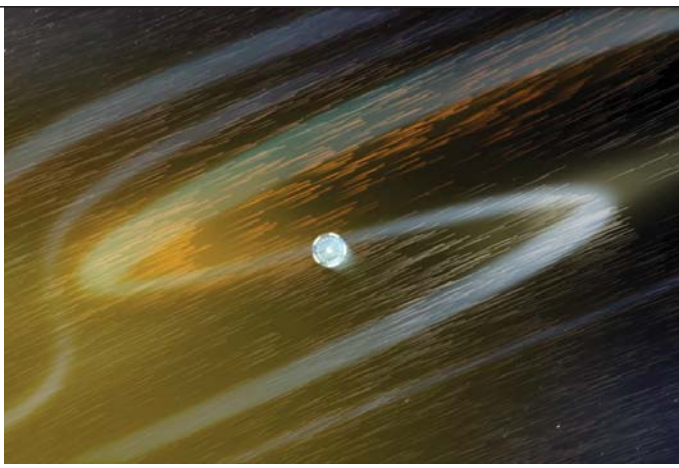
First Encounters

Data from Parker's first three perihelia have already shown scientists the unique environment that exists around our star.

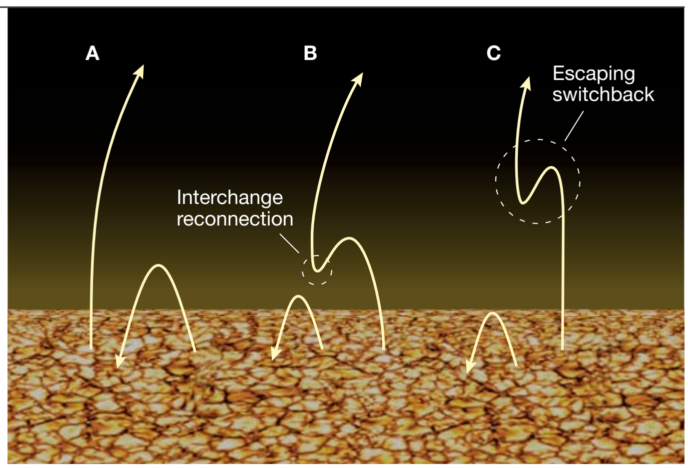
To study the solar wind, Parker's SWEAP and FIELDS instrument suites combine forces. SWEAP uses three instruments, including the Solar Probe Cup, to measure particles' density, speed, direction, and temperature. Meanwhile, FIELDS uses its three magnetometers and five voltage sensors to feel out the magnetic and electric fields entrained in the particles sweeping past.

Together, these measurements provide the data necessary to watch the sea of charged particles flowing by — and they have been crucial to identifying thousands of so-called *rogue waves* crashing over the spacecraft (*S&T:* Apr. 2020, p. 10).

These sudden bursts of speedy particles come with 180° flips in the magnetic field. "There's some dynamics down below Parker that's creating these impulsive things that are



▲ **SWITCHBACK** This still from an animation shows what a single switchback might look like, depicting both the S-shape curve to the magnetic field line and the accompanying burst of solar wind particles that Parker observes as it flies through the structure. While a known phenomenon, switchbacks surprised astronomers in their abundance during Parker's initial flybys.



▲ **SWITCHING SOURCE** One potential explanation of switchbacks is the reorganization of magnetic fields nearer the visible surface of the Sun by a process called *interchange reconnection*. Here, two opposing magnetic field lines meet (A), connecting at the point where they would cross (B), and then sending a burst of particles accelerating outward accompanied by an S-shape twist in the magnetic field (C).

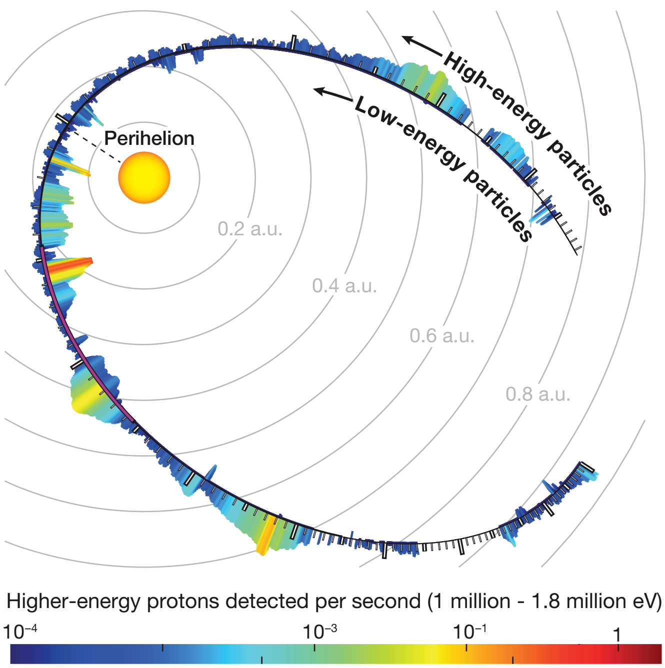
PARKER FLYING THROUGH SOLAR WIND: NASA; SWITCHBACKS ILLUSTRATION: NASA GODDARD / CIL / ADRIANA MANRIQUE GUTIERREZ; INTERCHANGE RECONNECTION: GREGG DINDERMAN / *S&T*; SOURCE: JUSTIN KASPER / LEVI HUTMACHER / UNIVERSITY OF MICHIGAN ENGINEERING being carried out by the wind," Bale explains. In other words, deep down in the corona, still beyond Parker's reach, *something* happens.

By the time it reaches Parker, the event appears as a huge S-shape twist in the magnetic field extending outward from the Sun that's about 50 times longer than it is across. The particles within this magnetic switchback are flowing about twice as fast as the particles outside.

Scientists had seen signatures of these switchbacks in data collected by the Helios and Ulysses missions. But Parker revealed that the events were both more transient and more prevalent than previously thought — basically, whatever's producing these events nearer the solar surface, it's happening everywhere, all the time. "The sheer number of them and the size of them is surprising," says Case.

Some have suggested that the rogue waves come from magnetic reconnection at or near the solar surface. When the magnetic field reorganizes — an open field line jumping from here to there — the process lets loose a burst of particles that then, much later, zooms past Parker.

"But my own feeling is that they are not direct evidence of reconnection," Bale says, "because it looks to us like the plasma inside the switchbacks and the plasma outside the switchbacks are basically the same." Reconnection, on the other hand, would be heating particles in addition to accelerating them.



▲ **SPED-UP PARTICLES** ISOIS's energetic particle instruments monitored particle energies and densities throughout the first pass around the Sun, with few gaps between October 2018 and January 2019. Most of the energetic particles are protons, at both low (30,000–200,000 eV) and high (1 million–1.8 million eV) energies. Both the color and length of the bars indicate how many particles per second the instruments were detecting in their respective energy ranges.

Instead, Bale suggests, the switchbacks could be heralds of *Alfvén waves* deep in the corona. Alfvén waves are a simple feature of just about any magnetized plasma. As charged particles move around, so do the magnetic fields tied to them, wiggling like so many plucked guitar strings. "We're just seeing Alfvén waves that have grown to be so big that they're flipping over on themselves," Bale speculates. But it's not the only idea out there, he adds: "Reasonable people would disagree with me."

Whatever switchbacks are, they're giving us information about what heats the solar corona, whether that mechanism involves magnetic reconnection, plain ol' Alfvén waves, or something else entirely. Thinking over the possible scenarios is half the fun. "The whole point of getting closer is that we'll see the [switchbacks] in more of their original state," Case says.

Harbingers of Storms

Not all of what comes from the Sun is solar wind. Some tiny fraction of charged particles in the corona somehow accelerate to near-light speed, following different paths than their brethren. While the solar wind typically streams at 400 km/s (almost 1 million mph), *solar energetic particles* can carry anywhere from 10 to 100,000 times that energy.

When the Sun is active, these particles can serve as the Paul Reveres of solar storms. But even during quiet times, as now, these particles — though few in number — are constantly flying out from the Sun.

Rather than blowing outward in bulk, the way most of the solar wind does, these charged particles are more like individuals, spiraling around the magnetic field lines that coil outward from the Sun. Because of their different paths, "they're actually sampling quite different regions than the [solar wind] plasma that you're measuring at the same time," explains David McComas (Princeton), principal investigator of the Integrated Science Investigation of the Sun (ISʘIS) instruments. So connecting the particles to the processes that created them can be tricky.

ISʘIS has two instruments that together detect energetic particles across a wide range of energies, from thousands to millions of electron volts. To maximize the number of particles it can capture, ISʘIS sits right at the edge of the heat shield. "It's completely out of the view of the Sun, but just by a degree or two," McComas says.

From this vantage point, ISʘIS has access to details impossible to tease apart near Earth. So McComas can finally start answering one of the many questions he has had since the beginning of his career: "Why is it that some particular proton ends up being the million-electron-volt particle and almost none of the rest of them do?"

The answer, he says, has to do with the very first processes, the ones that accelerate particles a little bit, so that they can then efficiently reach much higher energies later on. For the first time, ISʘIS can detect these tiny accelerating events, and it's showing that they may be much more common than previously thought.

GREGG DINDERMAN / *S&T*; SOURCE: MCCOMAS ET AL. / *NATURE* 2019 DECEMBER 12

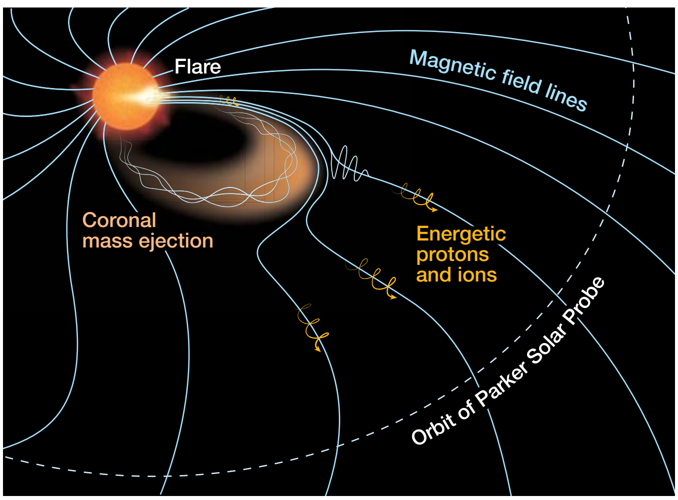
Researchers are only starting to untangle the data, and there are much more to come. "One of the most exciting things so far — and we haven't even gotten that close yet — is that we're seeing smaller and smaller and smaller events as we get in closer," McComas says.

Where the Dust Never Settles

There's one other thing that Parker encounters that doesn't actually come from the Sun: dust. The spacecraft is flying through the densest region of the solar system's *zodiacal cloud*. Comets and asteroids coming too close to the Sun break up and their fragments collide, grinding down until nothing but micron-scale electrically charged particles remain. Due to their interactions with sunlight, these particles slowly spiral in toward the Sun, though when the particles become small enough sunlight may instead push them away.

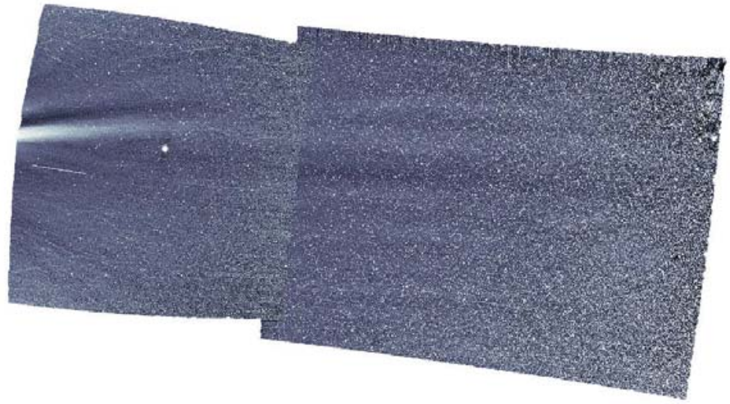
The Wide-field Imager for Solar Probe (WISPR) is Parker's only imager, a roughly shoebox-size telescope that peeks over the edge of the spacecraft to capture sunlight scattering off electrons and dust. The heat shield acts like a coronagraph, blocking the light from the Sun itself, which is 13 to 15 orders of magnitude brighter than the corona. The images provide context for Parker's other measurements, revealing structures — such as large-scale solar storms or even small-scale twists of the magnetic field — before the spacecraft flies into them and samples them directly.

Already, WISPR's PI Howard and colleagues have seen that the emission from dust-scattered sunlight drops off in a way that suggests a dust-free region extends out to at least 10 solar radii from the Sun's surface (*S&T:* Apr. 2020, p. 10). The drop-off is so smooth, Howard says, that he doesn't think the heat is sublimating dust grains, species by species, directly into gaseous form. Instead, he thinks the particles are eroding, broken up by the pervading solar wind, and gradually being pushed back out.



▲ **"PAUL REVERES"** This schematic shows an explosion on the visible surface of the Sun that ejects material out into the solar system, termed a *coronal mass ejection*. ISOIS scientists discovered that energetic charged particles rushed ahead of one such eruption that Parker witnessed during its first orbits. The particles could provide advance warning to satellites and astronauts of the incoming space weather threat.

SOLAR ENERGETIC PARTICLES: NASA / PRINCETON / JOHNS HOPKINS APL; WISPR IMAGE: NASA / NAVAL RESEARCH LABORATORY / PARKER SOLAR PROBE



▲ **SEEING SOLAR WIND** Parker's views of the streaming solar wind are oblique — its WISPR imager cannot stare straight at the Sun, so it looks off to the side in the direction that Parker is traveling. Nevertheless, the images are critical to seeing ahead of time what space environment Parker will encounter.

Parker's other instruments can detect dust indirectly, too. FIELDS, for example, measures the momentary voltage generated when a dust grain slams into the spacecraft and vaporizes into plasma. ISΘIS can likewise detect dust impacts. Jamey Szalay (Princeton) and colleagues have used these data to conclude that the Sun is ejecting dust from the solar system at a rate of at least half a ton per second. Ultimately, such results could help astronomers understand planetary formation in systems around other stars.

Every Orbit Closer

The Parker Solar Probe launched during solar minimum, giving scientists the opportunity to study the extraordinarily quiet Sun and its relatively undisturbed (but still churning) fields and particles.

But even as scientists continue to pore over the data from the initial orbits, the Sun's activity should begin to ramp up, and solar eruptions will dump more and more energy into the corona. The maximum in solar activity will come between 2023 and 2026 — around when Parker is at its closest to the Sun, swinging within 9 solar radii of the visible surface.

Other telescopes will soon be joining in on the fun. The Daniel K. Inouye Solar Telescope in Hawai'i, which is still in the process of coming online, took its first light images in January, and the European Space Agency's Solar Orbiter reached its first perihelion in June (see page 9).

Crucially, well before solar maximum, Parker will pass within the Alfvén radius. "We almost did it with encounter four," Bale says. "In the next couple of orbits for sure, probably." Once inside, the spacecraft will finally "touch" the Sun. Will scientists find answers there? Certainly. But as McComas points out, "The point is to get more questions. Answer the questions you've had for a while, and uncover the next, more difficult round."

■ *Sky & Telescope*'s News Editor **MONICA YOUNG** is glad to see that the Parker Solar Probe has put on sunblock before catching some rays.

 by Jennifer van Saders

Star Clocks

LAURITTA / SHUTTERSTOCK

Measurements of stellar rotation give astronomers insight into stars' ages. But they've also unearthed a mystery.

How do we tell time in the Milky Way? To understand the history of our galaxy, its star systems, and even its elements and molecules, we need a way to put a timeline to events — a timeline that spans billions of years. The Milky Way didn't form in one sudden burst of star formation, nor has it always been forming stars at the same rate. It didn't start rich in the heavier elements that make up most of the physical material we interact with on a day-to-day basis, either. These elements (carbon, oxygen, silicon, iron, etc.) are all the products of the lives and deaths of stars, built up over time and multiple generations (*S&T:* June 2020, p. 58). To understand the history of star formation and enrichment, we need a means of telling time.

Likewise, we've now discovered thousands of planets orbiting other stars. A whole cohort of scientists is devoting their lives to the search for Earth-like planets, ultimately trying to answer the question, "How unusual is Earth?" The answer requires more than just a tally of how many Earth-size planets there are in Earth-like orbits around Sun-like stars (we think the answer is "a lot"), but also where in their evolution those planets are. Earth is 4.6 billion years old; we've only had an oxygen-rich atmosphere for about 2.4 billion years. Complex animal life has only existed for 600 million years or so. If we're judging based on what our world looks like today, then a very young Earth would not have been Earth-like at all. Without a sense of time, it's hard to put our own solar system in context.

Stars are our galactic clocks. They are bright and therefore easy to see across vast distances, but they are also long-lived. Stars born throughout the history of the Milky Way are still burning today, keeping some record of the conditions of our galaxy's past. Because stars are born along with their planetary systems, the age of the host star is also the age of its planets. So if we can find an effective means of estimating stellar ages, we can reconstruct billions of years of galactic and planetary history.

Measuring stars' ages, however, is the hard part.

Aging Gracefully

You may have heard the adage, "Don't look a gift horse in the mouth," warning us not to find fault with otherwise positive happenings in our lives. The phrase is rooted in actual horse husbandry: Unless the horse is very old or very young, it's challenging to tell whether that horse is a teenager or creeping toward retirement. However, the wear and alignment of horses' teeth change as they age, meaning that the best way to tell a horse's age is in fact to look it in the mouth.

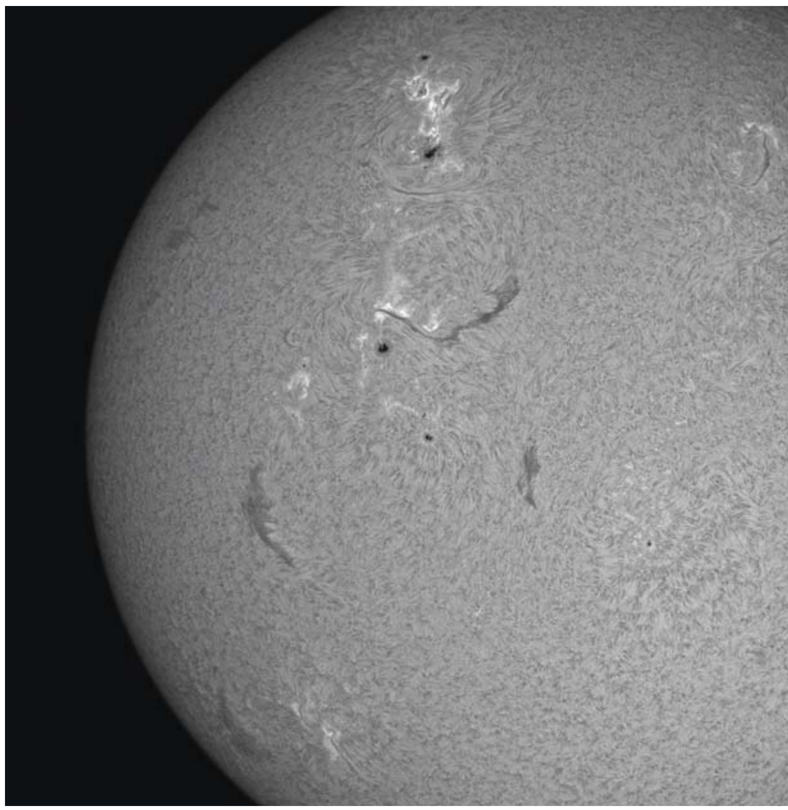
We find ourselves in somewhat the same situation when trying to age-date stars: Unless they are very old or very young, we generally struggle to find some property we can easily measure that quickly and accurately tells us the age.

The vast majority of a star's life is spent on what we call the *main sequence*. Main-sequence stars are stably burning hydrogen in their cores. The vast majority of stars in the Milky Way, including the Sun, are on the main sequence. A star like the Sun will shine by fusing its core hydrogen into helium for about 10 billion years, meaning our Sun is only halfway through the main sequence. However, the main-sequence lifetime depends very strongly on the mass of the star: More massive stars burn bright and die young, while less massive stars can burn hydrogen for many times the current age of the universe.

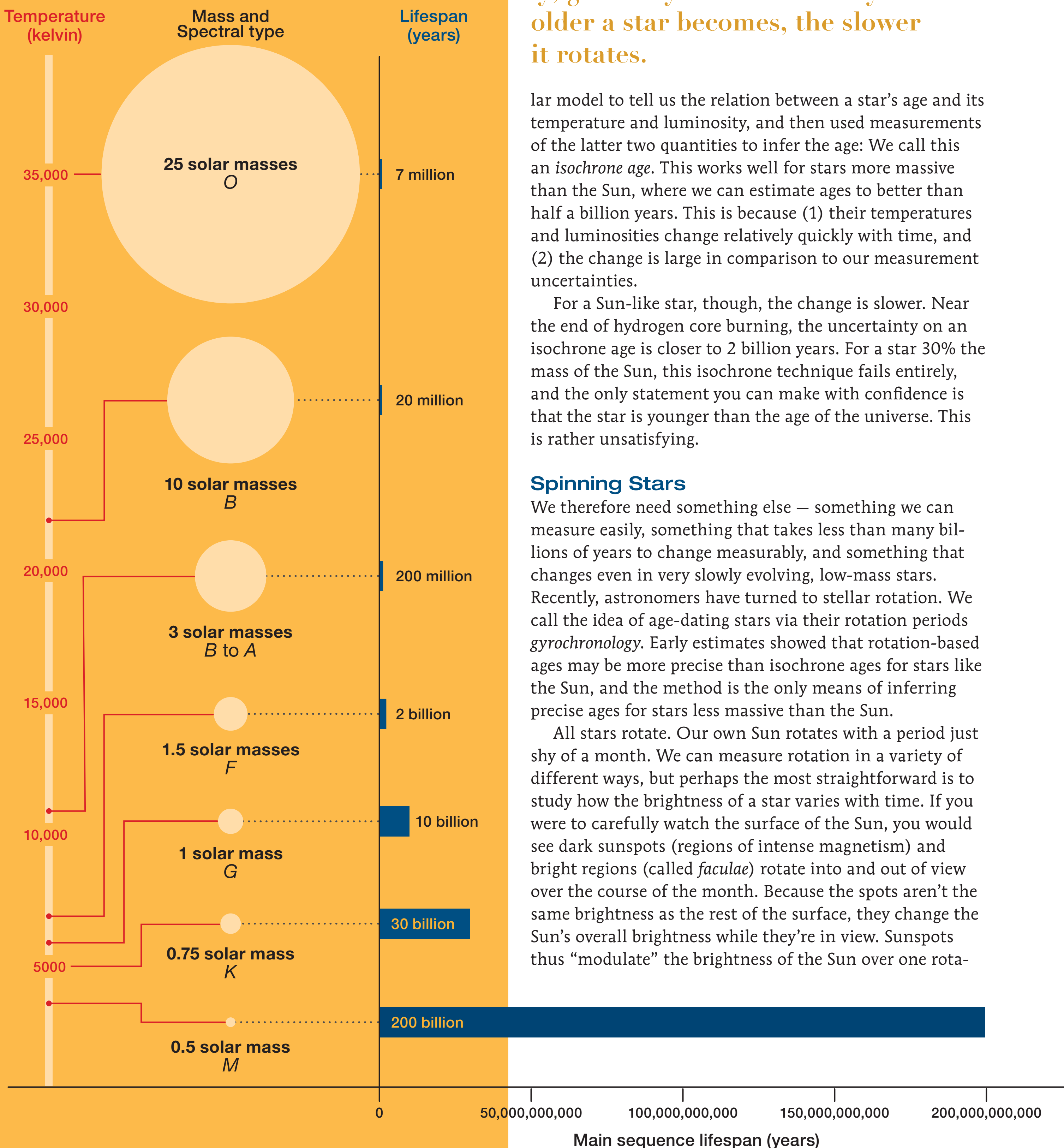
A star undergoes some mild changes on the main sequence. The Sun was about 30% less luminous when it first settled into stable hydrogen burning than it is today. It will continue to brighten and its surface temperature will get slightly hotter as it swells with age. By the time the Sun exhausts the hydrogen in its core, it will be about 70% brighter than it is today, although at its hottest it will be only about 40K (72°F) hotter.

It's tempting to use this fact to estimate a star's age, and historically this is the approach we've taken. We used a stel-

▼ **MOTTLED SURFACE** Seen here in hydrogen alpha (wavelength 656.3 nm) on July 29, 2012, the Sun sports a few spots as well as bright regions called *faculae*. Faculae are places where the solar magnetic field is concentrated, but in much smaller bundles than in sunspots.



ALAN FRIEDMAN



▼ **A STAR'S LIFE** The most massive stars live only a few million years, whereas the smallest will fuse hydrogen for hundreds of billions of years or longer. Shown here are a range of masses, which span the spectral types. Stars are not to scale.

> We've found that when we look at young stars they are rotating rapidly, generally in one to 10 days. The older a star becomes, the slower it rotates.

lar model to tell us the relation between a star's age and its temperature and luminosity, and then used measurements of the latter two quantities to infer the age: We call this an *isochrone age*. This works well for stars more massive than the Sun, where we can estimate ages to better than half a billion years. This is because (1) their temperatures and luminosities change relatively quickly with time, and (2) the change is large in comparison to our measurement uncertainties.

For a Sun-like star, though, the change is slower. Near the end of hydrogen core burning, the uncertainty on an isochrone age is closer to 2 billion years. For a star 30% the mass of the Sun, this isochrone technique fails entirely, and the only statement you can make with confidence is that the star is younger than the age of the universe. This is rather unsatisfying.

Spinning Stars

We therefore need something else — something we can measure easily, something that takes less than many billions of years to change measurably, and something that changes even in very slowly evolving, low-mass stars. Recently, astronomers have turned to stellar rotation. We call the idea of age-dating stars via their rotation periods *gyrochronology*. Early estimates showed that rotation-based ages may be more precise than isochrone ages for stars like the Sun, and the method is the only means of inferring precise ages for stars less massive than the Sun.

All stars rotate. Our own Sun rotates with a period just shy of a month. We can measure rotation in a variety of different ways, but perhaps the most straightforward is to study how the brightness of a star varies with time. If you were to carefully watch the surface of the Sun, you would see dark sunspots (regions of intense magnetism) and bright regions (called *faculae*) rotate into and out of view over the course of the month. Because the spots aren't the same brightness as the rest of the surface, they change the Sun's overall brightness while they're in view. Sunspots thus "modulate" the brightness of the Sun over one rotation cycle, making it possible to measure the period. Apart from a handful of large and nearby stars, we can't resolve the surfaces of other stars to see the individual starspots, but we still can see the periodic dimming as the stars rotate.

We've found that when we look at young stars they are spinning rapidly, generally completing a rotation in one to 10 days. The older a star becomes, the slower it rotates. Physically, we think this is the consequence of both mass loss and magnetism. Sun-like stars undergo slow but steady mass loss, blown away from the stellar surface as a wind of particles. The Sun loses about 2×10^{-14} solar masses of material a year. That's a lot in human terms: It's equal to about 70 times the biomass in carbon of all life on Earth, every year. However, it's nothing for the Sun: It would take the Sun 3,600 times the current age of the universe to lose all of its mass at this rate.

The wind may be insignificant in terms of mass loss, but it *is* significant in terms of angular momentum loss. The wind interacts with the Sun's magnetic field as it streams away, resulting in a torque on the star's rotation. The Sun loses angular momentum to these magnetized winds and thus spins down.

Turning an Idea into a Tool

It's one thing to recognize that old stars spin slower, and quite another to be able to translate that rotation period into an estimate of the age. Nor do we really understand the physics behind stars' mass loss and magnetism.

To overcome this challenge, we can let nature tell us the right answer: If we measure rotation periods in special systems where we can measure the age in some other way, then we can use these ages to tune our rotation-based clock and calibrate our models.

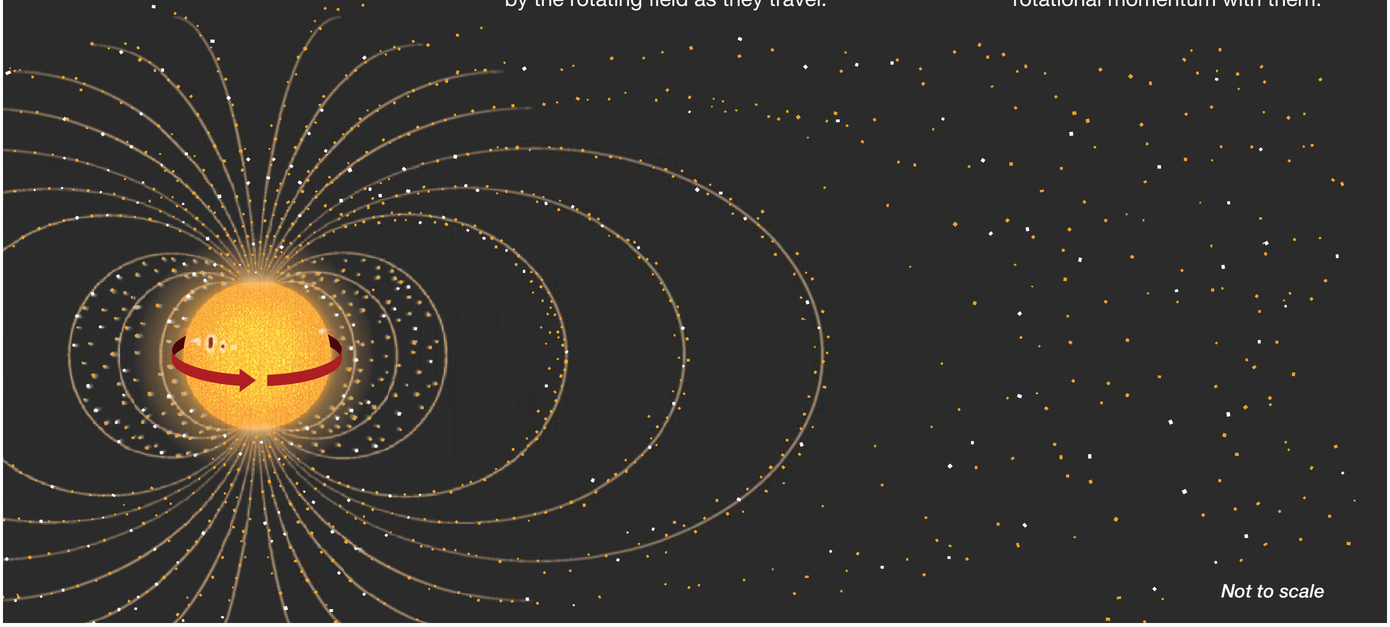
The Sun is one example of such a system, where we can use radioisotope dating of primordial meteorites to measure the age of the solar system, and thus the Sun. However, this only works for our own star, since we can't yet collect rocks from other planetary systems to directly measure their ages.

One important class of stellar system where age measurements are possible are open clusters: groups of stars born together. These stars are coeval and have the same composition; the only difference among them is their masses. In a cluster we can measure an isochrone-based age of the more rapidly evolving, massive stars and then apply that age to every star in the cluster. However, while clusters less than 1 billion years old tend to be common and nearby, open clusters disperse with time. Clusters older than the Sun tend to be rather rare and distant, making it a challenge to study the rotation of their stars.

Until recently, we only had a handful of clusters with rotation measurements, and essentially no stars older than the Sun with truly robust age and period measurements. The planet-hunting Kepler mission made all the difference. It gave us two critical new types of information: rotation periods for a much larger sample of stars than ever before, and access to a new way of measuring ages independent of rotation.

Kepler's view of the sky was pixelated, but it could detect exceptionally tiny variations in the brightness of stars. To understand how sensitive Kepler really was, let's consider an analogy. The Luxor Hotel in Las Vegas boasts the brightest spotlight in the world, which is actually made from a room

How a Star Slows Down



INFOGRAPHIC: TERRI DUBÉ / *S&T*; HOW A STAR SLOWS DOWN: GREGG DINDERMAN / *S&T*

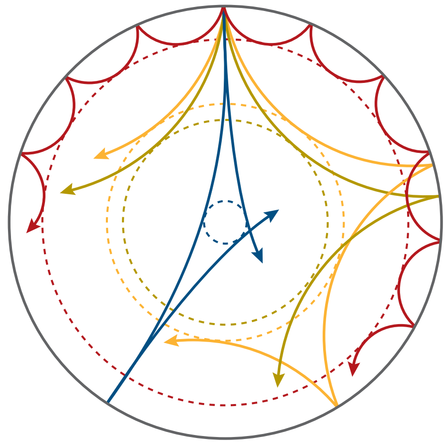
full of bright xenon lamps focused into a beam. Now imagine you go stand in among these lights with a small LED flashlight. Something with Kepler's sensitivity looking down would be able to detect the difference in intensity as you turned your flashlight on and off against the background of those spotlights: a signal of only a few to tens of parts per million. This was a requirement for Kepler's main mission to detect Earth-like planets passing in front of Sun-like stars, but it also made it an incredibly powerful tool for studying stars overall.

Kepler's sensitivity gave us the ability to detect spots even on quiet stars with relatively few of them, something very difficult to do from the ground. It enabled us to detect the rotation of tens of thousands of stars, and of older cluster stars than ever before.

Kepler also gave us access to another powerful technique: *asteroseismology* (*S&T:* Jan. 2018, p. 22). Just as seismology on Earth is the key to understanding the structure of Earth's core, asteroseismology allows us to peer into stars' deep interiors. In Sun-like stars, the churning convective regions in their outer layers produce sound waves and set the star ringing. These sound waves cause the star to pulsate, and the surface becomes slightly brighter and dimmer over the pulsation, a signal we could detect with Kepler.

Some of those sound waves pass near the stellar core where nuclear fusion is occurring. Sound passes at different speeds through a core rich in hydrogen fuel and one where most of that fuel has been converted to helium "ash." This means that by studying these acoustic waves, we effectively have a means of measuring how much of its fuel the star has burned. Because the fraction of the fuel a star has burned is closely connected to how long it has been burning, it gives us a tight constraint on the stellar age, even in old stars.

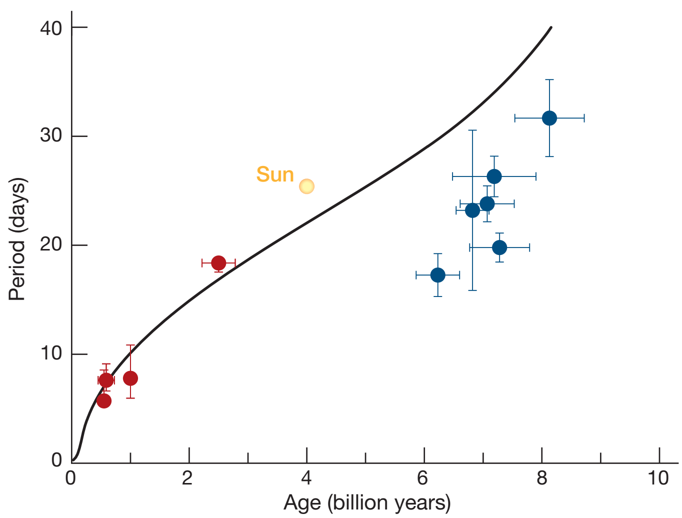
Asteroseismology is incredibly powerful, but it's also limited to the brightest stars. While Kepler stared at about



▲ **STELLAR SEISMIC WAVES** Acoustic waves take many paths through a star, depending on the density and temperature of the plasma that the waves travel through. These waves change the star's brightness in subtle ways, enabling astronomers to detect them.

150,000 main-sequence stars, it detected pulsations in only about 500 of those targets. And, because those pulsations become harder to detect in lower-mass stars, there are a mere handful of main-sequence stars less massive than the Sun with detected pulsations.

While stars with precise seismic ages are few in number, we can use this whole new class of calibrators to tune our rotation-based clocks. For the first time, we could test our period-age relations for stars older than the Sun.



▲ **SURPRISING SPINS** Stars in young clusters (red) spin down as expected with age (black line). But stars age-dated with asteroseismology (blue) spin too fast. The stars shown here have temperatures of 5600 to 5900 kelvin, similar to the Sun (about 5800K).

Surprises and Puzzles

The picture that emerged from Kepler was puzzling. Measurements of periods in the open clusters aligned beautifully with the period-age relations we already had, as did the seismic stars that were younger than middle-aged. However, the old seismic stars were a problem: They were spinning faster than expected for their old ages.

Furthermore, something was wrong with the full, 30,000-some-star sample with measured periods. The old, slowly rotating stars we thought should be there were missing. It's very possible we simply overlooked their subtle rotational signals: As stars age they become less spotty, and it becomes harder to detect the brightness modulation created by spots. However, it could also be that stars never actually manage to spin down to those long periods, a fact we had no way of knowing without having precise asteroseismic ages to highlight the old stars.

My collaborators and I put forward an idea that might explain what we saw: If stars stopped spinning down as quickly midway through their main-sequence lives, we could explain the behavior of both our young, trusted open clusters and the old seismic stars. However, in order for that to happen, something drastic needed to change in the spin-down. Either the strength or shape of the magnetic field, or the nature of the mass loss, must undergo a transition in order to weaken the angular momentum loss.

We think the magnetic fields in Sun-like stars are driven by a dynamo that results from the interaction between the star's rotation and the circulation of material in the outer convection zone. We argued that the spin-down might even-

HIGH SPINS: GREGG DINDERMAN / *S&T*, SOURCE: J. L. VAN SADERS ET AL. / *NATURE* 2016; STELLAR SOUND: LEAH TISCIONE / *S&T*, SOURCE: SOI / STANFORD UNIVERSITY tually change the nature of the dynamo, which would then weaken the angular momentum loss. If that transition also meant that stars were less spotty, it could explain the full sample as well: Stars never make it to long periods (they stop spinning down), and we don't see a pileup of stars that have stalled their slowdowns because they have very few spots and it's hard to see them rotating.

If this scenario is true, it means that all solar mass stars halfway through the main sequence — in other words, the same age as the Sun — are undergoing this transition, and that our Sun is at a somewhat "special" point in its life. This is an uncomfortable claim for any scientist who has had the Copernican Principle drilled into them for decades. But it's also intriguing. What if the Sun is undergoing a magnetic transition? What does that mean for space weather on Earth-like planets? Will the Sun continue to have an 11-year magnetic cycle? Will the number of spots on its surface decline?

Moving Forward

So far, our attempts to understand how rotation changes with age have raised more questions than they've answered. And it's very unlikely that the surprises are over: We've only looked at the tiny fraction of stars similar to the Sun, and as we expand that view we'll need to expand our physical understanding as well.

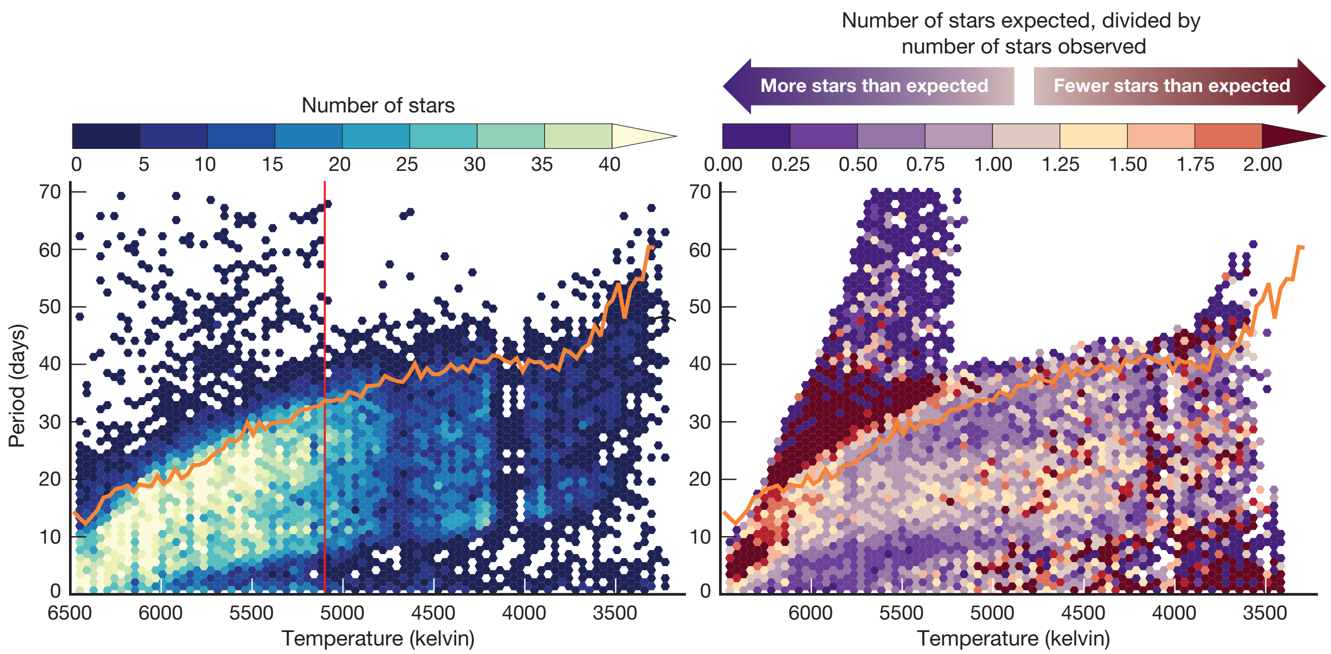
For example, we've still had little chance to study the rotational evolution of those low-mass stars that ignited our interest in gyrochronology to begin with. Kepler and its successor mission K2 added young, low-mass cluster stars to our sample, and already we're seeing that the picture we've constructed for the Sun's rotational evolution doesn't describe the behavior of these low-mass stars all that well. Calibrator stars are even harder to come by for these low masses, and the hunt is on to find them. We're very motivated in our search — these are the most numerous stars in the galaxy, the most difficult to age-date, and the most likely host stars for future interesting exoplanets discovered by the ongoing Transiting Exoplanet Survey Satellite (TESS) mission.

For researchers working on this problem, these puzzles are just as exciting as the prospect of creating a galactic timepiece. When we are eventually able to describe the spin-down well, we will suddenly have an incredibly powerful tool for measuring ages in our hands. However, every time a new observation breaks our models, we are equally excited: It's a chance to learn about deeply uncertain aspects of stellar evolution that stellar astronomers have struggled with for more than 100 years.

It turns out when you ask a star its age, you get its whole (magnetic) life story.

■ **JENNIFER VAN SADERS** is a professor at the University of Hawai'i at Manoa. She spent the first few years of her career convinced she didn't want to study stars, but then she saw the light and never looked back.

▼ **MISSING STARS?** When astronomers plotted some 30,000 stars' rotations, they found that far fewer of them spun slowly than expected. The lefthand plot shows the observed stars. The righthand plot is a comparison of the data to what's expected if stars continued to spin down with age. In both plots, 95% of stars lie below the orange line. The redder the region on the righthand plot, the more stars are "missing" compared to what astronomers expected to see. If there's a point at which the rotation rate is slow enough that it doesn't affect motions in the star's convective zone, then it could affect the magnetic field and explain why magnetic braking hasn't continued to spin stars down. Note that stars cooler than 5100K (red line) aren't old enough to have spun down yet. The tall purple "fin" on the righthand plot is from older, swollen stars, which the calculations don't handle well.



PLOTS: THE AUTHOR

The famed American astronomer was an avid observer yet didn't publish many of his findings — now, his unreported discoveries are coming to light.

The life of legendary astronomer Edward Emerson Barnard is a rags-to-riches story. Born in 1857, he endured an impoverished childhood in Nashville during the Civil War era. Before his ninth birthday, he was already working as a photographer's assistant in order to support his widowed mother. Despite severe economic hardships and the lack of a comprehensive education, he rose to become one of the leading astronomers of the late 19th and early 20th centuries.

At 19, Barnard purchased a 5-inch Byrne refractor for $380, which amounted to two-thirds of his annual salary. The lure of a $200 prize for finding new comets offered by Rochester, New York businessman and philanthropist Hulbert Harrington Warner, prompted him to start searching for them, and he discovered nine between 1881 and 1887. The prize money helped finance his first home, which he called "Comet House."

During this period, he took undergraduate classes in mathematics and physics at Vanderbilt University. He also made several astonishing discoveries using both Vanderbilt's 6-inch Cooke refractor and his own telescope. These include the Pacman Nebula (NGC 281), the California Nebula (NGC 1499), the eponymous Barnard's Galaxy (NGC 6822), and an independent discovery of the Rosette Nebula (NGC 2237).

▲ **PROLIFIC OBSERVER** E. E. Barnard might not have published as avidly as he could have, but thankfully he left a rich legacy in copious logbooks.

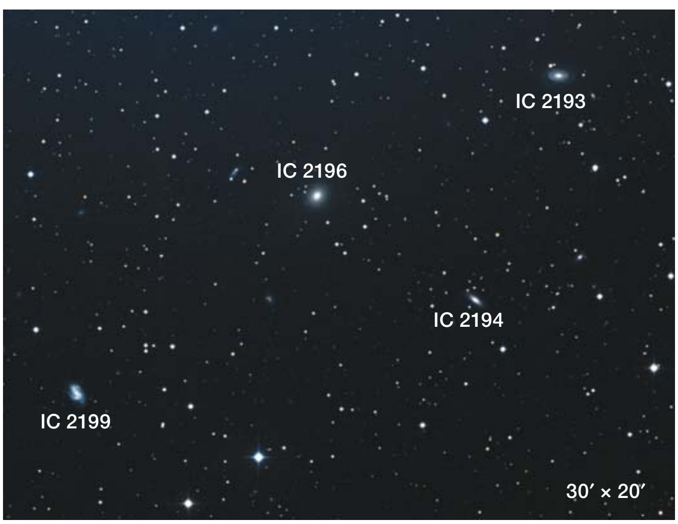
Although Barnard lacked advanced scientific training, Edward Singleton Holden, the first director of Lick Observatory, offered him a position. Holden was impressed with Barnard's visual prowess and anticipated the attention new comet discoveries would bring to the fledgling observatory. The staff for the world's first permanent mountaintop observatory also included the pioneering spectroscopist James Keeler and the skilled double-star observer Sherbourne Wesley Burnham.

Barnard jumped at the prospect of using the new 36-inch Clark refractor — the largest in the world at the time — under the inky skies seen from atop Mount Hamilton. During his Lick years, Barnard regularly documented features on Mars and Jupiter and was a trailblazer in wide-field photography of comets and the Milky Way. In 1892, he capped his visual career with the discovery of Amalthea, Jupiter's fifth moon — a supremely tough target and the last planetary satellite to be discovered visually.

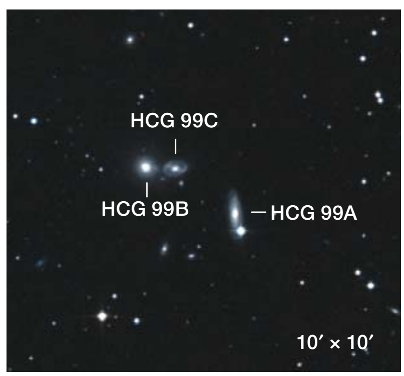
Spectacular photographic discoveries followed, many bearing his name: Barnard's Star, all the dark nebulae carrying the designation "Barnard" (or simply the letter "B"), Barnard's Loop (photographed earlier by William Henry Pickering at Harvard College Observatory), and more. But he was also an indefatigable visual observer of *nebulae*, a term used in his day to describe any nonstellar object, including galaxies. While scouring the heavens for comets, he must have run across many such unknowns. Yet, curiously, he published only a few of these discoveries.

Several years ago, I came across the Lick Observatory Historical Collections Project and their high-resolution scans of early staff logbooks (**collections.ucolick.org**). By examining Barnard's currently scanned logs from May 1888 through October 1890, I found a treasure trove of uncredited deep-sky discoveries that have lain hidden in his personal logbooks for more than 130 years.

▼ **QUARTET IN GEMINI** It was while he was pointing the Lick 12-inch telescope at Alpha Geminorum, familiarly known as Castor, that Barnard discovered these four galaxies shown below. Curiously, despite the fact that Castor is one of the most comprehensively observed double stars, nobody had noticed (or reported) these objects before Barnard did in 1888. It took him another nine years, though, before he published his finding.

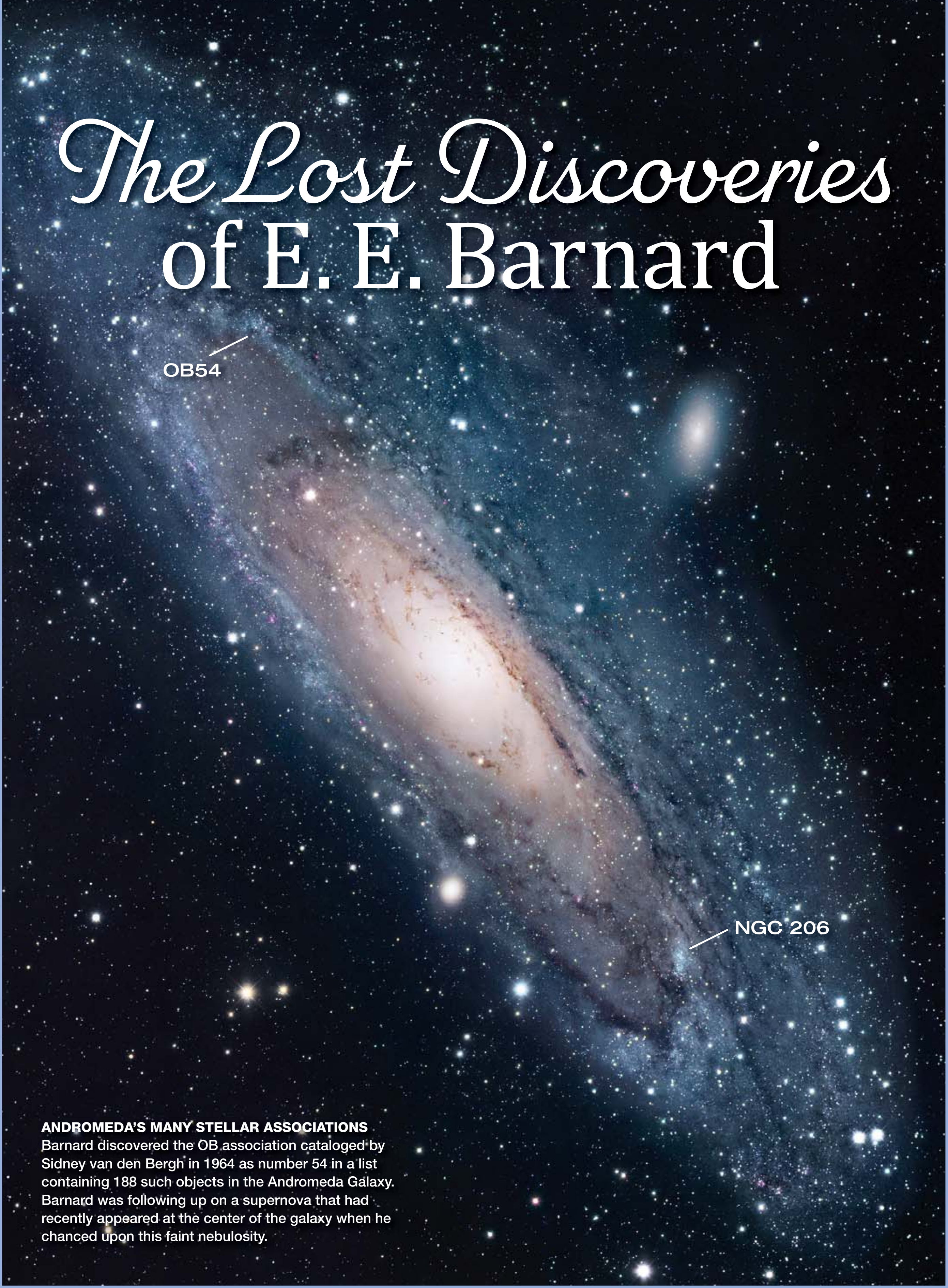


▶ **HICKSON GROUP 99** Part of a quintet later cataloged by Paul Hickson in 1989, Barnard observed these two members of the compact galaxy group on the night of January 27, 1889. The glare from the magnitude-11.5 star at lower right of the largest member of the group, HCG 99A, prevented Barnard from detecting the galaxy.



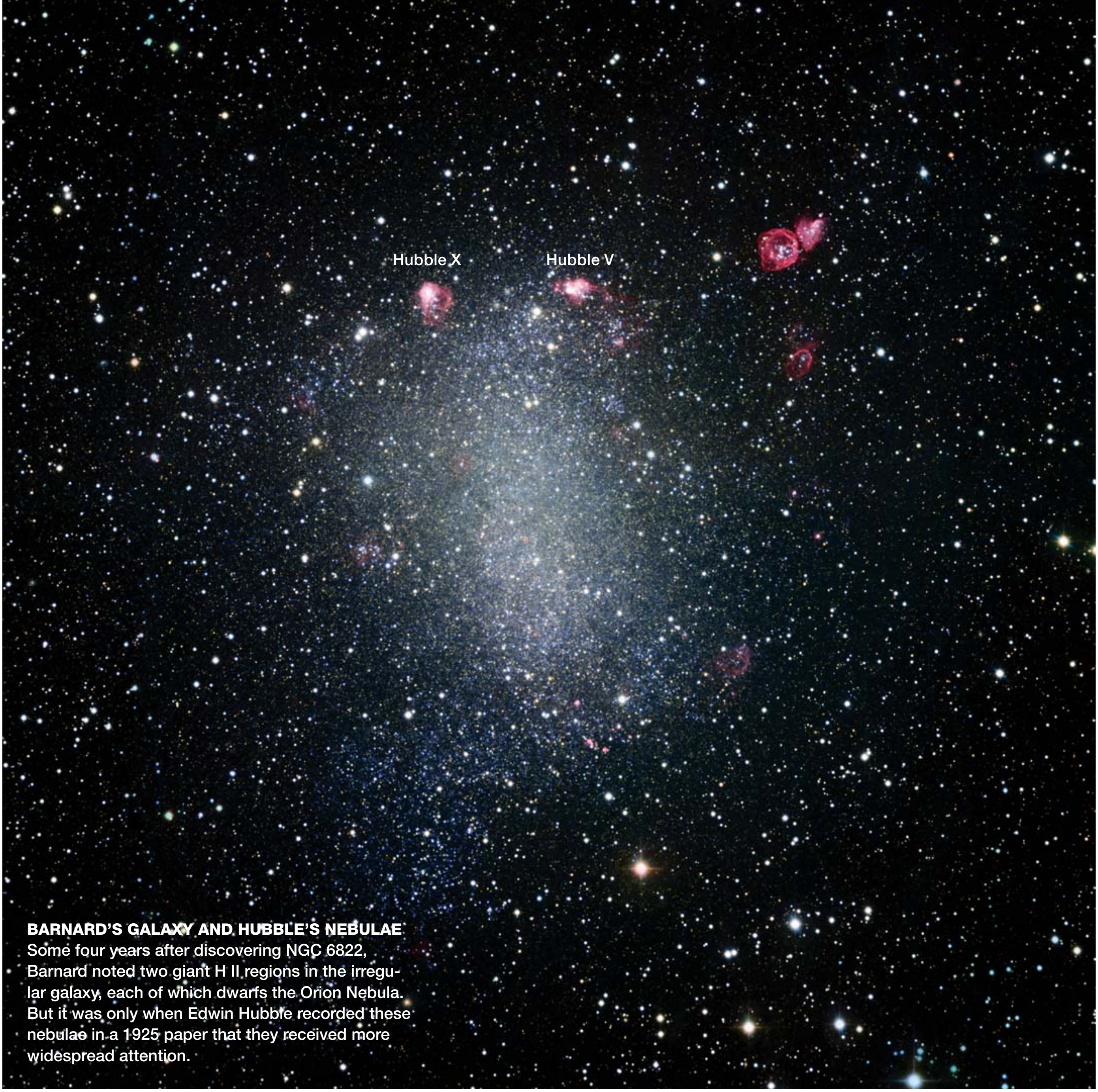
BARNARD: *S&T* ARCHIVES; POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (2)

The Lost Discoveries of E. E. Barnard



ANDROMEDA'S MANY STELLAR ASSOCIATIONS Barnard discovered the OB association cataloged by Sidney van den Bergh in 1964 as number 54 in a list containing 188 such objects in the Andromeda Galaxy. Barnard was following up on a supernova that had recently appeared at the center of the galaxy when he chanced upon this faint nebulosity.

R. GENDLER / ESA / HUBBLE



BARNARD'S GALAXY AND HUBBLE'S NEBULAE Some four years after discovering NGC 6822, Barnard noted two giant H II regions in the irregular galaxy, each of which dwarfs the Orion Nebula. But it was only when Edwin Hubble recorded these nebulae in a 1925 paper that they received more widespread attention.

Barnard's scribbled notes and measurements are difficult to decipher, but each entry includes a rough position, a brief description, and occasionally a diagram. I've documented some 50 unknown discoveries during his first 2½ years at Lick. These include every category of deep-sky object: galaxies, globular and open clusters, and reflection and emission nebulae. Later visual observers rediscovered a few of these objects, but most remained unknown until the photographic surveys of the second half of the 20th century.

Why didn't Barnard publish these discoveries? Computing precise positions of new nebulae was a time-consuming task, and by the late 1880s astronomers had already cataloged more than 7,800. His true passion was sweeping for new or known comets, so he spent a limited amount of time on most nebulae encountered along the way.

Nashville – October 8, 1885

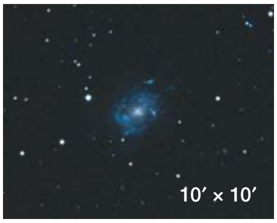
Many amateurs are familiar with NGC 206, an enormous star cloud near the southwest end of the Andromeda Galaxy (M31). But few are aware of **OB54**, a fainter patch exactly on the opposite side of the nucleus on the northeast end of the galaxy, 42′ from the center. The "OB" designation comes from Sidney van den Bergh's 1964 paper "Stellar Associations in the Andromeda Nebula," which lists 188 OB associations in M31.

Barnard noticed OB54 while observing the 6th-magnitude supernova SN 1885A, which German astronomer Ernst Hartwig had discovered at the center of M31 on August 20th. Although astronomers assumed the supernova was a galactic nova, it proved to be the first and brightest extragalactic supernova discovery until SN 1987A in the Large Magellanic Cloud.

ESO

Barnard wrote the following to the German journal *Astronomische Nachrichten*:

> *I have for some time suspected a faint Nebula near the following* [East] *end of the Great Nebula of Andromeda. Last night being fine I verified its existence. This object, though extremely faint, flushes out quite distinctly by averted vision. It lies about as far from the new star* [SN 1885A] *as the Nebula in the preceding end* [NGC 206] *does.*



▲ **UGC 10445** Some 3° south-southwest of 3rd-magnitude Zeta Herculis, this is one of several new galaxies Barnard discovered while comet hunting.

John Louis Dreyer, who compiled the *New General Catalogue of Nebulae and Clusters of Stars* in 1888, apparently missed this announcement, so OB54 didn't receive an NGC number. Through my 24-inch at 125×, this faint patch angles southwest to northeast and spans 2.5′ × 1.5′. The contrast against Andromeda's halo varies with the seeing — sometimes I find OB54 obvious; at other times, it's barely distinguishable.

Barnard headed west for the San Francisco Bay Area in September 1887. He was so eager to start his work at Lick that he arrived before observatory construction was completed — first light for the 36-inch refractor was planned for December 31, 1887, but occurred a week later due to weather and equipment issues. Once the observatory was up and running, Holden assigned Barnard the Lick's 12-inch Clark refractor (first used by Henry Draper in New York for double star observations), a 6.5-inch refractor, and a 4-inch comet-seeker. Eight long months after leaving Nashville, and suffering photon deprivation meanwhile, Barnard resumed his nightly comet sweeps.

▲ **LONG-LOST GLOBULAR** Palomar 8 remained unknown until the 1950s, some 60 years after Barnard first spotted it while keeping busy waiting for the comet that would bear his name to rise above the horizon.

Lick Observatory – May 9, 1888

Barnard began his first night on the 12-inch by pointing at Castor (Alpha Geminorum) and found four faint galaxies — **IC 2193**, **2194**, **2196**, and **2199** — only ½° south of the star. At the time, Castor was diving towards the western horizon and was only 22° in elevation. Why is this discovery noteworthy? Castor is one of the most widely observed double stars, yet no earlier astronomer had noticed this galactic quartet.

Barnard sketched a rough diagram and tried to compute precise offsets from Castor. This was a frustrating task without a *filar micrometer*, the device astronomers then used for measuring angular separations. During four nights, he filled several pages of his notebook with manual calculations for various corrections. Despite all the effort put into the task, Barnard didn't publish his discovery for another nine years; it finally appeared in the December 1897 *Astronomical Journal*.

These IC galaxies range from 13th- to 14th-magnitude and are visible in a 10-inch scope as small grayish fuzzies with brighter

Barnard's Comet Discoveries and Associated Finds

September 3 and October 30, 1888 Barnard found his first two comets at Lick, C/1888 R1 and C/1888 U1.

June 23, 1889 In the early hours, Barnard discovered the periodic Comet 177P/Barnard using the 6.5-inch refractor, his fourth catch in a little more than a year at Lick. He followed it intently over the next week as it moved through Andromeda, calculating the hourly motion and predicting its position for the following night.

August 1889 Prolific comet hunter William Robert Brooks discovered the extraordinary Comet 16P/Brooks on the morning of July 7, 1889. On August 1st, Barnard was startled to see two companions, B and C, accompanying the comet 1′ and 4.5′ from its nucleus. That same night he strapped the 6-inch Willard camera to the 12-inch refractor and made a wide-field, three-hour exposure, revealing an astounding tapestry of Milky Way clouds and dark nebulae in Sagittarius.

Three nights later Barnard joined Burnham and spied two fainter pieces, D and E, with the 36-inch. He reported that B and C each had a small nucleus and a short, faint tail, "presenting a perfect miniature of the larger comet." Barnard followed the entourage over the next several weeks as fragments B through E disintegrated. The break-up of 16P/Brooks followed a close passage within the Roche limit of Jupiter in 1886 — a similar scenario to that of Shoemaker-Levy 9 in 1992.

▲ **FRAGMENTS** Barnard witnessed and recorded the disintegration of Comet 16P/Brooks.

UGC 10445: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; PALOMAR 8: ROBERT PÖLZL / CCDGUIDE.COM; COMET DRAWING: LICK OBSERVATORY cores. Larger scopes will resolve ovals 30″ to 40″ across in various orientations.

July 7, 1888 – January 1, 1889

Barnard began the evening of July 7, 1888, by recording a wealth of detail in Jupiter's belts and the start of a shadow transit by Io. He then turned his attention to NGC 6822, the Local Group dwarf he had discovered four years earlier (and that bore his name) in the northeast corner of Sagittarius. His logbook entry reads,

> *Examining* [NGC 6822] *with power 175, it is a remarkable object, somewhat elongated and dense and irregular. At the northern side are two very small nebulae, the preceding is moderately bright, the following is faint, both near small stars.*

Barnard's "two very small nebulae" are in fact giant H II regions separated by 3′, each of which dwarfs the Orion Nebula in size. Edwin Hubble labeled these features **Hubble V** (western) and **Hubble X** (eastern) in his 1925 paper "NGC 6822, A Remote Stellar System." You might also recognize Hubble X as IC 1308.

I've glimpsed Hubble V and X as dim smudges in an 8-inch scope, though Hubble X hovers at the edge of visibility. Through my 18-inch at 220×, they both appear as dense 14th-magnitude knots, each 25″ in diameter. Try using a UHC (ultra-high contrast) or an O III nebula filter — I found they both mildly improved the contrast.

On New Year's Day 1889, a solar eclipse crossed northern California. Barnard took part in a Lick expedition, which set up equipment 130 miles north of San Francisco at Bartlett Springs. After photographing the Sun's corona, he rushed back to Lick to continue with his observing program, which he did at a fanatical pace. During the last three weeks of January, he was glued to the eyepiece every clear minute spanning a period of 15 nights.

▲ **SH 2-297** Also known as Cederblad 90, this nebula lies at the southern tip of the Seagull Nebula (that winds several degrees north and then northeast of Sh 2-297), a region rich in emission and reflection nebulae.

January 27, 1889

Before 8 p.m. Barnard spotted a small galaxy 1.8° southwest of 2nd-magnitude Alpheratz, or Alpha Andromedae, and 10′ west of a 7th-magnitude star. He returned to the field two nights later to measure its position and picked up a second, much fainter companion. These two galaxies, **HCG 99B** and **HCG 99C**, are part of a compact quintet later cataloged by Paul Hickson in 1989. Barnard missed HCG 99A, the largest member in the group, because of the masking glare of a superimposed 11.5-magnitude star.

HCG 99A is a phantom spike in my 18-inch, extending 30″ due north of the star. HCG 99B appears small and round with a tiny nucleus. HCG 99C, a faint droplet of light, is attached to the western edge of HCG 99B's halo.

January 29, 1889

While combing the skies for comets, Barnard encountered several new galaxies. **UGC 10445** is located 3° south-southwest of 3rd-magnitude Zeta Herculis, the southwest corner star of the Keystone asterism. Following William Herschel's reporting format, Barnard described it as "faint, not large, round, very gradually brighter in the middle."

UGC 10445 is an isolated dwarf spiral at a distance of 50 million to 60 million light-years. Classified as a blue starburst galaxy, its dusty but bright nucleus is surrounded by gas-rich blue arms undergoing vigorous star formation. The object appears irregular in my 24-inch, with a mottled 1′ halo containing two low-contrast patches.

February 4, 1889

Scanning east of Puppis, Barnard found a small 12th-magnitude galaxy, which modern research reveals is extraordinary. **Hen 2-10** lies 24′ southwest of 5.3-magnitude Eta Pyxidis and shares the same low-power field. It wasn't until 1967 that astronomer-astronaut Karl Henize rediscovered this object during a hydrogen-alpha survey of the galactic plane, though he misidentified it as a planetary nebula.

Hen 2-10 is an irregular dwarf galaxy comprising only 3% the mass of our Milky Way. Astronomers classify it as a *Wolf-Rayet galaxy* — its spectrum is replete with broad emission lines arising from a sizeable population of massive Wolf-Rayet stars. At the galaxy's heart is an actively feeding black hole that weighs in at 3 million solar masses and a nuclear starburst that's furiously pumping out newborn stars. A study published in 2017 found superbubbles expanding at high velocity, the result of gas ejected from the central star-forming regions.

Visually, the most prominent feature is a bright nucleus wrapped in an oval halo. Large-scope owners may find a modest contrast gain using a narrowband filter.

July 3, 1889

While waiting for the comet that bears his name to appear over the eastern horizon (see box on page 37), Barnard swept northeast of Jupiter and discovered an object he described as,

> *. . . small, round, gradually brighter in the middle, 2′ or 3′* [diameter] *. . . with 700× probably resolvable. It is likely a globular cluster. I can occasionally see the stars. Much compressed, 13th mag . . . With lower powers, it looks like a small faint comet or nebula.*

When I checked Barnard's position, I realized he had discovered the globular cluster Palomar 8. It remained unknown until the 1950s, when George Abell found it again on the *National Geographic-Palomar Observatory Sky Survey* plates.

To locate **Palomar 8**, start at the large naked-eye cluster M25 and slide 2.4° to the east-southeast, passing an elongated group of 7th- to 10th-magnitude stars. The globular is visible with direct vision in my 8-inch reflector as a small, granulated glow with no noticeable core. My 18-inch scope resolves at least a dozen stars over a lively 3′ halo.

October 28, 1889

In the early evening, Barnard observed Comet 16P/Brooks with the 36-inch and simultaneously discovered the HCG 97 quintet (IC 5351, 5352, 5356, 5357, and 5359) in Pisces, which he described as a "nest of nebulae." The comet's location was only ¼° away from these galaxies. He published the discoveries, but not until 1906 when he was at Yerkes Observatory.

After discovering the quintet, Barnard returned to the 12-inch and found **Sharpless 2-297**, a small nebula in northern Canis Major. He described it as a "faint, diffused nebulous atmosphere, 2′ in diameter" surrounding the 8.0-magnitude star HD 53623. Sh 2-297 lies at the southern tip of the photogenic Seagull Nebula (Sh 2-296), a 2.5°-long nebulosity that winds from Monoceros into Canis Major.

The surrounding complex houses scores of massive stars, part of the CMa OB 1 association, as well as 30 or more emission and reflection nebulae. A 2019 study reported that a chain of molecular clouds rims the Seagull Nebula, forming a shell-like structure that extends 3.6° × 2.5°. The authors suggest multiple supernova explosions occurred 1 million to 6 million years ago in this area. The blasts ejected three known runaway stars and triggered several localized regions of star formation. Sh 2-297 may be an example of such a star-forming region — it harbors a young infrared cluster discovered in 2003.

My 18-inch displays a 3′ hazy glow with a wide pair of 10th-magnitude stars off the east side. A narrowband filter yields a small contrast gain, with a stronger response using a hydrogen-beta filter. The diameter swells to at least 4′ with a dim extension to the east.

February 9, 1890

Having observed Comet 16P/Brooks (page 37, the sidebar), Barnard swept up **Cederblad 51**, a weak nebulosity on the north side of 11th-magnitude HK Orionis. This million-year-old star is a pre-main-sequence Herbig Ae/Be binary, still encased in a dusty, embryonic accretion disk. Search for HK Orionis 2.4° to the north-northwest of Meissa (Lambda Orionis), the 3.5-magnitude star marking the head of Orion.

On wide-field images, HK Orionis sits along the north side of the Lambda Orionis Molecular Ring, also known as Sh 2-264. Within this immense star-forming region are young Herbig-Haro objects, T Tauri stars, pre-brown dwarf candidates, and several dark nebulae. Through my 18-inch scope, I logged Cederblad 51 as a 4′ wide, diffuse patch just north of the star.

▲ **CEDERBLAD 51** Associated with the Herbig Ae/Be binary star HK Orionis, this reflection nebula is at the northern end of the Lambda Orionis Molecular Ring, a gigantic star-forming region.

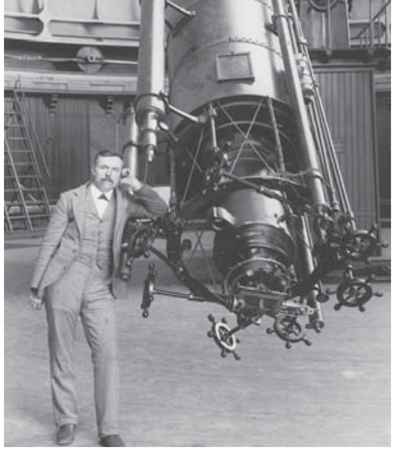
▼ **GRACEFUL FACE-ON SPIRAL** Due to its proximity to the plane of the Milky Way, IC 342 is challenging to observe — the intervening dust dims the object by two magnitudes. But the image clearly shows the two strings of stars superimposed on the galaxy's core that Barnard noted in his logbook on the night of August 11, 1890.

August 11, 1890

Barnard began the evening by tracking down his early Lick comet C/1888 R1, which he called "most excessively difficult." He then moved low in the northeast and discovered the galaxy **IC 342** in Camelopardalis. Barnard's sketch shows the galaxy's core within two converging strings of three and five stars, respectively, forming a distinctive V. Two years later, British amateur William Denning made an independent sighting of the galaxy while comet hunting with his 10-inch reflector, and Barnard yet again missed out on receiving credit by failing to publish.

IC 342 is a large face-on spiral with loose open arms spreading across 20′. Situated only 10° from the plane of the Milky Way, the veil of intervening dust reddens and dims IC 342 by two magnitudes. If we had an unimpeded view, IC 342 would be a magnificent spiral but for its mean surface brightness, which is a meager 15 magnitudes per square arcminute. However, I find the visibility more dependent on sky quality than aperture. Under dark, transparent skies you can spot IC 342 using a small scope or large binoculars, 3.2° south of 4.6-magnitude Gamma Camelopardalis.

My 8-inch at low power shows a prominent 12th-magnitude core adjacent to a star of similar brightness. Surrounding the core is a diaphanous halo that stretches beyond 10′ in diameter. Viewing through my 18-inch, the 30″ core rises to a stellar nucleus, and the halo shows hints of patchy spiral structure. The field contains a jumble of 10th- and 11th-magnitude stars — to identify IC 342, look for a distinctive line of five superimposed stars.



◀ **BARNARD WITH THE 36-INCH TELESCOPE** The prolific astronomer was so eager to start observing with the new instruments at Lick Observatory that he arrived several months before first light of the telescopes. The 36-inch saw first light on January 7, 1888, after a week of weather and technical issues.

LICK OBSERVATORY

Barnard continued his remarkable career at Lick until 1895, after which he joined the staff at Yerkes Observatory. His photographs of the Milky Way, taken during the spring and summer of 1905 at Mount Wilson, formed the basis of his opus, *A Photographic Atlas of Selected Regions of the Milky Way*. In 1916 he discovered Barnard's Star, a nearby, low-mass red dwarf with the largest-known proper motion across the sky (10.3 arcseconds per year). He found his eponymous star by comparing his Lick plate from 1894 with photographic plates taken in 1916 with the 40-inch Yerkes refractor.

When the Lick Historical Project processes Barnard's later notebooks, I expect it will uncover dozens of additional discoveries — I'm sure they'll reveal a horde of exciting finds.

■ When he's not out observing, Contributing Editor **STEVE GOTTLIEB** has been investigating the discovery history of deep-sky objects for more than 35 years. His article "Restoring Order to the Deep Sky" is in *S&T:* November 2003, p. 113.

Lost Treasures

Object	Constellation	Mag(v)	Size	PA	RA	Dec.
OB54	And	—	3.4′ × 1.7′	48°	$00^h 44.6^m$	+41° 52′
IC 2193	Gem	13.3	1.5′ × 0.9′	87°	$07^h 33.4^m$	+31° 29′
IC 2194	Gem	13.7	1.0′ × 0.3′	50°	$07^h 33.7^m$	+31° 20′
IC 2196	Gem	12.5	1.4′ × 1.1′	150°	$07^h 34.2^m$	+31° 24′
IC 2199	Gem	13.6	1.1′ × 0.6′	25°	$07^h 34.9^m$	+31° 17′
Hubble V	Sgr	~13.5	40″ × 30″	—	$19^h 44.9^m$	–14° 43′
Hubble X	Sgr	~14	45″	—	$19^h 45.1^m$	–14° 43′
HCG 99B	Peg	13.7	1.0′ × 0.9′	—	$00^h 00.8^m$	+28° 24′
HCG 99C	Peg	14.7	0.8′ × 0.4′	87°	$00^h 00.7^m$	+28° 24′
UGC 10445	Her	13.1	1.9′ × 1.5′	145°	$16^h 33.8^m$	+28° 59′
Hen 2-10	Pyx	11.6	1.7′ × 1.3′	130°	$08^h 36.2^m$	–26° 25′
Palomar 8	Sgr	11.2	4.7′	—	$18^h 41.5^m$	–19° 50′
Sh 2-297	CMa	—	7′	—	$07^h 05.3^m$	–12° 20′
Ced 51	Ori	—	4′	—	$05^h 31.5^m$	+12° 10′
IC 342	Cam	8.4	21′ × 21′	167°	$03^h 46.8^m$	+68° 06′

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

OBSERVING
November 2020

Venus is in Virgo this month, only a few degrees from Spica, as it was in November 2018 when this photo was taken. ALAN DYER

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

2 EVENING: The waning gibbous Moon is just shy of 4° from Aldebaran.

12 DAWN: Look toward the east-southeast before sunrise to see the waning crescent Moon, Venus, and Spica in a curving line some 12½° long, with tiny Mercury lower left.

12 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:11 p.m. PST.

13 DAWN: The thinnest sliver of the Moon, Venus, Spica, and Mercury are arranged in a trapezoid.

15 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:00 p.m. EST.

16 DAWN: Venus and Spica continue to adorn the east-southeastern horizon before sunrise with less than 4° separating them. Spot Mercury lower left of the pair.

17 MORNING: The Leonids are predicted to peak, with best viewing in the pre-dawn hours. Take advantage of a moonless sky to witness this usually modest shower (see page 50).

18 DUSK: Watch as the waxing crescent Moon, Jupiter, and Saturn emerge in the gloaming, forming a shallow arc some 10° long.

19 DUSK: The Moon has leapfrogged past Jupiter and Saturn and now forms a triangle with them. Follow the trio as it sinks toward the southwest.

25 EVENING: The waxing gibbous Moon and Mars are less than 5° apart high in the south-southwest.

29 DAWN: The almost-full Moon gleams between the Hyades and the Pleiades, forming a pretty tableau in Taurus.

30 FULL MOON (4:30 A.M. EST) A penumbral lunar eclipse is visible across nearly all of North and Central America and northern Russia, with partial phases visible in all of South America, Australia, and the Far East (see page 48).

— DIANA HANNIKAINEN

NOVEMBER 2020 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					

LAST QUARTER

November 8

13:46 UT

NEW MOON

November 15

05:07 UT

FIRST QUARTER

November 22

04:45 UT

FULL MOON

November 30

09:30 UT

DISTANCES

Perigee	November 14, 12ʰ UT
357,837 km	Diameter 33′ 23″
Apogee	November 27, 00ʰ UT
405,894 km	Diameter 29′ 26″

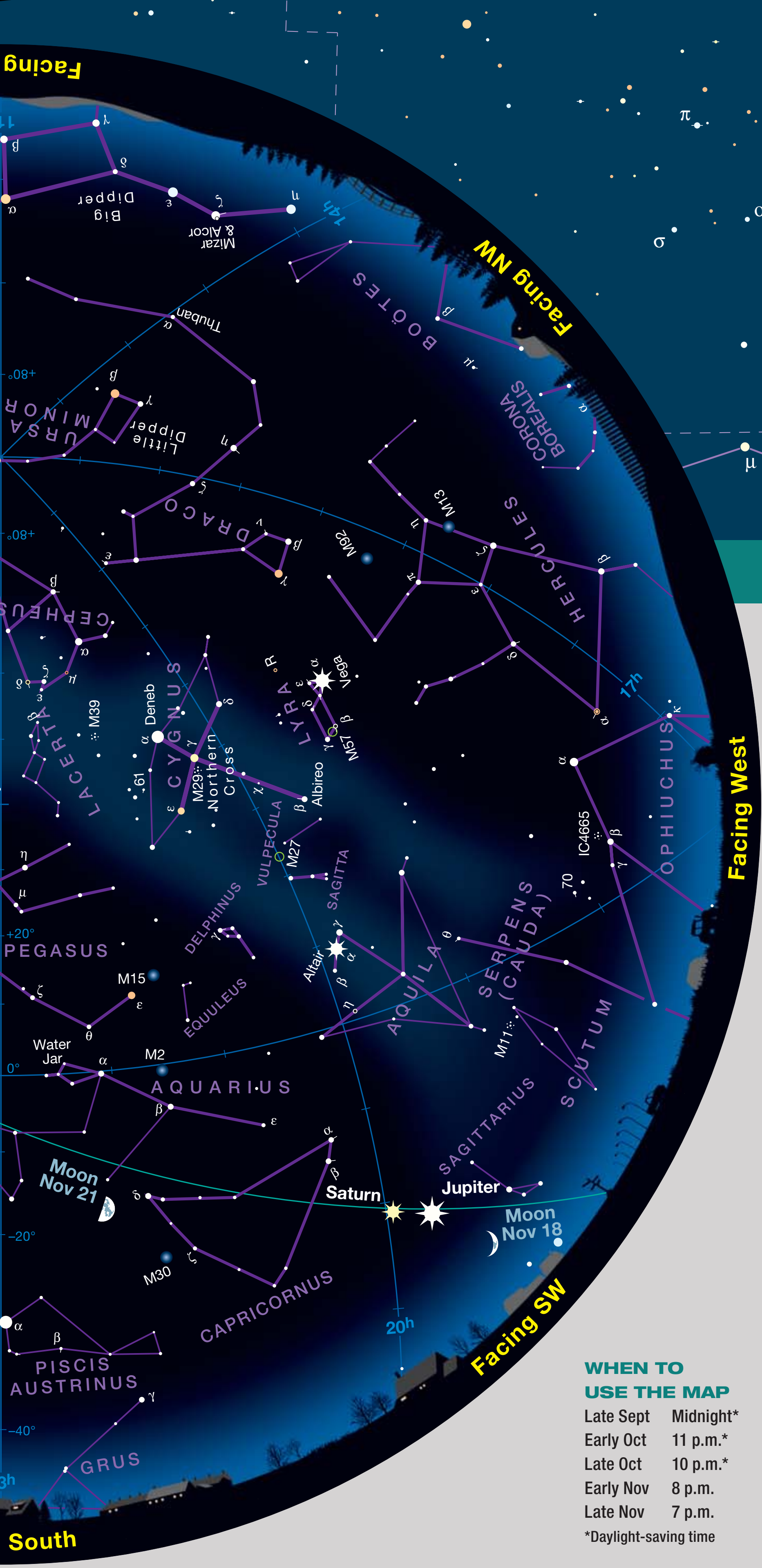
FAVORABLE LIBRATIONS

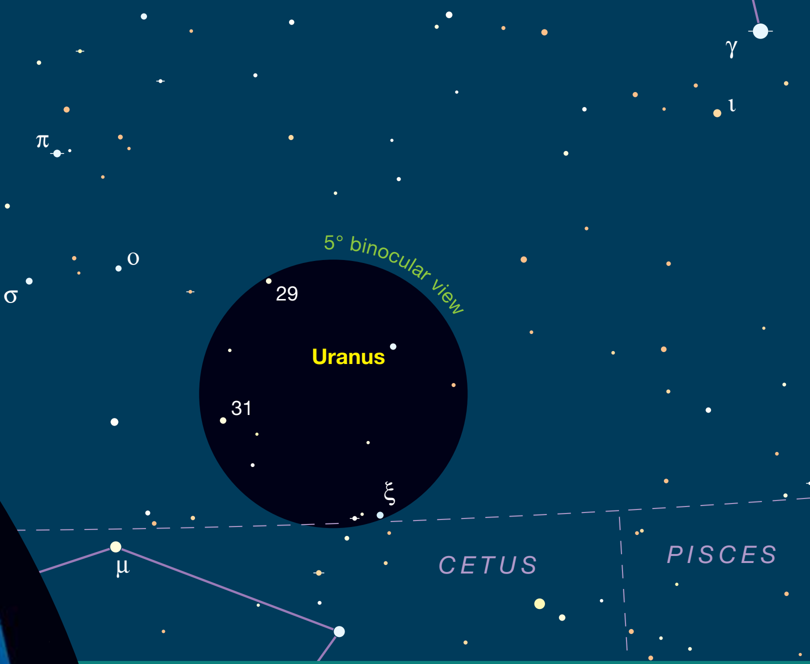
- Lacus Veris — November 5
- Shaler Crater — November 8
- Schickard Crater — November 11
- Vestine Crater — November 21

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.





Binocular Highlight by Mathew Wedel

Wandering Star

Our target this month is **Uranus**. As pointed out in last month's Celestial Calendar, the planet is a great binocular target. Unless you have a big planet-killing telescope, you're not going to see a heck of a lot more than a little dot anyway, so you might as well use a more convenient instrument. Another reason to observe Uranus through binoculars is to get some sense of what it was like for early observers. The analogy isn't perfect; binoculars tend to have lower magnifications and wider fields of view than telescopes. But the challenge remains the same: to pick a bright point of light out of the surrounding star field and determine that there's something different about it.

It's not an easy task, as witnessed by the number of skilled historical observers who spotted the outer gas giants without realizing what they were. Galileo himself is suspected to have observed Neptune at least twice, in 1612 and 1613. John Flamsteed unknowingly observed Uranus several times starting in 1690 but cataloged it as a star. It wasn't until William Herschel independently discovered Uranus in 1781 that anyone realized it was a solar system object, and even Herschel took it for a comet at first.

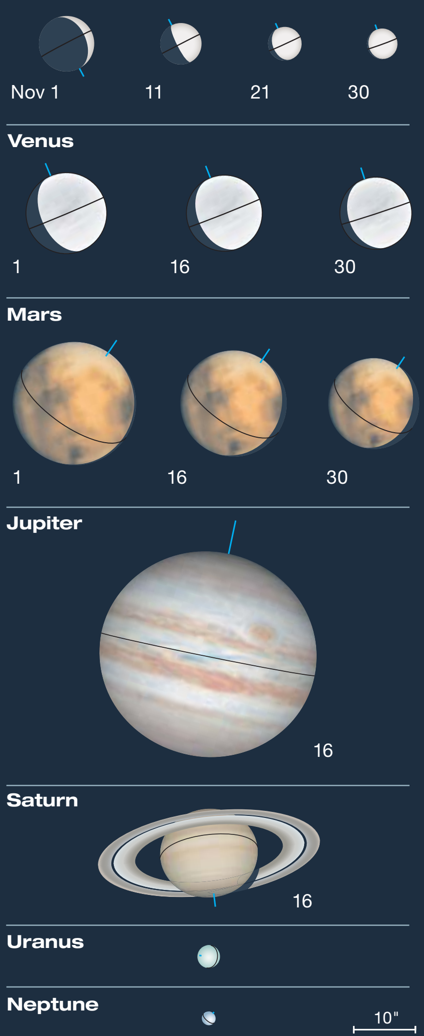
So here's an exercise that may give you some appreciation of the challenges that our forebears faced: Observe Uranus, sketch its position against the background stars, and see how many nights of observation it takes to determine that the planet has moved. The stars Xi (ξ) Arietis, 31 Arietis, and 29 Arietis will be good visual anchors with which to judge the planet's movement. While you're out there, imagine that it's 1620, and that your binoculars are the finest optics in all the world — and for you, for that time, they will be.

■ **MATT WEDEL** is always amazed at how much of the universe you can unlock with a handful of aluminum and glass.

WHEN TO USE THE MAP

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

*Daylight-saving time



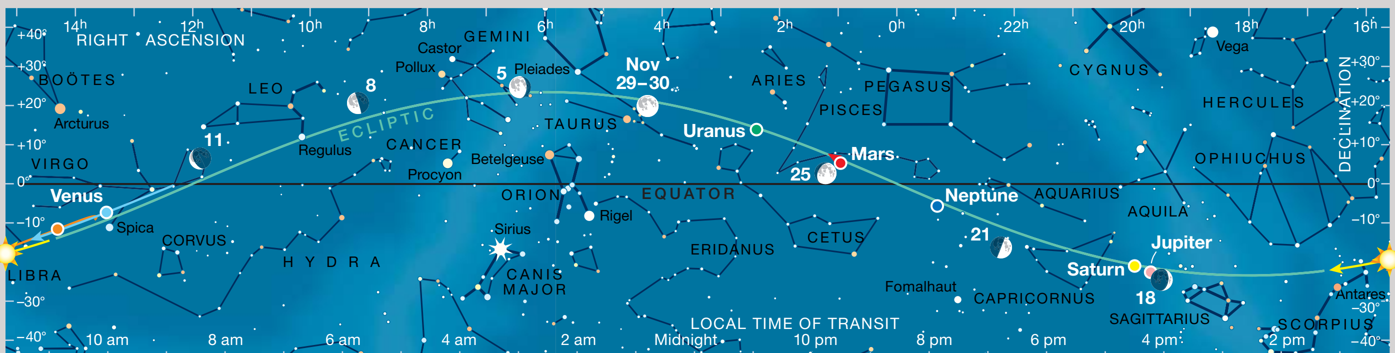
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury:** visible at dawn from the 2nd to the 29th • **Venus:** serves as the brilliant Morning Star all month • **Mars:** transits the meridian in the evening and sets before dawn • **Jupiter:** visible at dusk all month • **Saturn:** culminates around sunset

November Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$14^h\ 25.4^m$	–14° 25′	—	–26.8	32′ 14″	—	0.992
	30	$16^h\ 24.7^m$	–21° 38′	—	–26.8	32′ 26″	—	0.986
Mercury	1	$13^h\ 39.3^m$	–9° 09′	12° Mo	+1.6	9.0″	14%	0.748
	11	$13^h\ 54.2^m$	–9° 16′	19° Mo	–0.6	6.7″	60%	1.001
	21	$14^h\ 44.5^m$	–14° 09′	16° Mo	–0.7	5.5″	86%	1.225
	30	$15^h\ 39.0^m$	–18° 48′	11° Mo	–0.7	5.0″	95%	1.355
Venus	1	$12^h\ 19.0^m$	–0° 19′	34° Mo	–4.0	13.1″	81%	1.271
	11	$13h\ 04.3^m$	–4° 57′	32° Mo	–3.9	12.6″	84%	1.328
	21	$13^h\ 50.5^m$	–9° 29′	30° Mo	–3.9	12.1″	86%	1.381
	30	$14^h\ 33.2^m$	–13° 17′	28° Mo	–3.9	11.7″	88%	1.426
Mars	1	$1^h\ 01.9^m$	+4° 43′	157° Ev	–2.1	20.1″	98%	0.467
	16	$0^h\ 56.4^m$	+5° 10′	141° Ev	–1.6	17.3″	95%	0.542
	30	$1^h\ 01.2^m$	+6° 26′	129° Ev	–1.2	14.8″	93%	0.634
Jupiter	1	$19^h\ 30.1^m$	–22° 17′	72° Ev	–2.2	37.0″	99%	5.335
	30	$19^h\ 50.9^m$	–21° 28′	48° Ev	–2.0	34.5″	99%	5.718
Saturn	1	$19^h\ 52.0^m$	–21° 17′	77° Ev	+0.6	16.3″	100%	10.169
	30	$20^h\ 00.8^m$	–20° 54′	50° Ev	+0.6	15.7″	100%	10.596
Uranus	16	$2^h\ 22.3^m$	+13° 39′	164° Ev	+5.7	3.7″	100%	18.826
Neptune	16	$23^h\ 17.3^m$	–5° 47′	114° Ev	+7.9	2.3″	100%	29.510

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. is 149,597,871 kilometers, or 92,955,807 international miles.) For other dates, see skyandtelescope.org.



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

Shine On With Firsts and Bests

Come get your share of the November night sky.

Why in the world are we here?
Surely not to live in pain and fear
And why on earth are you there
When you're everywhere,
Come and get your share.
And we all shine on
Like the moon, and the stars, and the sun.
Yes, we all shine on,
Everyone.

— From the song *Instant Karma* by John Lennon

In February, 1970, two months before the Beatles break-up became public, John Lennon composed, recorded, and released his song *Instant Karma* in just 10 days. Fifty years later, the song seems especially relevant with the world in the grip of a pandemic and the U.S. experiencing social and political upheaval once again.

Of course, the main astronomical reference in the song is the repeated chorus about humankind shining on "like the moon, and the stars, and the sun." It strikes me as at least a cousin to Carl Sagan's famous *Cosmos* comment, "We're made of star-stuff," and poet Walt Whitman's *Songs of Myself* line about a blade of grass being "the journeywork of the stars." But there's another section of the Lennon song that suggests an intimate link between us and all parts of the universe

A month of firsts and bests. Before we get to that link, however, let's consider the many first sights that make mid-November evenings special. The time we want to focus on is 0h sidereal time. That's when the 0h line of RA (the one that passes through the vernal equinox point) is on the meridian. This happens at about 9:15 p.m. as November starts and about 7:15 p.m. as the month ends (both given in standard time). This year a spectacular, colorful, and very bright interloper is nearby. I'm talking of course about Mars, which is only a few weeks removed from its maximum brightness, on October 6th. The Red Planet spends November near the 1h line of RA, meaning it transits roughly one hour later than the times mentioned above.

For most of this magazine's readers the change from daylight-saving time to standard time happens on the first Sunday of November, which this year falls on the 1st. And this means that November is the month when sunsets suddenly happen one hour earlier on the clock. That also means the sky fills with stars an hour earlier too — including the mighty constellations of the winter sky.

At 0h sidereal time mid-month Orion's Belt is making its majestic rise as a vertical line of three stars exactly due east. High in the north, the westernmost stars in Cassiopeia's W pattern are reaching the meridian. This is also the time for an important first below Polaris: The Big Dipper is reaching its lower culmination. So, the most famous asterism is due north at the same time the brightest constellation is due east.

High in the south, the trailing edge of the Great Square of Pegasus is near the meridian. Low in the south, 1st-magnitude Fomalhaut (in Piscis Austrinus) and 2nd-magnitude Diphda (also known as Deneb Kaitos, in Cetus) straddle the meridian. Facing due west, the Summer Triangle is still high enough for good viewing, but the Vega-to-Altair line is parallel to the horizon.

What's best for viewing at this hour? Galaxies M31 (in Andromeda) and M33 (in Triangulum) are near the zenith, and Taurus's Pleiades and Hyades clusters are ascending in the east along with the Double Cluster in Perseus.

When you're everywhere. In *Instant Karma*, Lennon sings "why on earth are you there, when you're everywhere." What's the cosmic connection? Think of it this way. You're "everywhere" (or at least many places at once) when you view the November evening sky and take in sights that span vast distances — from Mars within our own solar system, all the way out to the Andromeda Galaxy some 2.5 million light-years away. In this context, seeing everywhere is the closest thing to being everywhere, and a fine way to "get your share" of the universe surrounding us.

■ **FRED SCHAAF** welcomes your letters and comments at **fschaaf@aol.com**.

AKIRA FUJII

WINTER RISING Orion, winter's iconic constellation, clears the eastern horizon at roughly 0h sidereal time on November evenings.

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

Planets Delight at Dusk and Dawn

All five bright naked-eye planets are on display this month.

Mars fades and shrinks rapidly in November but offers another month of truly extraordinary views. Meanwhile, Jupiter and Saturn are setting earlier each evening as the gap between them shrinks dramatically. Venus remains high at dawn, and Mercury has a superb monthlong apparition.

DUSK THROUGH EVENING

Jupiter and **Saturn** are near the meridian at sunset as November opens, but even at their highest they're still pretty low for observers at mid-northern latitudes. As the month progresses, they'll become even lower and farther west when darkness falls. However, there's no mistaking the bright pair, whose separation decreases from 5.1° down to just 2.3° by month's end.

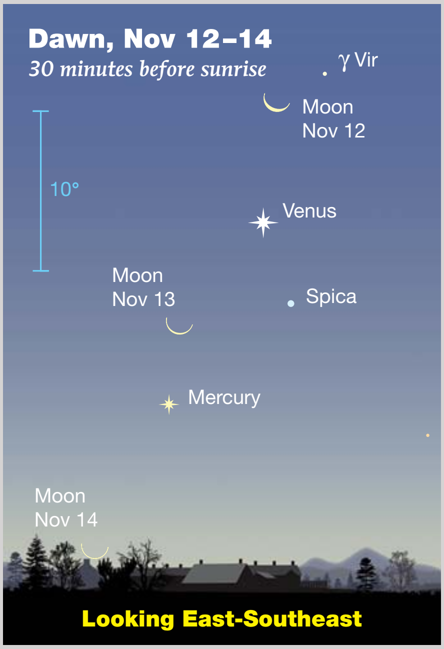
Even though Jupiter fades from –2.2 to –2.0 in November, it's once again brighter than Mars, which has been dimming at a rapid pace since its closest approach to Earth on October 6th. Saturn, meanwhile, holds steady at magnitude 0.6. During November, Jupiter's equatorial diameter shrinks from 37.0″ to 34.5″ and Saturn's from 16.3″ to 15.7″. Saturn's lovely rings (still favorably tilted at an angle of 22°, mid-month) span slightly more than the apparent width of Jupiter.

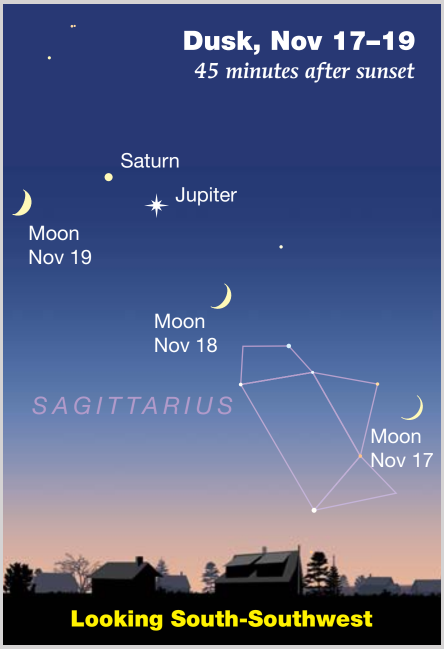
Jupiter and Saturn are currently in eastern Sagittarius but will cross the border into Capricornus in late December, just before Jupiter catches up to Saturn for their first conjunction in 20 years, and their closest in centuries.

ALL NIGHT

Mars remains *the* showpiece planet this month. As darkness falls, its steady, fire-hued glow comes into view in the east. Now that Earth is leaving Mars behind as the two worlds orbit the Sun, this month we see the Red Planet drop nearly a whole magnitude, fading from –2.1 (about as bright as Jupiter) to –1.2 (slightly dimmer than Sirius). The equatorial diameter of Mars also decreases dramatically in November, dwindling from 20.1″ to 14.8″.

Make no mistake, however, this is still a rare and superb time for observing Mars. Its size at the beginning of November is only reached a few times a decade, and even at month's end its globe appears larger than it does during unfavorable aphelic oppositions. Mars is north of the celestial equator, in Pisces, and so climbs high enough to offer crisp telescopic views to observers at mid-northern latitudes. Of course, Mars is highest when it transits the meridian, which happens at convenient evening hours this month: not long after 10 p.m. (standard time) in early November, and about 8:30 p.m. as the month ends. The planet ceases retrograde (westward) motion on the 15th when it pauses briefly before beginning direct (eastward) motion. To find out which face of Mars is viewable at a given date and time, refer to our Mars Profiler tool at **https://is.gd/marsprofiler**. Detailed information about observing Mars can be found on page 48 of the October issue.





▶ 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.

Neptune transits the meridian one or two hours after the end of evening twilight, and **Uranus** transits late in the evening. (A Neptune finder chart appeared in the September issue on page 48; for a Uranus finder chart, turn to page 51 of the October issue.)

Pluto is a challenging, 14.6-magnitude speck located just 41′ south of Jupiter on the evening of the 12th. (For a Pluto chart see the July issue, page 48.)

PRE-DAWN AND DAWN

Venus and **Mercury** put on a very interesting dawn performance this month. Venus dims and shrinks a bit, but it remains high in the east-southeast during morning twilight. The magnitude –3.9 dazzler rises almost 3 hours before the Sun as November begins, but less than 2½ hours before sunrise as the month ends. Mercury is visible for the entire month, though initially it shines a relatively modest magnitude 1.6. If you've never seen Mercury as a tiny crescent, this is your chance. On the 2nd, the planet rises well over an hour before the Sun, and its 21%-illuminated disk has a diameter of 8.6″ — not much smaller than gibbous Venus's 13.0″. Also on the 2nd, Mercury is 4° to the left of the similarly bright Spica. Venus has its own encounter with Spica on the 16th when it sits just 3.8° east-northeast of the star.

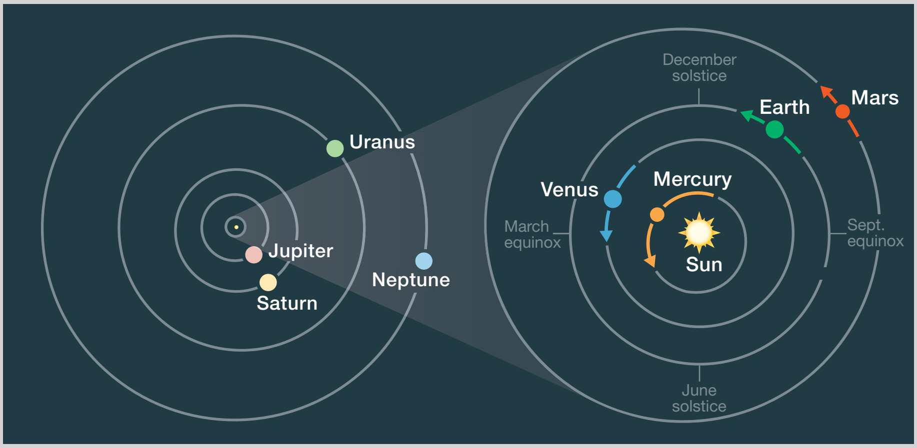
Mercury is at greatest elongation on November 10th, when it's 19° west of the Sun and is visible more than 90 minutes before sunrise. By this date, the planet has brightened to magnitude –0.6. Even at month's end, Mercury still rises almost an hour before the Sun.

MOON PASSAGES

The waning crescent **Moon** is attractively placed 6° above Venus on the morning of the 12th, and on the 13th it's between Venus and Mercury, forming a lovely pattern that includes nearby Spica. In the evening sky, the waxing lunar crescent skips past Jupiter and Saturn on the 18th and 19th, then, as a waxing gibbous, lies a few degrees below Mars at nightfall on the 25th.

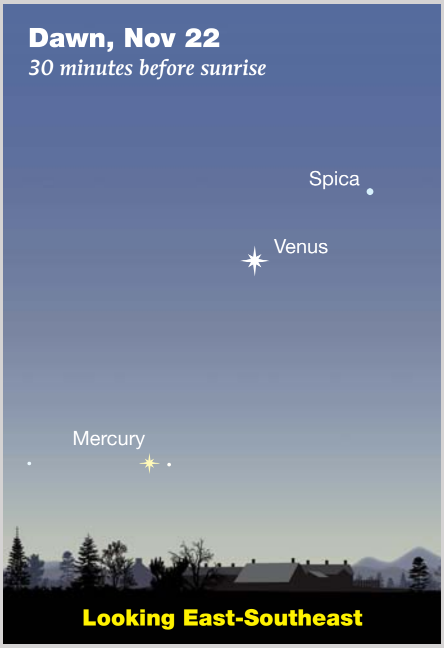
The Moon undergoes a penumbral eclipse visible all across North America in the predawn or dawn hours of November 30th (see page 48 for details).

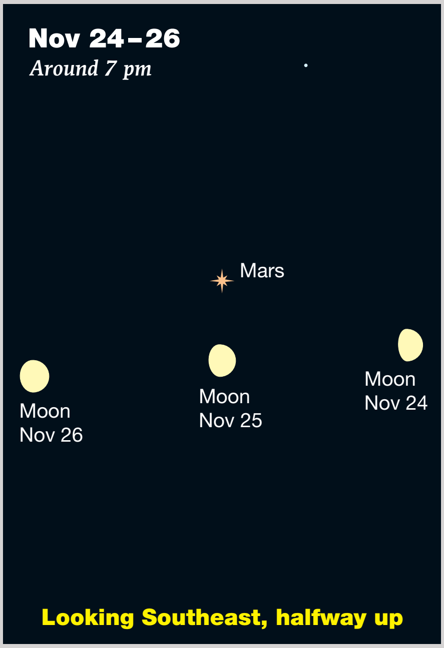
FRED SCHAAF published his first book, *Wonders of the Sky: Observing Rainbows, Comets, Eclipses, the Stars and Other Phenomena*, 40 years ago.

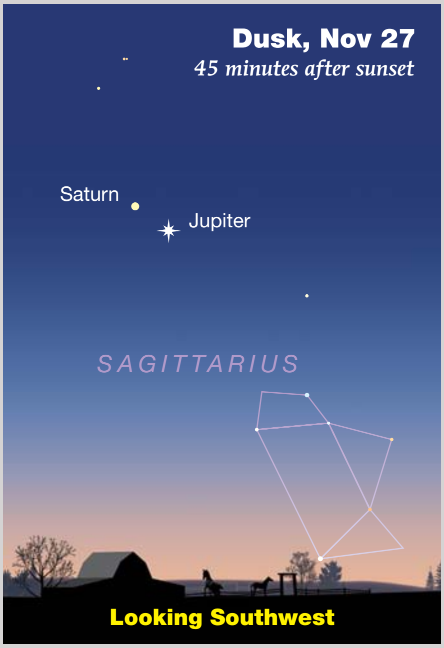


ORBITS OF THE PLANETS

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







Photographers capture the Moon rising alongside the Duluth North Pier Light in Minnesota during the deep penumbral eclipse of February 11, 2017. November's event will be similar, with the Earth's outer shadow visible to the unaided eye.

A Fourth Penumbral Lunar Eclipse

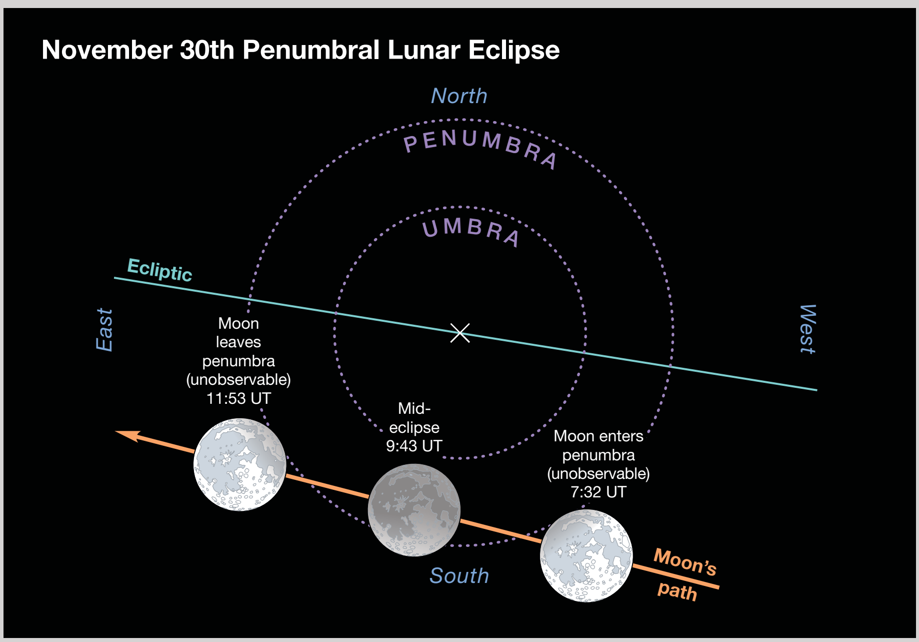
This month the Moon slips through Earth's faint outer shadow for the final time this year.

If you weren't convinced that you saw any trace of Earth's shadow during July's penumbral eclipse, you should have no doubt as the November 29–30 event unfolds. At maximum eclipse, 83% of the Moon will lie in Earth's outer shadow compared to July's 36%.

I struggled at first but eventually succeeded in seeing a trace of penumbral shading during July's eclipse, by carefully comparing the bright highlands along the Moon's northern limb (the part deepest in shadow) with the highlands edging the southern limb. The shadow betrayed its presence through a difference in tone between the two regions around the time of maximum eclipse.

Observers across nearly all of North America will get to see the entire November event and should be able to easily detect a gray veil across the northern third of the lunar disk around the time of maximum. As the chart at right shows, the Moon enters the penumbra at 7:32 UT (2:32 a.m. EST), reaches its greatest depth at 9:43 UT, and exits the shadow at 11:53 UT. The eclipse will be most obvious during the half-hour centered on 4:43 a.m. EST.

I don't know about you, but after four penumbral eclipses in a row this year (January 10th, June 5th, July 5th, and November 30th), I'm a little starved for some umbra. Thankfully, in 2021 there will be a total lunar eclipse on May 26th, followed by a near-total event on November 19th. Both will be at least partly visible from the Americas.



PENUMBRAL ECLIPSE: BOB KING; ECLIPSE ILLUSTRATION: GREGG DINDERMAN / S&T

◀ The gegenschein and part of the zodiacal band are visible in this photo showing the European Southern Observatory's Very Large Telescope facility in Chile's Atacama Desert. Also called *counterglow*, the gegenschein is a fuzzy patch of sunlit interplanetary dust.

Midnight Meeting with the Gegenschein

YEARS AGO, I THOUGHT the gegenschein was reserved for mountaintops and desert locations hundreds of kilometers from city lights. I never expected to see it from my own backyard. But observational barriers have a way of falling when one decides to ignore convention and look anyway.

The gegenschein is a cousin of the zodiacal light and may be the closest thing to nothing that you'll ever lay eyes on. An ovoid glow about 10° wide by 5° high, the gegenschein is centered on the ecliptic at the *antisolar point* — the spot directly opposite the Sun's location in the sky. Like the zodiacal light, the gegenschein is composed of minute grains of comet and asteroid dust illuminated by sunlight. This should come as no surprise, because they're both manifestations of the same phenomenon.

The zodiacal light shines brightest nearest the sunset (or sunrise) point on the horizon, and gradually fades as you follow its conical form upwards. Seen from the darkest locales, the light arcs along the ecliptic across the entire sky as the exceedingly faint *zodiacal band*. Midway along its length, directly opposite the Sun, the band brightens as the gegenschein, a German word meaning "counterglow."

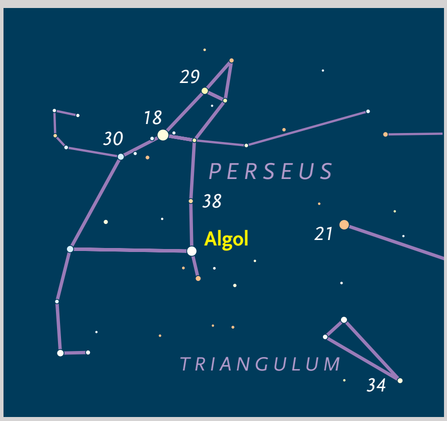
Much like with the full Moon or planet at opposition, sunlight strikes the dust particles in the gegenschein head-on. And just as the full Moon reaches its greatest altitude around local midnight, so too does the gegenschein.

I first noticed the phenomenon about 15 years ago from a dark-sky site. Once I knew what to look for, I started noticing the gegenschein more often and under less pristine skies. You can, too.

November is one of the best times of year to look for the gegenschein, because at midnight the ecliptic stands high in the sky in Aries and Taurus. Atmospheric extinction is at a minimum, no bright background stars get in the way, and the Milky Way doesn't muddle the view. The counterglow, however, is high enough to seek by 11 p.m. local time, and remains well-placed into the early morning hours.

While a dark sky is crucial, it doesn't have to be perfect. As I mentioned earlier, I've seen the gegenschein from home, where I deal with modest light pollution in the southwest from Duluth, Minnesota. Plan to look when the Moon is absent from the midnight sky, from November 9th to 21st. Early in the month, the ghostly, oval-shaped patch appears about 10° southwest of the Pleiades, and by the 20th it hovers southeast of the cluster. Use averted vision and sweep around the area until you discern a hazy presence that's a little brighter toward its center.

Once you see the gegenschein, the zodiacal band awaits as your next midnight challenge!



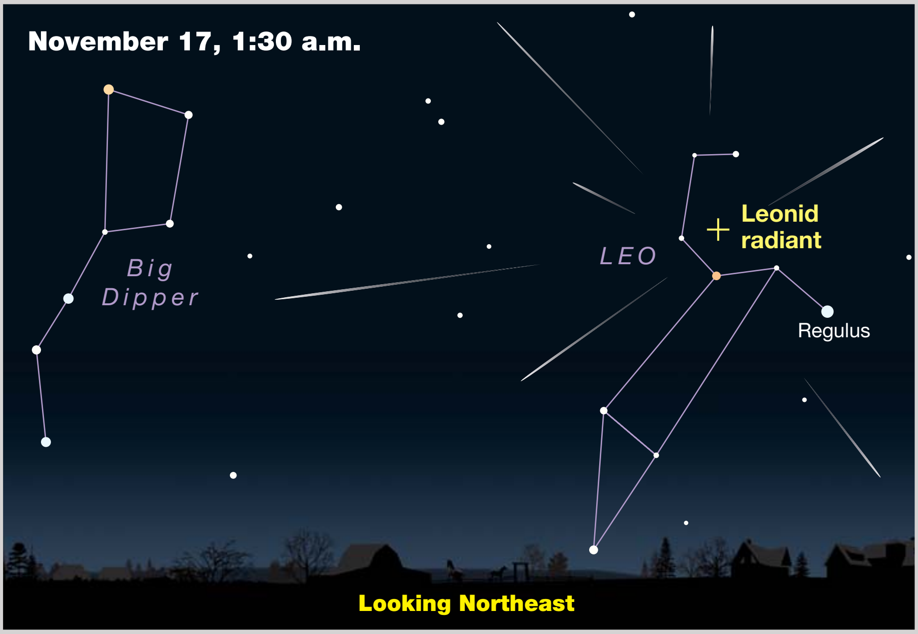
▲ Perseus climbs high in the northeastern sky during evening hours in November. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Minima of Algol

Oct.	UT	Nov.	UT
1	4:59	1	17:56
4	1:48	4	14:44
6	22:37	7	11:33
9	19:25	10	8:22
12	16:14	13	5:11
15	13:03	16	2:00
18	9:52	18	22:49
21	6:40	21	19:38
24	3:29	24	16:27
27	0:18	27	13:16
29	21:07	30	10:05

These geocentric predictions are from the recent heliocentric elements Min. = JD 2445641.554 + 2.867324*E*, where *E* is any integer. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.

ESO / YURI BELETSKY



Meteors Spark from Leo and Taurus

NOVEMBER HAS NO STRONG meteor showers unless there happens to be an outburst from the annual Leonids. That occurred most recently in 2002 when up to 3,000 meteors an hour blazed across the sky. According to the American Meteor Organization, we won't get a repeat performance until 2099, when Earth next passes through a dense strand of debris shed by the shower's parent, Comet 55P/Tempel-Tuttle. Moderately rich Leonid displays of around 100 meteors per hour are also expected when the comet returns in 2031 and 2064. In the meantime, the plain vanilla version offering 10–15 meteors per hour will have to do.

But why twiddle your thumbs? Viewing conditions are ideal for the Leonids this year. The shower peaks in a moonless sky at around 12 UT (7 a.m. EST) on the morning of November 17th. Watch for a smattering of extremely fast meteors streaking from the Sickle of Leo (as shown in the chart above) between 3 and 5:30 a.m. local time, when the radiant stands high in the southeastern sky.

The Northern Taurids and Southern Taurids are also active this month. Both derive from Comet 2P/Encke and produce a handful of meteors per hour at best. Despite their low rates, both Taurid streams are fireball-rich so expect excitement.

The Northern version reaches its maximum rate on the night of November 11–12, with a harmless morning lunar crescent in play. These meteors radiate from a point roughly 1° southeast of the Pleiades, in Taurus.

Although the Southern Taurids peaked on the night of October 29–30 (when the Moon was just shy of full), the display has a broad maximum and remains active until November 20th. These meteors radiate from a location roughly 12° southwest of the Pleiades.

Action at Jupiter

AT THE START OF NOVEMBER, Jupiter transits the meridian around sunset, just before 5:00 p.m. local time. The best time to observe the planet in a telescope is at dusk, when it's highest in the south-southwest. On November 1st, Jupiter gleams at magnitude –2.2 and presents a disk 37″ in diameter.

Any telescope shows the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions.

All the November interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for early evening in your time zone, when Jupiter is at its highest.

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

October 1: 8:02, 17:57; **2**: 3:53, 13:49, 23:45; **3**: 9:41, 19:36; **4**: 5:32, 15:28; **5**: 1:24, 11:19, 21:15; **6**: 7:11, 17:07; **7**: 3:03, 12:58, 22:54; **8**: 8:50, 18:46; **9**: 4:42, 14:37; **10**: 0:33, 10:29, 20:25; **11**: 6:20, 16:16; **12**: 2:12, 12:08, 22:03; **13**: 7:59, 17:55; **14**: 3:51, 13:47, 23:42; **15**: 9:38, 19:34; **16**: 5:30, 15:26; **17**: 1:22, 11:17, 21:13; **18**: 7:09, 17:05; **19**: 3:01, 12:56, 22:52; **20**: 8:48, 18:44; **21**: 4:40, 14:35; **22**: 0:31, 10:27, 20:23; **23**: 6:19, 16:14; **24**: 2:10, 12:06, 22:02; **25**: 7:58, 17:53; **26**: 3:49, 13:45, 23:41; **27**: 9:37, 19:32; **28**: 5:28, 15:24; **29**: 1:20, 11:16, 21:11; **30**: 7:07, 17:03; **31**: 2:59, 12:55, 22:50

November 1: 8:05, 18:45; **2**: 4:42, 14:37; **3**: 0:33, 10:29, 20:25; **4**: 6:21, 16:16; **5**: 2:12, 12:08, 22:04; **6**: 7:59, 17:55; **7**: 3:51, 13:47, 23:43; **8**: 9:39, 19:34; **9**: 5:31, 15:26; **10**: 1:22, 11:18, 21:14; **11**: 7:10, 17:05; **12**: 3:01, 12:57, 22:53; **13**: 8:49, 18:44; **14**: 4:41, 14:36; **15**: 0:32, 10:28, 20:24; **16**: 6:02, 16:15; **17**: 2:11, 12:07, 22:03; **18**: 7:59, 17:55; **19**: 3:51, 13:46, 23:42; **20**: 9:38, 19:34;

21: 5:30, 15:25; **22**: 1:21, 11:17, 21:13; **23**: 7:09, 17:05; **24**: 3:01, 12:56, 22:52; **25**: 8:48, 18:44; **26**: 4:40, 14:36; **27**: 0:32, 10:27, 20:23; **28**: 6:19, 16:15; **29**: 2:11, 12:06, 22:02; **30**: 7:58, 17:54

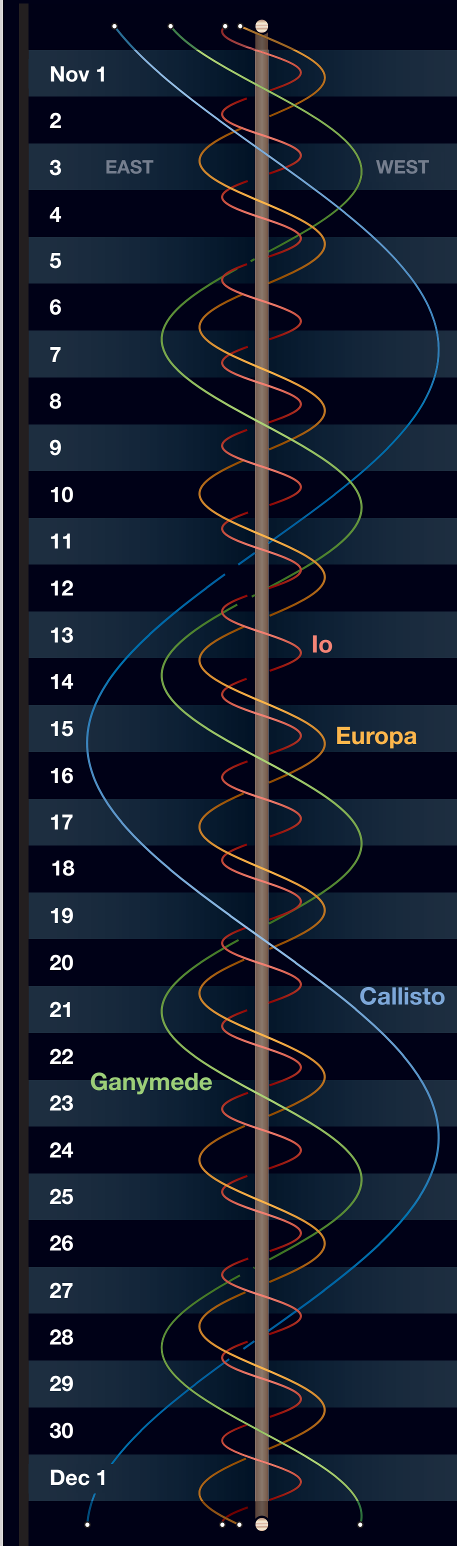
These times assume that the spot will be centered at System II longitude 344° on November 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 344° and 1⅔ minutes later for each degree more than 344°.

Phenomena of Jupiter's Moons, November 2020

Nov. 1	0:03	I.Tr.I
	1:17	I.Sh.I
	2:19	I.Tr.E
	3:33	I.Sh.E
	17:37	III.Tr.I
	21:00	III.Tr.E
	21:10	I.Oc.D
	22:37	III.Sh.I
Nov. 2	0:43	I.Ec.R
	2:06	III.Sh.E
	10:25	II.Oc.D
	15:44	II.Ec.R
	18:33	I.Tr.I
	19:46	I.Sh.I
	20:48	I.Tr.E
	22:02	I.Sh.E
Nov. 3	1:45	IV.Tr.I
	6:00	IV.Tr.E
	13:21	IV.Sh.I
	15:40	I.Oc.D
	17:55	IV.Sh.E
	19:12	I.Ec.R
Nov. 4	4:37	II.Tr.I
	7:04	II.Sh.I
	7:26	II.Tr.E
	9:56	II.Sh.E
	13:02	I.Tr.I
	14:14	I.Sh.I
	15:18	I.Tr.E
	16:30	I.Sh.E
Nov. 5	7:47	III.Oc.D
	10:10	I.Oc.D
	11:12	III.Oc.R
	12:40	III.Ec.D
	13:41	I.Ec.R
	16:12	III.Ec.R
	23:46	II.Oc.D
Nov. 6	5:02	II.Ec.R
	7:32	I.Tr.I
	8:43	I.Sh.I
	9:47	I.Tr.E
	10:59	I.Sh.E
Nov. 7	4:39	I.Oc.D
	8:10	I.Ec.R
	17:59	II.Tr.I
	20:24	II.Sh.I
	20:49	II.Tr.E
	23:15	II.Sh.E
Nov. 8	2:01	I.Tr.I
	3:12	I.Sh.I
	4:17	I.Tr.E
	5:28	I.Sh.E
	21:51	III.Tr.I
	23:09	I.Oc.D
Nov. 9	1:15	III.Tr.E
	2:37	III.Sh.I
	2:39	I.Ec.R
	6:07	III.Sh.E
	13:08	II.Oc.D
	18:20	II.Ec.R
	20:31	I.Tr.I
	21:41	I.Sh.I
	22:47	I.Tr.E
	23:57	I.Sh.E
Nov. 10	17:39	I.Oc.D
	21:07	I.Ec.R
Nov. 11	7:22	II.Tr.I
	9:42	II.Sh.I
	10:11	II.Tr.E
	12:34	II.Sh.E
	13:12	IV.Oc.D
	15:01	I.Tr.I
	16:09	I.Sh.I
	17:16	I.Tr.E
	17:33	IV.Oc.R
	18:26	I.Sh.E
Nov. 12	0:05	IV.Ec.D
	4:43	IV.Ec.R
	12:02	III.Oc.D
	12:09	I.Oc.D
	15:28	III.Oc.R
	15:36	I.Ec.R
	16:41	III.Ec.D
	20:13	III.Ec.R
Nov. 13	2:29	II.Oc.D
	7:38	II.Ec.R
	9:30	I.Tr.I
	10:38	I.Sh.I
	11:46	I.Tr.E
	12:54	I.Sh.E
Nov. 14	6:38	I.Oc.D
	10:05	I.Ec.R
	20:45	II.Tr.I
	23:01	II.Sh.I
	23:35	II.Tr.E
Nov. 15	1:54	II.Sh.E
	4:00	I.Tr.I
	5:07	I.Sh.I
	6:16	I.Tr.E
	7:23	I.Sh.E
Nov. 16	1:08	I.Oc.D
	2:08	III.Tr.I
	4:34	I.Ec.R
	5:33	III.Tr.E
	6:39	III.Sh.I
	10:09	III.Sh.E
	15:52	II.Oc.D
	20:56	II.Ec.R
	22:30	I.Tr.I
	23:36	I.Sh.I
Nov. 17	0:46	I.Tr.E
	1:52	I.Sh.E
	19:38	I.Oc.D
	23:03	I.Ec.R
Nov. 18	10:08	II.Tr.I
	12:20	II.Sh.I
	12:58	II.Tr.E
	15:12	II.Sh.E
	17:00	I.Tr.I
	18:05	I.Sh.I
	19:16	I.Tr.E
	20:21	I.Sh.E
Nov. 19	14:08	I.Oc.D
	16:20	III.Oc.D
	17:32	I.Ec.R
	19:47	III.Oc.R
	20:41	III.Ec.D
	21:18	IV.Tr.I
Nov. 20	0:13	III.Ec.R
	1:40	IV.Tr.E
	5:14	II.Oc.D
	7:30	IV.Sh.I
	10:14	II.Ec.R
	11:30	I.Tr.I
	12:08	IV.Sh.E
	12:33	I.Sh.I
	13:46	I.Tr.E
	14:50	I.Sh.E
Nov. 21	8:38	I.Oc.D
	12:01	I.Ec.R
	23:31	II.Tr.I
Nov. 22	1:39	II.Sh.I
	2:22	II.Tr.E
	4:32	II.Sh.E
	6:00	I.Tr.I
	7:02	I.Sh.I
	8:16	I.Tr.E
	9:18	I.Sh.E
Nov. 23	3:08	I.Oc.D
	6:27	III.Tr.I
	6:30	I.Ec.R
	9:53	III.Tr.E
	10:39	III.Sh.I
	14:11	III.Sh.E
	18:37	II.Oc.D
	23:31	II.Ec.R
Nov. 24	0:30	I.Tr.I
	1:31	I.Sh.I
	2:46	I.Tr.E
	3:47	I.Sh.E
	21:39	I.Oc.D
Nov. 25	0:59	I.Ec.R
	12:55	II.Tr.I
	14:58	II.Sh.I
	15:46	II.Tr.E
	17:51	II.Sh.E
	19:00	I.Tr.I
	20:00	I.Sh.I
	21:16	I.Tr.E
	22:16	I.Sh.E
Nov. 26	16:09	I.Oc.D
	19:28	I.Ec.R
	20:40	III.Oc.D
Nov. 27	0:08	III.Oc.R
	0:41	III.Ec.D
	4:14	III.Ec.R
	8:00	II.Oc.D
	12:49	II.Ec.R
	13:30	I.Tr.I
	14:28	I.Sh.I
	15:46	I.Tr.E
	16:45	I.Sh.E
Nov. 28	9:02	IV.Oc.D
	10:39	I.Oc.D
	13:30	IV.Oc.R
	13:56	I.Ec.R
	18:14	IV.Ec.D
	22:54	IV.Ec.R
Nov. 29	2:19	II.Tr.I
	4:17	II.Sh.I
	5:11	II.Tr.E
	7:10	II.Sh.E
	8:00	I.Tr.I
	8:57	I.Sh.I
	10:16	I.Tr.E
	11:14	I.Sh.E
Nov. 30	5:09	I.Oc.D
	8:25	I.Ec.R
	10:49	III.Tr.I
	14:16	III.Tr.E
	14:40	III.Sh.I
	18:12	III.Sh.E
	21:23	II.Oc.D

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



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

Tips for Planetary Observers

Innovative use of accessories can enhance your observing experience.

▲ Using a pair of 90° diagonals produces an even number of reflections in the light path of a refractor or Cassegrain reflector, correcting the mirror-reversed view commonly seen through these popular instruments. An added benefit is the two diagonals are easily adjusted to provide a comfortable viewing angle.

TOM DOBBINS

Inverted images with south at the top and west at left have long been the convention for drawings and photos of astronomical objects, as well as lunar atlases and maps of Mars intended for telescopic observers.

A Newtonian reflector produces an inverted image, making comparisons with the eyepiece view straightforward — simply rotate the photo or drawing to match the view. Unfortunately, the image through a refractor or Cassegrain reflector (including Schmidt and Maksutov variations) equipped with a conventional mirror or right-angle prism star diagonal is erect (north at the top) but flipped left-to-right (with west at the left). This disorienting mirror-image reversal occurs in any optical system that reflects light an odd number of times.

Righting the View

Observers with refractors and Cassegrains can still enjoy an inverted image like those in a Newtonian reflector by removing the star diagonal and looking straight through the instrument. Accessing the eyepiece, however, requires uncomfortable contortions when training the instrument on targets located at an appreciable distance above the horizon. Prolonged observing in this fashion is literally a pain in the neck.

Fortunately, you can eliminate both physical and mental gymnastics by using a pentaprism diagonal. Pentaprisms employ two internal reflections to divert the light path by 90° while at the same time providing an inverted image with no mirror reversal. Unfortunately, quality pentaprism diagonals are 3× to 5× more expensive than a conventional star diagonal. Economics aside, they present a further difficulty. In the standard 1¼-inch format a typical pentaprism diagonal has an optical path length of about 120 millimeters (4.7 inches). Some instruments will lack sufficient in-travel to allow access to the focal plane with such an arrangement.

The late Danish planetary observer Per Darnell devised a simple, elegant solution to the vexing problem of image orientation. He employed a pair of conventional star diagonals to provide an even number of reflections, yielding an inverted image with no left-to-right reversal. Both mirror and right-angle prism diagonals are suitable for this novel use, though mirror diagonals are preferable for instruments with focal ratios faster than f/8 to avoid chromatic and other aberrations introduced by prisms.

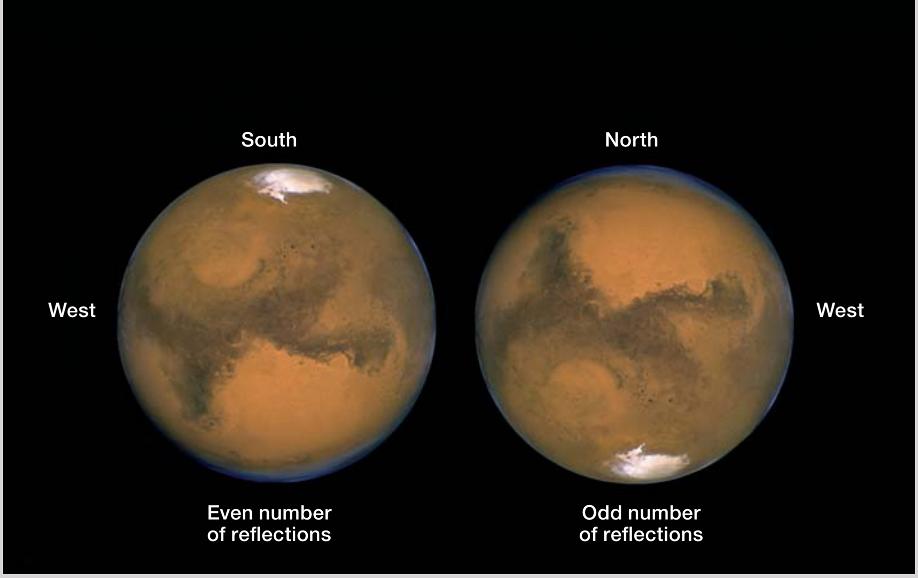
The optical path length of a typical 1¼-inch mirror star diagonal is about 75 mm (3 inches), while that of a right-angle prism diagonal is about 60 mm (2.4 inches). In 2-inch format, a typical mirror star diagonal has an optical path length of 110 mm (4.3 inches), while a right-angle prism diagonal prism diagonal requires about 80 mm (3.1 inches) of inward focus travel.

The combination of a pair of conventional diagonals has an optical path length that equals or exceeds that of a pentaprism diagonal, but Darnell solved this problem by threading a Barlow lens into the entrance of the second (outer) diagonal. This wrinkle makes the focal plane accessible in any instrument while providing the high magnifications required to discern lunar and planetary details with eyepieces of longer focal length and comfortable eye relief.

Most 1¼-inch format star diagonals of recent vintage feature internally threaded barrels that accept standard eyepiece filters. These have a 28.5-mm external thread with a pitch of 0.6 mm. Happily, the lens cells of many Barlows feature the same external filter thread that can be easily unscrewed from their barrels and screwed into a star diagonal. The Barlow's stated amplification factor will be preserved if the length of its original tube is approximately equal to the optical path length of the star diagonal.

Schmidt- and Maksutov-Cassegrains that focus by moving the primary mirror can easily accommodate a pair of star diagonals without recourse to the Barlow lens, but it's best to use a 2-inch-format diagonal as the first diagonal of the pair to avoid vignetting.

The first star diagonal is inserted in the focuser and rotated until the output barrel is parallel to the ground. You then insert the second diagonal with the attached Barlow lens into the output barrel of the first diagonal. You can simply swivel the second diagonal to a comfortable viewing angle, regardless of the altitude of the object under study.



▲ Newtonian reflectors produce a correct-reading, though upside-down image because they reflect the light path twice (left). Cassegrains and refractors usually reflect the optical path an odd number of times, resulting in a view that is right-side-up, but mirror-reversed as seen at right.

Dimming the View

Another accessory that increases its "bang for the buck" when used in an unconventional way is a variable polarizing filter. This device consists of a pair of identical polarizing filters screwed together, each serving as a miniature picket fence that permits only light waves vibrating in the direction of the pickets to pass. When the axes of the polarizers are parallel, the amount of incident light transmitted is maximized (typically at about 40%), but when the axis of one polarizer is oriented perpendicular to the axis of the other virtually no light is transmitted. You can precisely adjust the brightness of the image over a broad range simply by rotating one filter with respect to the other, much as with a dimmer switch.

I prefer to separate the polarizing filters and screw one into the eyepiece and the other into a short extension tube that remains stationary. This varies the image brightness by simply rotating the eyepiece without interrupting observation. Steer clear of variable polarizing filters that cannot be separated in this fashion, to avoid the annoyance of having to withdraw the eyepiece in order to rotate one filter relative to the other.

One vastly under-appreciated attribute of a variable polarizing filter is its ability to render the chromatic aberration of refractors less obtrusive. Not long after the invention of the telescope, smoked-glass lenses were often employed to suppress the false color produced by the era's primitive single-element objectives. Simply reducing image brightness makes the defocused red, blue, and violet light that constitute the purple haze of "secondary spectrum" of doublet achromat refractors much less conspicuous. Unlike the "minus violet" filters that are widely used for this purpose, a variable polarizing filter will not impart a yellow cast to the image, which many observers find objectionable.

Low-contrast markings on a uniform background are best discerned under moderate levels of illumination, an attribute of human perception that psychologists call *Weber-Fechner's law*. Dimming excessively bright images often reveals markings that would otherwise elude detection, notably delicate lunar rilles or festoons and narrow belts and rifts on Jupiter.

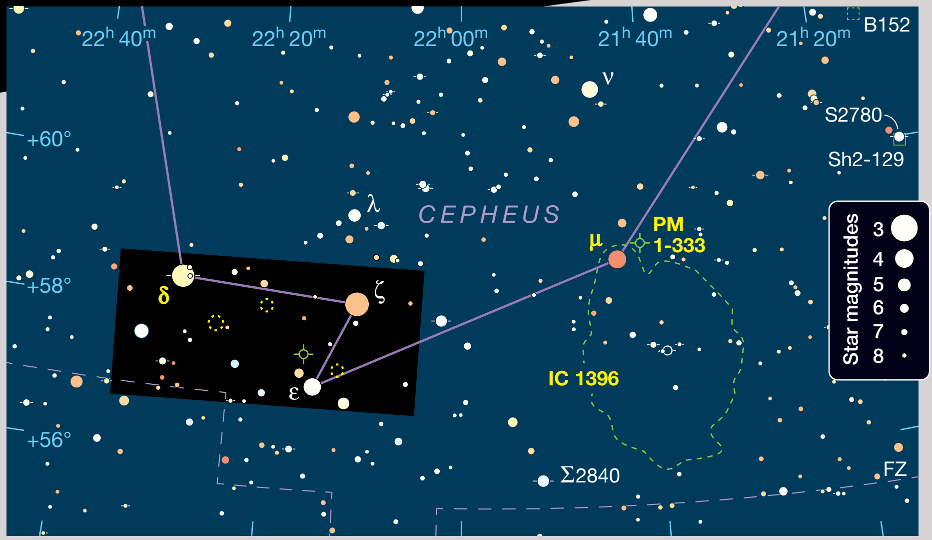
Variable polarizing filters are indispensable when observing Venus. Enveloped in a canopy of highly reflective clouds that have an apparent surface brightness almost 10× greater than the full Moon, Venus about invariably appears featureless unless steps are taken to reduce the intense glare. The cloudscape of Venus is rarely devoid of markings if its dazzling brilliance is sufficiently subdued. Other targets that are sufficiently bright to benefit from variable polarizing filters, albeit to a lesser degree, are the Moon, Mars, and Jupiter.

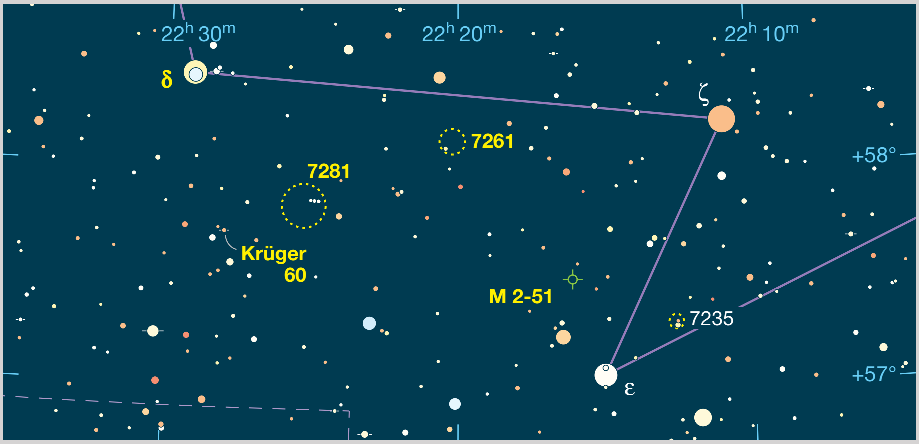
With my 6-inch f/8 achromat, I'm consistently able to see more detail on Jupiter's disc at 140× using a variable polarizing filter transmitting about 25% of incident light than I can at 200× without the filter, despite the smaller image scale that lower magnification provides. This holds true even when seeing conditions are excellent and the higher magnification should provide the more detailed view. The saturation of the planet's subtle pastel hues is also increased.

▶ Attaching each half of a variable polarizing filter to the eyepiece and the other to an extension tube allows you to simply rotate your eyepiece to reduce the glare of a bright planet or lunar crater.

MARS: STSCI / NASA; POLARIZER: TOM DOBBINS

■ Contributing Editor **TOM DOBBINS** always enjoys observing the planets from comfortable viewing angles.





Uneasy Lies the Head

Cepheus contains one of the sky's most noteworthy nebulae.

Unhappy Cepheus, though of race divine!
From Jove himself descends the royal line,
And not unmindful of his noble birth
To heaven Jove rais'd him from /
this lower earth.

— Aratus, *Phaenomena*

According to myth, King Cepheus had a troubled life. Although he was descended from the ruler of the gods, divine wrath was loosed upon his kingdom in the form of a sea monster because of his wife's careless vanity. To stop the slaughter, Cepheus had to offer his daughter Andromeda to the beast. Brave Perseus slew the monster to win Andromeda's hand, but her former fiancé vehemently protested. In the ensuing affray, the king's brother and much of the royal court were killed. Cepheus now reigns with celestial splendor in the night sky, unfettered by earthly concerns.

Let's begin our tour of the king's starry realm with **Delta (δ) Cephei**, one of the most famous stars in the sky. Delta is the prototype of a class of pulsating stars known as Cepheid variables. Their period of variability is related to their intrinsic brightness.

To celebrate 20 years of Sue French's stellar contributions to *Sky & Telescope*, we will be sharing the best of her columns in the coming months. We have updated values to current measurements when appropriate.

Knowing how luminous an object truly is and how bright it appears helps us determine how far away it is. Classical Cepheids can be seen in galaxies up to 100 million light-years away, making them valuable tools for distance determination. A recent study indicates that we may be able to use ultra-long-period Cepheids to calculate distances to galaxies three times farther away.

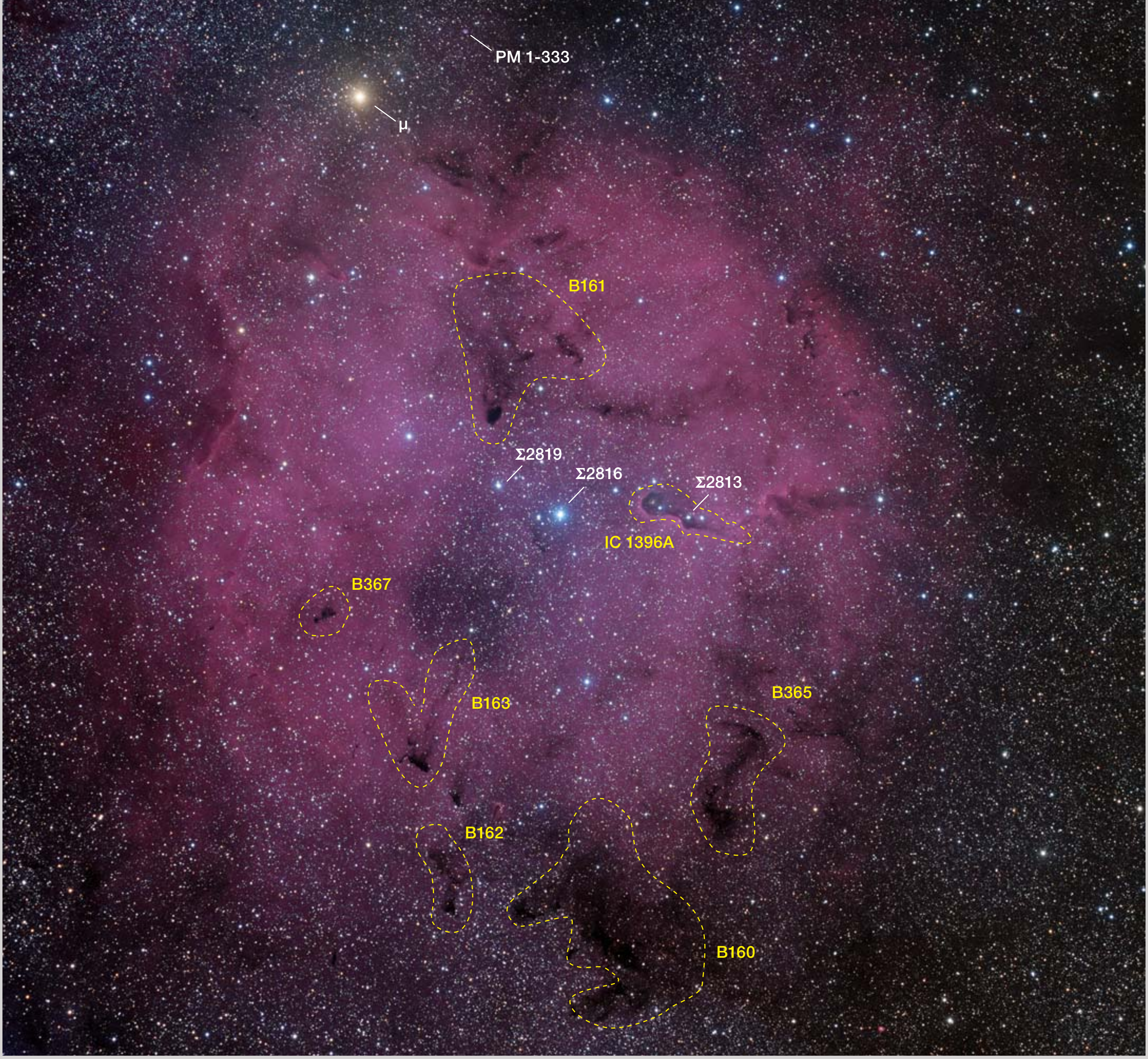
Delta Cephei is a yellow giant star that changes from magnitude 3.5 to 4.4 and back over 5.4 days. Through a small telescope, I see it as yellow-white when brightest and yellow when dimmest. It also reveals a lovely, blue-white, 6th-magnitude companion at low power. The pair is 900 light-years away.

Just ¾° south-southwest of Delta, **Krüger 60** is a wonderful binary star consisting of two red dwarfs. These peewee stars are only 27% and 17% as massive as our Sun, but they're visible in a small scope because they're relatively close by at about 13 light-years away. Their average separation during their nearly 45-year orbit puts them nearly as far apart as the Sun and Saturn.

In my 5-inch refractor at 164×, Krüger 60's 9.9-magnitude primary appears reddish orange. The 11.4-magnitude companion is close north-northeast, but too faint for me to detect its color. If you're very lucky, you might catch the temperamental companion star flaring up to become almost as bright as its primary. Such sporadic outbursts generally reach maximum in a matter of seconds and fade nearly back to normal over several minutes.

Two NGC star clusters dwell nearby. **NGC 7281** is one-third of the way from Delta to Epsilon (ε) Cephei, with **NGC 7261** about ¾° to its west-northwest.

My 105-mm (4.1-inch) refractor at 87× shows NGC 7261 as an irregular group of 15 faint stars, oblong north-northwest to south-southeast for about 7′. Similarly bright stars scattered south and southwest make the cluster's boundary uncertain. NGC 7281 displays three 10th-magnitude stars in an



▲ *Clockwise from top:* This deep color composite of the IC1396 nebula complex displays several dark nebulae, including B161, B365, B160, B162, B163, and B367 at left. At the top of the field is planetary nebula Preite-Martinez 1-333, while triple-star system Σ2819, double Σ2816, and Σ2813 form a rough line ending within IC 1396A, the Elephant Trunk Nebula at the right.

SEAN WALKER / S&T

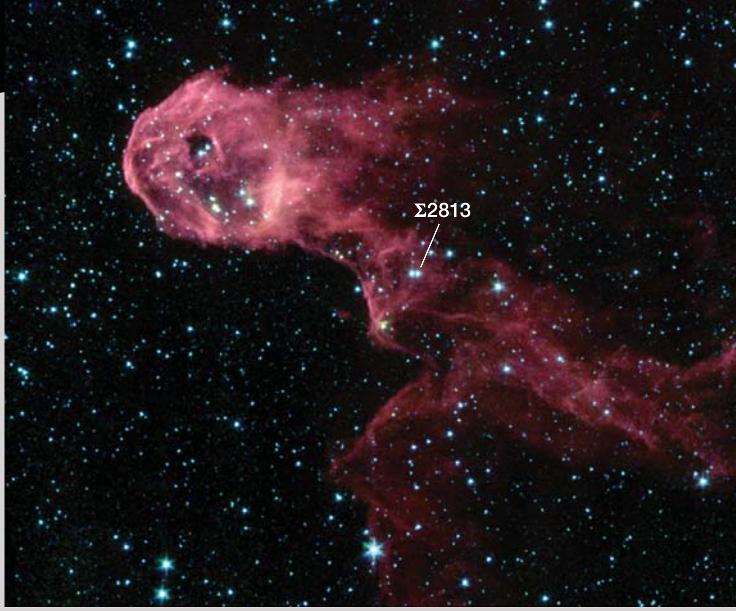
east-west line plus a dozen fainter stars scattered mostly to the east and south.

Through my 10-inch reflector at 43×, NGC 7261 and NGC 7281 share the field of view and are linked by what I call the Dit Dit Dit asterism. It consists of three 3-star lines, all about the same length. The first is formed by three 10th-magnitude stars (dits) in NGC 7281. Follow this line 22′ west and veer slightly north to reach the second line, which points 16′ northwest to the three brightest stars in NGC 7261.

NGC 7261 is pretty in my 10-inch scope at 68×, the bright star at its southeastern edge gleaming with golden hue. A magnification of 187× reveals about 25 stars. NGC 7281 shows a few dozen stars even at low power. A core group 5′ across includes the cluster's dit-dit-dit stars. A starry spiral arm proceeds southward from this group, curves around through the east, and then peters out north of the core.

The interesting planetary nebula **Minkowski 2-51** lies 27′ north-north-east of Epsilon. Through my 10-inch reflector at 68×, it's fairly faint and shows two superposed stars, the fainter one pinned to the nebula's southwestern edge. With an O III filter, the planetary yields traces of a darker center. Taking a closer look with my 15-inch reflector at 284×, Mink 2-51 is a weakly annular, north-south oval about ¾′ tall. The brighter star, magnitude 13.4, rests a little east of center.

If you have a 20-inch or larger scope, try to detect the faint halo that swells Mink 2-51 to 1.2′ and gives it an overall tilt to the north-northwest. Don't strain your eyes looking for



▶ Compare this infrared image of IC1396A, the Elephant Trunk Nebula, to the visible-light picture on page 55. Dense clouds of gas and dust absorb light from stars and re-emit the energy as heat, so they're dark in visible light and bright in infrared.

the central star, which glimmers at a wretchedly dim 20th magnitude.

Our next stop is **Mu (μ) Cephei**. In 1783, William Herschel wrote, "It is of a very fine deep garnet colour . . . and a most beautiful object, especially if we look for some time at a white star before we turn our telescope to it." Today, it's often called Herschel's Garnet Star.

Mu is a red supergiant and one of the largest and brightest stars in our galaxy. It's approximately 100,000 times more luminous than our Sun. If Mu took the Sun's place, its outer edge would lie between the orbits of Jupiter and Saturn. Like most red supergiants, Mu is unstable. It pulsates in size, brightness, and color with a semiregular period of roughly 860 days and a magnitude range of 3.4 to 5.1. To my eyes, Mu seems to vary from deep orange to a striking red-orange.

Mu burnishes the northern extremes of the emission nebula and star cluster **IC 1396**. Through my 130-mm refractor at 23×, the cluster covers about 1½° and presents more than 100 stars. Near its center, the bright triple star **Σ2816** shows three blue-white stars in a 30″-long arc. About 13′ east-northeast, the double **Σ2819** has a 7.4-magnitude yellow-white primary with an 8.6-magnitude yellow attendant 13″ to its east-northeast.

The 2½° nebula engulfing the cluster is irregular in outline and brightness, with a fairly large dimmer region in the center. A narrowband filter accentuates details in the nebula and around its edges. These include several intricate dark nebulae from Edward Emerson Barnard's 1927 catalog: B160 through B163, B365, and B367.

The most famous object within IC 1396 is **IC 1396A**, the Elephant Trunk Nebula, a subtle lane of darkness trending east-northeast. Look 25′ west of Σ2816 for an east-west pair of widely spaced stars, 9th and 8th magnitude, respectively. The eastern star is the double **Σ2813**, a nearly matched duo of yellow-white stars 10″ apart. Σ2813 pins the northern edge of one of the darkest patches. To the west, it tapers to a little wisp that passes into obscurity south of the 8th-magnitude star. To the east, the patch narrows, widens again as it engulfs a 9th-magnitude star, and then ends in a 4′ bulb. A hazy glow near the bulb's center cocoons a faint star.

The Elephant Trunk is a globule of dense dust sculpted by fierce stellar winds from the intensely hot primary star of Σ2816. Many such structures are sites of star formation. The faint star in the bulb is only a million years old, quite young for a star, and illuminates the little nebula surrounding it.

The IC 1396 complex is about 2,500 light-years distant.

Our final target is the little-known planetary nebula **Preite-Martinez 1-333**, which resides 23′ west-northwest of Mu Cephei. Through my 10-inch scope at 187×, the nebula is faintly visible with averted vision, but a narrowband filter makes it fairly easy. It appears perhaps 40″ across and brighter in the southeast. My 15-inch scope at 216× shows a couple of extremely faint superposed stars, and adding an O III filter nicely emphasizes brightness variations in the nebula.

■ Contributing Editor **SUE FRENCH** wrote this column for the November 2010 issue of *Sky & Telescope*.

Treasures of the Celestial King

Object	Type	Mag(v)	Size/Sep	RA	Dec.
δ Cep	Variable/double star	3.5–4.4, 6.1	41″	$22^h 29.2^m$	+58° 25′
Krüger 60	Double star	9.9, 11.4	1.7″	$22^h 28.0^m$	+57° 42′
NGC 7281	Open cluster	8.2	12′	$22^h 25.3^m$	+57° 49′
NGC 7261	Open cluster	8.4	7′	$22^h 20.2^m$	+58° 07′
M 2-51	Planetary nebula	13.5	47″ × 38″	$22^h 16.1^m$	+57° 29′
μ Cep	Variable star	3.4–5.1	—	$21^h 43.5^m$	+58° 47′
IC 1396	Nebula/cluster	3.5	2.8° × 2.3°	$21^h 39.1^m$	+57° 30′
IC 1396A	Dark globule	—	18′ × 3′	$21^h 36.1^m$	+57° 28′
PM 1-333	Planetary nebula	—	105″ × 50″	$21^h 41.0^m$	+58° 59′

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.

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The Strange Case of
Comet Biela

It vanished, then returned, then vanished again, only to possibly return anew. **What gives?**

Our story begins with Isaac Newton and his law of universal gravitation. The theory put all motion in the solar system under a single mathematical law, one that possessed a high degree of precision. It worked for the planets and their satellites. Soon after Newton published his theory, some wondered if it applied to those singular, fleeting objects, comets.

Among those who thought it did was a younger contemporary of Newton's, Edmond Halley. In his 1705 paper "A Synopsis of the Astronomy of Comets," Halley wrote that comets observed in 1531, 1607, and 1682 all had very similar orbits, and he declared that they were all the same object returning every 76 years. He predicted its return in 1758. Halley died in 1742, so he didn't get to see this icy body again. But astronomers honored his discovery of the first comet known to be a member of the solar system by giving his name to it.

In 1819, the German astronomer Johann Franz Encke calculated the orbit of a comet that was also found to coincide with several others. In doing so, he had discovered the second comet identified as periodic. As with Halley's Comet, this one, officially known as 2P/Encke, was named after Encke and not after the astronomer who'd first observed and reported it — Pierre Méchain, in 1786.

There matters stood for seven years.

Discovery!

In the 18th and early 19th centuries, most observational work was done by amateur astronomers. (Even today, amateurs are deeply involved in regularly monitoring comets, asteroids, variable stars, and other celestial objects.) In the early 1800s, one of those amateurs was a German-Austrian military officer named Baron Wilhelm von Biela.

Astronomers gave up on ever laying eyes on either piece of the comet again. But stories of Comet Biela's demise were premature.

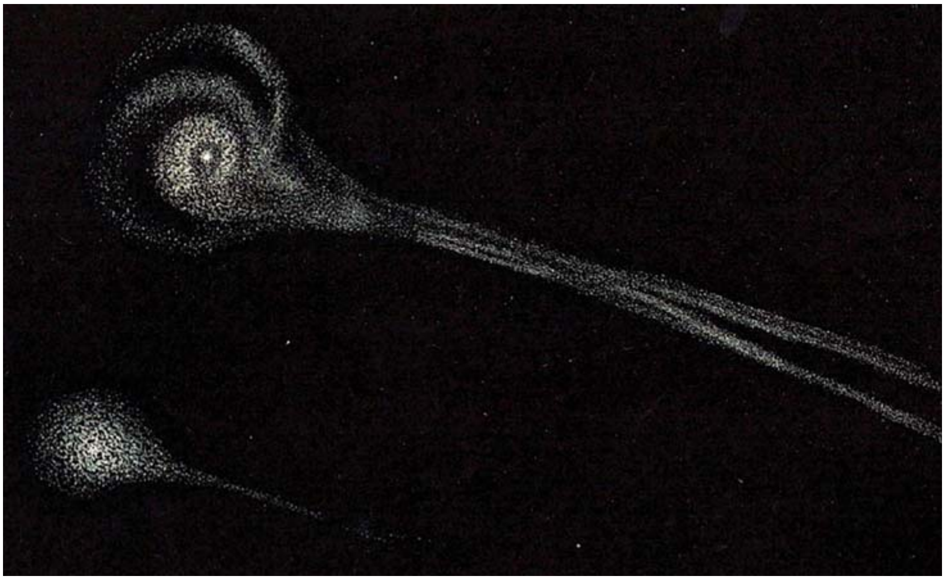
Biela was born in 1782 in what is now northern Germany. Not much is known about his early life, but in 1802 he joined the Austrian army, and because he was an aristocrat he was made an officer. Biela later served in several campaigns in the war against Napoleon. Astronomy apparently was not an abiding interest of his until 1815, when he began a study of the subject in Prague under the Bohemian clergyman and astronomer Alois Martin David. Still, Biela kept his day job. He was in eastern Bohemia, stationed at Fort Josefov, when he made his discovery.

On the night of February 26, 1826, Biela observed the comet that would come to bear his name. It was faint enough to be visible only in a telescope. He calculated the comet's orbit and found it to be an ellipse with a 6.6-year period. The French astronomer Jean-Félix Adolphe Gambart independently discovered the same comet a short time later. Gambart also calculated its orbit and managed to link this comet with another seen in 1805. This made Biela's Comet, officially designated 3D/Biela, only the third comet determined to be periodic. (In subsequent decades, some astronomers, particularly in Gambart's home country of France, felt that his name should have been attached, perhaps even solely, to the comet. But Biela's Comet it remains.)

It might seem unusual today for an amateur to both observe and do calculations, but it was not so back then. Professional astronomers busied themselves with cataloging precise positions of the stars and planets, to determine such things as ships' positions on Earth. They were not observers of the heavens for the love of it. Thus, most discoveries fell to amateurs. The Herschels — William, Caroline, and John — were perhaps the best known. William, for instance, was not a professional astronomer but a musician and composer when he discovered Uranus (in 1781) and conducted his first and second all-sky surveys. In those days there was no place an amateur could go to calculate cometary orbits from obser-

◀ **A DAZZLING SPECTACLE** When Earth passed through the dusty tail of Comet Biela on the night of November 27, 1872, Europeans out that night enjoyed one of the finest meteor showers in recorded history, as depicted in this period illustration.

SPL / SCIENCE SOURCE



SPLITSVILLE Comet Biela in February 1846, not long after it broke into two separate comets

vations. If you wanted it done, you did it yourself.

In 1806 Carl Friedrich Gauss, the greatest mathematician of his day and one of the greatest of all time, went further in calculations of what would become known as Biela's Comet. He tentatively linked the 1805 comet to one that French astronomers Jacques Leibax Montaigne and Charles Messier had seen in 1772. After further mathematical analysis, the three comets were tied together. Despite the previous sightings, Wilhelm von Biela's name became attached to the comet because his calculations first confirmed it to be periodic.

Comet Biela was unexceptional, however. It usually brightened to no more than 8th magnitude during its apparitions. Its orbital period of 6.6 years (specifically the 0.6) ensured that at least half the time it would be on the opposite side of the Sun from our planet when it arrived in the inner solar system, making it almost impossible for telescopes of the time to see it. Except when it approached near to Earth, one needed a good-quality telescope in order to detect it.

As far as anyone knew, Comet Biela had probably traveled this same path for hundreds of years. It was later determined to be part of the Jupiter family of comets — those short-period comets with orbital periods of less than 20 years whose orbits are primarily determined by Jupiter's gravitational influence.

Panic Among the People

Comet Biela was next observed during its 1832 return, when it created quite a stir amongst the public. This wasn't because it became visible to the unaided eye — it remained strictly a telescopic sight — but because predictions showed that Comet Biela would intersect Earth's orbit, albeit a month after our planet had vacated the vicinity. Nonetheless, the popular press was captivated by the notion of a close comet-Earth encounter, and the fact that the two were predicted to miss each other by 32,000 kilometers (20,000 miles) got lost in the resulting excitement. Newspaper accounts of the day reveal that a bit of a mass hysteria ensued. The frenzy was not about whether the comet's gas would lethally poison everyone, but whether or not the comet would collide with our planet.

Of course, nothing untoward happened. Comet Biela passed safely across the skies, witnessed only by those who sought it out with telescopes.

In 1839 the comet was not favorably positioned for observation, and no one saw it. This was due to that 0.6 portion of a year in Comet Biela's orbital period, which resulted in the icy body getting lost in the Sun's glare some years. So, astronomers waited for the comet's 1845 approach.

One Comet Becomes Two

The comet was recovered on November 26, 1845, by the Italian astronomer and Jesuit priest Francesco de Vico, himself a famous comet hunter. A month later, on December 29th, two observers using a 5-inch refractor at Yale College in New Haven, Connecticut, sighted a faint secondary comet one arcminute northwest of the primary comet; the American astronomer and naval officer Matthew Fontaine Maury found the same on January 13th. Astronomers subsequently observed the slow separation of what was clearly a pair of comets. No one had observed a comet splitting up before. Reports indicated that the two alternated in brightness, with one brighter on one night, then the other brighter the next night.

There were even drawings and reports of a bridge of material linking the two comets for a short time. Much later, during the mid-1900s, astronomers thought this bridge had likely

In Comet Biela's Orbit

Many people over the past several hundred years figure, even if indirectly, into the story of Comet Biela. See the main text for details on how these individuals — amateur astronomers, mathematicians, and others — factor into the questions surrounding this icy visitor from afar, which may or may not still exist in any form beyond the particles that make up the almost-extinct Andromedid meteor shower.

Edmond Halley
(1656–1742)

COMET BIELA: E. WEISS / *BILDERATLAS DER STERNENWELT* / WIKIMEDIA COMMONS / PUBLIC DOMAIN; HALLEY: RICHARD PHILLIPS / NATIONAL PORTRAIT GALLERY / WIKIMEDIA COMMONS / PUBLIC DOMAIN

▲ **STRING OF PEARLS** In this Hubble image, Comet Shoemaker-Levy 9 appears in 21 individual chunks in May 1994, two months before the comet's remains smashed into Jupiter. Did Comet Biela have its own string between its two large fragments after it split?

been an *antitail* of the brighter comet. An antitail is part of a comet's dust tail that only appears to extend toward the Sun because of our perspective from Earth. But recent speculation has it that perhaps a string of very small comet pieces between the two main ones produced this effect. Something similar happened with Comet Shoemaker-Levy 9 after it passed close to Jupiter in 1992. It's obvious that Comet Biela broke apart, and it's not unreasonable to think that a debris field lay strewn between the two large chunks.

Astronomers continued to observe the two comets that spring as they drifted apart, until they finally faded from sight in April.

During the comet's next approach, in 1852, the Italian Jesuit astronomer Angelo Secchi observed the main comet on August 26th. But Secchi didn't locate the second comet until September 15th. Of course, the separation between the two had increased. By the end of September both comets vanished from sight. Neither was ever seen again, even though astronomers searched for them in 1859, 1866, and 1872. During the 1872 attempt, some reported seeing nebulous objects near the predicted position of Comet Biela, but none of the reports was substantiated. As a result, Comet Biela became the first to acquire the "D" designation (meaning potentially "lost") rather than the usual "P" designation of periodic comets.

After this, astronomers gave up on ever laying eyes on either piece of the comet again. But stories of Comet Biela's demise were premature.

A Show of Shows

On the evening of November 27, 1872, people out and about in Europe were treated to a truly spectacular sight. A meteor storm appeared unlike anything anyone had seen before. For

Johann Franz Encke
(1791–1865)

Wilhelm von Biela
(1782–1856)

Alois Martin David
(1757–1836)

William Herschel
(1738–1822)

SHOEMAKER-LEVY 9: NASA / ESA / H. WEAVER / E. SMITH / STSCI; ENCKE: WIKIMEDIA COMMONS / PUBLIC DOMAIN; BIELA: HULTON FINE ART COLLECTION / GETTY IMAGES; DAVID: TUSIMAN / WIKIMEDIA COMMONS / CC-BY-SA 3.0; WILLIAM HERSCHEL: LEMUEL FRANCIS ABBOTT / NATIONAL PORTRAIT GALLERY / WIKIMEDIA COMMONS / PD-US

▲ **SHOOTING STARS** Meteors from the 2016 Perseid meteor shower dart out from their radiant in Perseus.

several hours the skies above Europe and elsewhere hosted a display that was said to approach 3,000 meteors per hour. That's about 50 per minute, or almost a meteor a second! Some estimates put the rate as high as 10,000 meteors per hour — an average of nearly 3 per second.

Once, while watching the Perseid shower, I measured a peak of 140 meteors per hour. Meteor showers don't occur at a constant rate, and I remember periods of several seconds when I observed no meteors, then a burst would happen in which I'd see several at once. But 140 per hour averages to only a little over 2 per minute, so I can hardly imagine how the 1872 storm would have appeared to those extremely fortunate European observers.

The meteors on that long-ago night appeared to be coming

PERSEIDS: WISANUBOONRAWD / ISTOCKPHOTO.COM; CAROLINE HERSCHEL: MELCHIOR GOMMAR TIELEMAN / HERSCHEL FAMILY ARCHIVES / MICHAEL HOSKIN / *DISCOVERERS OF THE UNIVERSE*; GAUSS: C. A. JENSEN / WIKIMEDIA COMMONS / PUBLIC DOMAIN; MESSIER: NICOLAS ANSEAUME / STOYAN R. ET AL./ *ATLAS OF THE MESSIER OBJECTS: HIGHLIGHTS OF THE DEEP SKY* / WIKIMEDIA COMMONS / PUBLIC DOMAIN; DE VICO: PASQUALE TOLA / *THE BIOGRAPHICAL DICTIONARY OF THE ILLUSTRIOUS MEN OF SARDINIA* / WIKIMEDIA COMMONS / PUBLIC DOMAIN

Caroline Herschel
(1750–1848)

Carl Friedrich Gauss
(1777–1855)

Charles Messier
(1730–1817)

Francesco de Vico
(1805–1848)

The Andromedids – *A Checkered History*

The saga of the Andromedid meteor shower did not begin with the stupendous display of 1872.

Indeed, strong meteor showers, with rates ranging from dozens to some 400 per hour, had been noted on December 5th, 1741; December 6th, 1798; December 7th, 1830; December 7th, 1838; December 6th, 1847; and November 30th, 1867. Edward C. Herrick, of New Haven, Connecticut, who was a witness to the 1838 display, was able to cull additional observations from other parts of Connecticut, New York, and Georgia. He concluded that the meteors appeared to emanate from a region of the sky "not far from Cassiopeia; or perhaps more nearly, from the vicinity of the cluster in the sword of Perseus."

In 1867, Viennese astronomer Edmund Weiss, quickly followed by German astronomer Heinrich Louis d'Arrest, proposed a connection between the orbit of Biela's Comet and these unusual late-autumn meteor displays. But Weiss went even further, noting in an 1868 paper published in *Astronomische Nachrichten* (one of the first international journals in the field of astronomy) that meteor activity produced by Biela's Comet was possible on November 28th in either 1872 or 1879.

Those who remembered his paper were thus on high alert and carefully monitoring the skies around the time of the appointed night in 1872 and caught the magnificent meteor storm. But the meteor show was far from over.

While nothing was seen in 1879, several astronomers predicted a recurrence in 1885, and these predictions were more than fulfilled. From Broughty Ferry, Scotland, on November 27th, James Smieton recorded a maximum of 100 meteors per minute, most of which "had brilliant phosphorescent trains, which continued to glow for several seconds after the meteors themselves had vanished." William F. Denning, observing from Bristol, England, commented that observers with especially clear skies experienced rates of roughly 1 meteor per second, or 3,600 per hour.

After 1885, the meteors from Biela's Comet became much less numerous, as the shower began to fade with the returns of 1892 (300-700 per hour), 1899 (100 per hour), and 1904 (only 20 per hour).

Today, this once-intense shower, which some sources refer to as the Bielids after the parent comet, has become seemingly almost extinct. That's primarily because the orbit of the main stream of meteor particles was shifted significantly after 1892 by planetary perturbations so that it no longer crosses Earth's orbit, the gap eventually having widened to a distance of about 0.04 a.u. As a consequence, these meteors are scarcely detectable and are more or less widely scattered from the middle of November through the first week of December, with no obvious maximum. If any Andromedid meteors are reported nowadays (one or two per hour?), they might be caused by meteoroids that got separated from the main stream. It is also quite possible that the stream has dispersed over the last 150 years so that its density has been significantly reduced.

Quite unexpectedly, however, on the night of December 4, 2011, six Canadian radar stations, which send out pulses of radio waves that bounce off meteor trails, detected a *zenithal hourly rate* of about 50 meteors, which marked a revival of the Andromedids, according to astronomer Paul Wiegert (University of Western Ontario). In modeling the 2011 shower, Wiegert traced the meteors' origin to particles that Biela's Comet shed in 1649, more than a century before the comet itself was seen. In a paper published in the March 2013 issue of the *Astronomical Journal*, Wiegert and colleagues made forecasts regarding other appearances of the Bielid shower in the years 2000–2047 based on a numerical model. Notes Peter Brown, a coauthor of that paper: "A shower in 2023 (Dec. 2) might yield as many as 200 meteors an hour, surpassing the Perseids and Geminids; not a storm, but a very strong outburst."

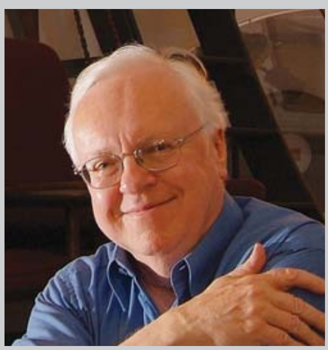
What more can we say? Mark your calendars!

—*Joe Rao*

MAURY: LEIGH WILLIAMS / *SCIENTIST OF THE SEA* / LIBRARY OF CONGRESS / WIKIMEDIA COMMONS / PUBLIC DOMAIN; SECCHI: FRATELLI D'ALESSANDRI / SMITHSONIAN INSTITUTION LIBRARIES / WIKIMEDIA COMMONS / PUBLIC DOMAIN; MARSDEN: HOWARD DORWIN / CENTER FOR ASTROPHYSICS / HARVARD & SMITHSONIAN; KOHOUTEK: NASA

Matthew Fontaine Maury
(1806–1873)

Angelo Secchi
(1818–1878)



Brian Marsden
(1937–2010)

Luboš Kohoutek
(1935–)

In succeeding years, the Andromedid meteors periodically reappeared, though they never again rose to the spectacular level seen in 1872.

from near the star Gamma (γ) Andromedae, so they're called the Andromedids (see sidebar on page 63).

Astronomers tried to figure out what caused this tremendous display. Eventually they determined that, because Earth had passed very close to the comet's orbit that night, our planet likely traveled through dust from the comet's tail that had been emitted during the frozen body's previous passages through the inner solar system. This was one of the first instances in which a comet's debris field was tied to an exceptional meteor storm.

So, long after astronomers had given it up for lost, Comet Biela had returned, in a way, to give one more show. It was a display that was far more impressive than the comet itself had ever been.

In succeeding years, the Andromedid meteors periodically reappeared, though they never again rose to the spectacular level seen in 1872. The Andromedids continued to decline until they, like their parent body, pretty much disappeared.

That *should* have been the end of the story. But it wasn't.

Comet Biela, Where Are You?

In the late 1960s, Brian Marsden, best remembered for his long tenure as director of the Minor Planet Center at the Harvard-Smithsonian Center for Astrophysics, used computers to find lost comets and asteroids. Comet Biela was one of those he tackled.

▲ **BLAZING SADDLE** Comet Kohoutek appears in this false-color, far-ultraviolet image taken during a Skylab spacewalk on Christmas Day, 1973.

NASA

Marsden began by assuming that the nucleus of the smaller of the separated pair had disintegrated completely, so he concentrated on the bigger fragment. Assuming the non-gravitational forces (that is, jets) had ceased after the last confirmed sighting in 1852, he calculated the position for this object and found that it would reach perihelion on December 21, 1971, at a distance of only 0.05 astronomical unit from Earth, or roughly 7.5 million kilometers (4.6 million miles).

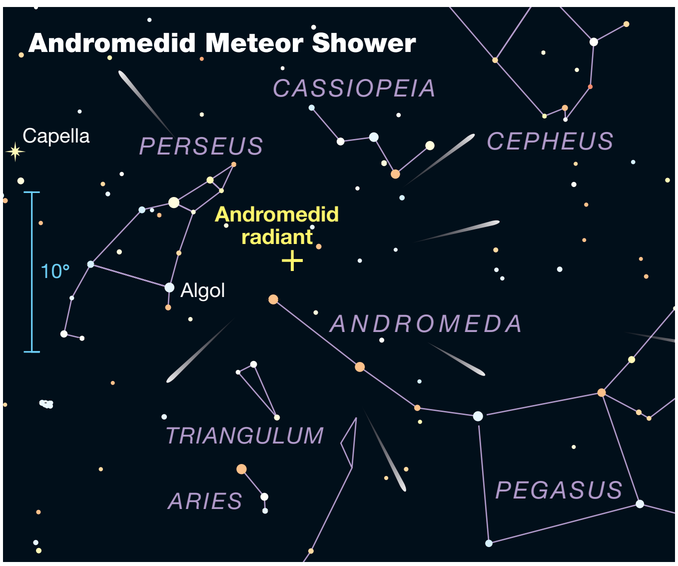
Astronomers searched for this fragment, but they observed only a few very faint asteroids, which they were never able to connect to Comet Biela.

However . . . .

One of the searchers was Czech astronomer Luboš Kohoutek, who used the 800-mm (31.5-inch) Schmidt camera at the Hamburg Observatory. In his hunt Kohoutek discovered a comet. Amateurs active in the early 1970s will remember that Comet Kohoutek, formally designated C/1973 E1, was predicted to become bright enough to be seen with the naked eye, and it rocketed to fame. But when it failed to fulfill its predicted promise, it became quite infamous. Through Comet Kohoutek's fate, it seemed vaguely as if Wilhelm von Biela's comet had reared its head again.

Two other comets have orbits similar to Comet Biela's, and a few astronomers have tried to find a link between them and the baron's comet. The first is Comet 18D/Perrine-Mrkos, originally discovered in 1896. Its orbit is similar to Biela's save for the *argument of perihelion*, the orientation of the comet's orbit around the plane of the ecliptic, so most astronomers don't accept it as a match for Biela's Comet. Oddly enough, this intrinsically faint comet has also been lost; it was last seen in 1969. The second suspect is Comet 207P/NEAT (P/2001 J1), discovered in 2001 by the NEAT asteroid survey. But again, astronomers have not been able to establish a connection to Biela's Comet.

So, whether Comet Biela is truly lost or just frustratingly elusive remains to be seen.



▲ On December 2, 2023, the Andromedids "might yield as many as 200 meteors an hour, surpassing the Perseids and Geminids," according to Paul Wiegert and colleagues. As Joe Rao notes, "Mark your calendars!"

■ **DAVE NAKAMOTO** has been an amateur astronomer for more than 50 years. His most recent article for *S&T* is "The Enigma That Is BL Lacertae" (*S&T:* Sept. 2018, p. 30).

FURTHER READING

"The Return of the Andromedids Meteor Shower," by Paul A. Wiegert, Peter G. Brown, Robert J. Weryk, and Daniel K. Wong. *The Astronomical Journal*, Vol. 145, No. 3, March 2013: **https://is.gd/Andromedids**

iOptron's GEM45 Equatorial Mount

This innovative Go To mount can bear a surprisingly heavy load.

GEM45 German Equatorial Mount

U.S. Price: $2,188 with tripod and hard case.
ioptron.com

What We Like

Highly accurate slewing and tracking

Integrated electronic pole finder

Large payload capacity

What We Don't Like

Assembly requires tools in the field

Hard-to-grip knobs

▲ iOptron's new GEM45 German equatorial mount is deceptively small and lightweight for its stated payload capacity of 45 pounds.

IOPTRON HAS A REPUTATION of producing innovative telescope mounts, from German equatorials to the novel "CEM" series of center-balanced mounts that place the telescope saddle over the tripod's center of gravity, creating more stability (*S&T:* Nov. 2018, p. 66).

Among the latest in its line of traditional German equatorial designs is the GEM45. Its noteworthy feature isn't hardware or software related. It's the number 2.8. That's the advertised ratio of mount weight to payload capacity. Given that the mount's equatorial head weighs a bit less than 16 pounds (without counterweights), the 2.8 ratio implies it can carry a hefty 45-pound payload.

I tested the GEM45 with four telescopes of various focal lengths and weights. All of my tests were done with the GEM45 mounted on its iOptron LiteRoc tripod, which features 1¾-inch-diameter steel legs. The tripod stands 29 inches tall and can extend to 48½ inches. Also included in the package is a hard case with fitted foam for the mount head, hand control, counterweight shaft, and the tripod accessory tray.

A Sleek Mount

The GEM45 is an attractive mount with many CNC-machined parts finished in red anodizing that contrasts well with its black drive housings and removable stainless-steel declination shaft.

The mount has clutch knobs on each axis that fully disengage the worm gears from the main drive gears to allow quick and easy balancing, and to prevent damage to the gears during transportation. Each 110-mm-diameter worm wheel on the GEM45 is mounted on large 46-mm-diameter shafts. The stated periodic error is ±7 arcseconds. Two additional models of this mount are available: the GEM45EC ($2,848), which includes a high-resolution encoder on its right-ascension axis that reduces its periodic error to less than 0.25 arcsecond. And as this review was underway, iOptron announced a version with its newly integrated iGuider system for $2,498, though it was unavailable at the time of my tests.

Setup in the Field

Though the GEM45's Go To and tracking were outstanding, the mount's assembly lacked some conveniences included in other iOptron mounts.

The tripod's central rod is threaded on the bottom to permit tightening of the tripod accessory tray and leg spreader. Its top is rounded to provide a central pivot point for the equatorial head, which is secured to the tripod with two stainless-steel flathead hex bolts that require use of an included 4-mm hex wrench. These bolts must be loosened slightly to permit fine azimuth

▼ The mount features clutches on each axis that disengage the worm gears to aid with balance and protect the gears from damage during transit. Also seen here is a USB 2.0 input jack and iPORT that accepts the GPS dongle or an optional WiFi adapter.

adjustments during polar alignment — a somewhat tedious job in the dark. There is a nice storage slot for the hex wrench just above one of these bolts, but knobs or some other tool-free solution instead of the hex bolts would be more convenient. The wrench performs double duty since it can be inserted into holes around the edge of the small knurled wheel that adjusts the altitude axis during polar alignment. This knurled wheel is tucked under the polar axis and is tough to grab with just your thumb and forefinger, so inserting the wrench adds greater leverage. GEM45 has a generous latitude range of 14° to 68°.

The mount includes iOptron's new Universal Self-Centering Saddle, which accepts both Vixen-style and the wider Losmandy-style dovetail mounting plates. To swap between the two formats, users disconnect the two jaws with the onboard hex wrench and reattach them upside-down. Two of the four mounting screws on the stationary clamp are shorter than the other two, so be sure to note where each goes. The Losmandy-style setting also includes an alignment scale to help accommodate narrower dovetail plates.

The two saddle clamping knobs are 1 inch wide but protrude less than an

▲ iOptron's Universal Self-Centering Saddle accepts both Losmandy- and Vixen-style dovetail mounting plates. Users remove the clamps and replace them upside-down to switch between formats. The back end of the saddle includes passthrough ports for USB 2.0 accessories and an ST-4 standard autoguider. The center-positive barrel connector power jack typically requires a male-to-male cord to power a camera or other accessory.

inch from the saddle jaws, making it difficult to get a solid grip on them. The center of each knob accepts a 5-mm hex wrench. Once, while mounting my 8-inch Ritchey-Chrétien OTA, the mounting bar slipped in the saddle due to insufficiently tightening the knobs. A stop screw on the bar prevented any damage, but afterwards I always used a 5-mm hex wrench to make sure the saddle jaws were sufficiently tight.

The Universal Self-Centering Saddle works well, though it places telescopes farther from the center of the polar axis, which means you may need more counterweights than typically required. For example, when using a heavy SCT with a diagonal and eyepiece weighing 32 pounds, it required 40 pounds of counterweights to balance.

While the hex-head bolts and the lack of sizeable clamping knobs are minor inconveniences when assembling the GEM45, the mount does have several convenience features. The counterweight included with the mount has compression rings rather than a lock-down screw to prevent marring the counterweight shaft.

The lower end of the saddle plate has its own 12 VDC output power jack, a port that accepts an ST-4-compatible autoguider cable, as well as a USB 2.0 passthrough socket. (The input is located on the rear of the RA axis.) I routinely used these ports to power my camera's cooler and connect my autoguider. Configured in this way, all these

▼ Unlike with other iOptron mounts, the center post is not threaded to attach the GEM45 head. Instead, the center post is merely a pivot point, and the mount is secured using two of the threaded holes on the tripod head. The azimuth adjustment pin can be moved to any of the four threaded holes to ensure the counterweight shaft does not strike the tripod legs when using the mount at low latitudes.

▼ Connecting the GEM45 equatorial head to the tripod base requires the included 4-mm hex wrench to tighten down the two cap screws, which also double as the azimuth lockdown mechanism. The hex wrench can also be used to adjust the altitude of the mount by inserting it into the holes on the knurled knob at right.

ALL PHOTOS BY THE AUTHOR

▲ The Go2Nova 8407+ Hand Controller features eight lines of information on its back-illuminated LCD display, which is easily readable day or night.

cables and their connections move with the scope as it tracks across the sky, preventing snags. You'll need a male-to-male barrel connector cable to access the 12 VDC output. An included 5-amp, 110 VAC to 12 VDC adapter provides power to the mount as well as to the additional connected accessories.

The GEM45's Go2Nova 8407+ Go To hand control displays 8 lines of information about the mount status, target object's location, and tracking. The system's onboard database contains 212,000 objects. A small fabric loop attached the hand control lets you hang it from several knobs on the mount. The Go To alignment and other operational elements of the 8407+ menus are very intuitive.

The hand paddle also includes recordable periodic error correction (PEC) that lets you to record guiding corrections during the 400-second cycle of the right-ascension worm gear, and then play back the recorded loop. Activating this PEC feature significantly reduced the GEM45's periodic error.

Included with the mount is a small GPS dongle. Plugging this accessory into the iPORT automatically enters location, date, and time as soon as the dongle receives a GPS connection. Once completed, you can unplug and store the GPS for the rest of the night.

A serial cable that connects the hand paddle to a laptop or other computer is provided to update the Go2Nova firmware, if necessary. You can also directly connect a PC to the mount via the USB 2.0 input socket on the base of the mount to the right of the iPORT. Most popular desktop planetarium programs will recognize the mount as an ASCOM device and control the GEM45. There's also an optional WiFi adapter that allows control of the mount with many Apple or Android planetarium apps.

iPolar Alignment

Instead of a traditional polar alignment scope in the RA axis, the GEM45 comes with iOptron's iPolar electronic polar-alignment tool permanently installed. This internal camera looks through a 19-mm objective that produces a 13° field of view on screen and connects to your computer via a USB 2.0 cable.

To operate the iPolar device, you first download the *iPolar* electronic polar-scope control for PCs from iOptron's website (a Mac version is available on Apple's app store). The program has a wide range of gain settings and exposure times to ensure Polaris and fainter field stars around the pole are visible.

Once an image of the polar region is on screen, the software recognizes the field and directs you to rotate the polar axis so that it can determine the exact center of the mount's rotational axis.

◀ The included GPS dongle plugs into the iPORT and automatically inputs the date, time, and location information into the Go2Nova hand control. It can be removed as soon as the information appears on the hand paddle.

▲ Instead of a polar-alignment bore scope, the GEM45 includes iOptron's iPolar digital alignment system. Seen at the top is its 19-mm objective lens with the protective cap removed. Above, the back end of the polar axis includes the USB input to connect the iPolar device to your PC. To the right is the USB 2.0 passthrough input port.

You're then given a screen overlay on the star field consisting of a small red dot and crosshair. Turning the altitude and azimuth adjustments on the GEM45 base moves the crosshair directly over the red dot. When the dot and crosshair get close, the view automatically shifts to a 10× magnified view to help refine your alignment. When completed, the right ascension axis should be pointed to within 30 arcseconds of the pole.

I was initially confused when I had clicked on the "raw" image display option in the control software, which displays what appears to be a blank image of the field. It turns out the stars are there, and disabling raw setting applies an automatic stretch to the image, producing white stars against a black sky with no gradation in between.

Alignment with iPolar takes a little more time than using a traditional bore scope, but it's worth the few extra minutes. The iPolar device is extremely accurate — using it virtually eliminated declination drift even when using a long-focal-length scope.

Under the Stars

Over the course of testing during the spring and early summer, I mounted on the CEM45 a 102-mm refractor, an 8-inch Ritchey-Chrétien (RC), a Celestron 8-inch Rowe-Ackermann Schmidt Astrograph (RASA), and finally a hefty Celestron 11-inch Schmidt Cassegrain (C11).

The refractor and RC weigh about 18 lbs with all their accessories, and the little mount carried them without any problems using two 10-lb counterweights. A sharp rap on the tube of both scopes dampened in under a second. The RASA astrograph and its piggyback guidescope required an additional 7-lb counterweight to properly balance. As for the accuracy of the tracking performance during imaging, exposures up to 3 minutes long were routinely made unguided using the 400-mm focal length f/2 RASA.

After many sessions with the GEM45, I consider it an ideal match for

▶ Comet C/2017 T2 (PanSTARRS) appears here near galaxies M81 and M82 taken through an 8-inch Celestron RASA on the GEM45 mount. Twenty unguided 1-minute exposures were combined to produce this sharp result.

▲ *Left:* This screen from the *iPolar* software shows a real-time 13°-wide view of the polar star field showing the relationship of the true pole position (red dot) relative to the mount's right ascension axis (crosshair). Simply adjust the mount's altitude and azimuth adjustments to put the crosshair centrally atop the red circle. *Right:* As you adjust the mount to move its rotational axis as measured by *iPolar* to meet the true pole, the software automatically zooms in 10× to ensure accuracy to within 30 arcseconds.

▲ Spiral galaxy M51 imaged with the author's 8-inch f/8 Astrotech Ritchey-Chrétien and ZWOptics ASI071MC camera riding atop the GEM45. Of the 64 one-minute unguided exposures shot of this target without activating the PEC, only 7 were rejected due to slightly elongated stars.

▲ The GEM45 tracks flawlessly with an autoguider. Taken on the evening of July 22nd, this image of C/2020 F3 (NEOWISE) consists of a single 5-minute exposure with the ZWO ASI071MC color camera and RASA telescope guided with a Starlight Xpress Lodestar 2 autoguider and a piggybacked guidescope.

All 30 of the two-minute exposures used to assemble this colorful view of the M8 and M20 region were shot unguided on the GEM45 using the author's 8-inch Celestron Rowe-Ackermann Astrograph and a ZWO ASI071MC camera.

the 8-inch RASA. I used it during the evening apparitions of several comets when I had to travel to a dark site.

One particularly memorable night, I loaded the GEM45 into the back of my van on a hunt for Comet C/2020 F8 (SWAN). When fully retracted, the tripod with the mounted GEM45 head measures just 44 inches tall. That's short enough to allow it to stand completely assembled just behind the front seat. Arriving at my site, I would just keep the tripod legs retracted as I placed the mount on the ground while installing the counterweights and RASA tube assembly. I then did a quick and accurate iPolar session and a one-star Go To alignment. Once set, I then slewed to the comet's position before it rose. As the comet cleared my horizon, it was dead center in the field of the RASA. It was one of the quickest, most accurate setups for imaging I have ever experienced.

Targeting the galaxy M51 with the 8-inch f/8 Ritchey-Chrétien and its relatively long 1,625-mm focal length, I made 64 back-to-back, unguided, one-minute exposures without enabling the PEC and dumped them all into my image stacking software that automatically evaluates the star images in each frame. The software was satisfied with 57 of the 64 unguided exposures and created the final image stack seen on the facing page. When autoguiding with the mount, you can set the guide rates on each axis differently to better accommodate imaging close to the celestial poles.

The C11 and its accessories weighed just over 43 pounds (and required an additional counterweight). The mount performance with this load was almost as good as with the other OTA's. A rap on the tube took slightly longer to dampen down — about two seconds. The mount's maximum slewing speed of 4½° per second wasn't affected by the heavy load, and pointing was just as precise as with the other instruments.

Summing Up

The iOptron GEM45 can indeed carry a load 2.8 times the weight of the mount and carry it well, though you should plan on getting a few additional counterweights to get the most out of this capable platform.

Purchasers of the GEM45 will appreciate the mount's accurate Go To, as well as its smooth tracking and guiding motions. Its built-in conveniences, including its GPS, thoughtfully placed USB and power ports, and the iPolar alignment device make setting up extremely accurate every time. Its design and features bring welcome advantages particularly for those of us who frequently set out on the road in search of dark skies.

■ Contributing Editor **JOHNNY HORNE** enjoys imaging from several dark locations in rural North Carolina.

▲ *Top pair:* Several setups used to test the GEM45 include a Celestron 8-inch Rowe-Ackermann Schmidt Astrograph (top left), and an Astro-Tech 8-inch f/8 Ritchey-Chrétien astrograph. *Bottom pair:* A Celestron C11 Schmidt-Cassegrain with finder required the most counterwights, while the William Optics 102-mm triplet apochromat balanced comfortably with two 10-lb counterweights.

▶ POLAR FINDER

Explore Scientific now offers a polar-alignment scope for its compact IEXOS-100 German equatorial mount. The IEXOS-100 Polar Finder and Adapter ($89.99) is a small, focusable alignment scope with an etched reticle that shows the positions of Polaris and stars near Sigma Octans in the Southern Hemisphere to help accurately align the IEXOS-100 mount. The device includes a mounting bracket that attaches to the front plate of the mount's declination motor housing and can be folded underneath the motor when not in use. Explore Scientific also provides all necessary mounting hardware and a battery-powered, variable-brightness illuminator.

Explore Scientific
1010 S. 48th St., Springdale, AR 72762
866-252-3811; explorescientific.com

▶ DEEP-SPACE IMAGER

Orion Telescopes & Binoculars adds a new camera to its line of deep-sky detectors. The Orion StarShoot G16 Deep Space Mono Imaging Camera ($1,279.99) features a 4/3-format,16.2-megapixel Panasonic MN34230 CMOS detector with 3.8-micron-square pixels in a 4,640 x 3,506 array. The camera uses dual-stage thermoelectric cooling to achieve stable operating temperatures down to 40° below ambient, dramatically reducing thermal noise. The unit is capable of recording 22 full-resolution, 12-bit frames per second through its USB 3.0 interface. The StarShoot G16 also includes a 2-port USB 2.0 hub to connect a filter wheel and guide camera and Windows-compatible control software. Each purchase includes an AC adapter, 2-inch nosepiece, and a hard storage case.

Orion Telescopes & Binoculars
89 Hangar Way, Watsonville, CA 95076
831-763-7000; telescope.com

▶ LENS MOTORS

Rigel Systems now offers two focusing motors for its camera lens focusing system. The Belt Drive Stepper Kit ($119.95) remotely adjusts the focus on most camera lenses and helical telescope focusers using a stepper motor and belt. The motor can be adjusted along a crossbar to accommodate several lens diameters. Alternatively, Rigel's Split Gear Stepper Kit ($179.95) includes a plastic gear and ADM R100 mounting ring, which make it better suited for larger designs. Both models can bear lenses weighing up to 8 lbs, and each uses the same stepper motor that moves in 0.1° increments. The Stepper Kits are compatible with most astronomical focus control systems that accept an RJ12 6-pin connector, including controllers from Starlight Instruments Feather Touch, Technical Innovations RoboFocus, and MoonLite Telescope Accessories, as well as Rigel's own usb-nSTEP controllers.

Rigel Systems
rigelsys.com

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

A Place for Everything

Better storage solutions for home observatories

ANYBODY WHO'S BEEN INTO amateur astronomy for a while has faced the relentless buildup of equipment. We buy foam-lined cases for our eyepieces, toolboxes for our collimators and wrenches and lasers and flashlights and sky quality meters and spare batteries, more toolboxes for finders and binoculars and shrouds and dew heaters, briefcases for notebooks and charts and reading glasses, and so on.

Astrophotographers add an additional half dozen cases for that equipment alone. Now try to remember where everything is . . . and where it goes when you pack up for the night. It can get plenty frustrating, especially when you need that one thing you can't find even after scattering everything out onto the ground.

If you observe at home, there's no reason to put up with this proliferation of small cases. Here are two ideas to help consolidate all your gear into a single, organized, easy-to-use place.

Oregon amateur Larry Myers found that a mechanic's rolling tool chest works beautifully. The drawers are graduated in size from top to bottom, so small items can go in the top drawers and large ones below. Custom-cut foam liners keep things from rolling around and provide easy visual reference for where to put them, so they don't get lost. The wheels allow Larry to roll the chest out of his garage for observing and back inside when he's done, carrying all his gear in a single trip, and they lock down to hold the chest in place while he's observing.

Larry is into imaging, so he took it a step further: He mounted his computer on the tool chest, too. Not a laptop, either: There's room on the top for a full-blown desktop system, complete with speakers for soft music while observing. The CPU is mounted in back. Larry reports that it took him a few nights to figure out where everything ought to go, but now that he's got it just right, his star-time where-did-I-put-it frustration levels have greatly decreased.

New Hampshire amateur Douglas Arion has a roll-off-roof observatory with several scopes in it, so he built a mobile desk that he can roll into place next to whichever telescope he's using. He made it with leftover cherry plywood from a house project and built a matching chair to go with it.

Doug's is an open-front cabinet with two deep shelves for equipment and a separate top with two hinged lids. The larger compartment in back of the top section holds charts, and since it's supported on a riser at the rear and has an edge stop for the charts to rest against, those charts lie at a comfortable reading angle when in use.

The smaller front compartment holds eyepieces and accessories. Since Doug has plenty of power right there at hand, he added a nifty feature to the eyepiece compartment: a low-wattage pad made for keeping reptile cages warm. Eyepieces and accessories never dew up now.

An aside: Doug learned that machining a 2- to 1¼-inch adapter out of Delrin or a 3D-printed one keeps his eyepieces warm much longer in the scope. Plastic insulates better than the more traditional metal adapters, so eyepieces don't cool off nearly as quickly.

These storage ideas are just two examples in a more-or-less endless realm of possibility. The key concepts are convenience and organization, two qualities that are appreciated everywhere, but never more so than in the dark.

As Doug says, and Larry echoes, "It's great to have a place for everything, and everything in its place."

▲ A mechanic's tool chest makes a perfect cabinet for your observing equipment. There's even room on top for an entire desktop computer.

▲ Doug Arion built this beautiful equipment desk out of leftover cherry plywood. The top serves as an easel for charts, which are stored inside.

■ Contributing Editor **JERRY OLTION** is thinking on the drive to his observing site: "Cabinet in back of the car. Hmm . . ."

FRONT VIEW: LARRY MYERS; CHAIR AND DESK: DOUGLAS ARION

▲ The back side of the tool chest holds the computer and cabling.

▲ The eyepiece compartment is perfectly placed for easy access and is heated to prevent dew.

BACK VIEW: LARRY MYERS; EYEPIECE COMPARTMENT: DOUGLAS ARION

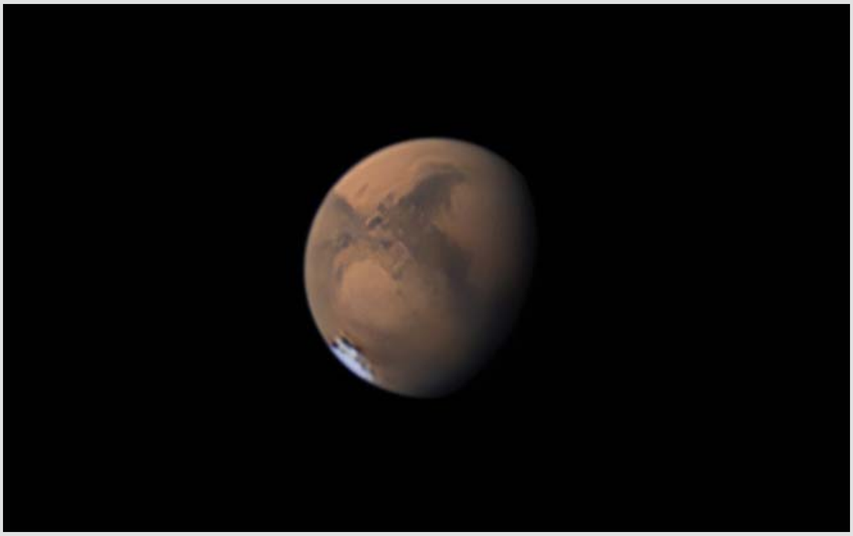
SHARE YOUR INNOVATION
Do you have a telescope or observing accessory that *S&T* readers would enjoy knowing about? Email your projects to Jerry Oltion at j.oltion@gmail.com.

The Big "W"

Tom O'Donoghue

Dozens of deep-sky targets riddle this mosaic of the main asterism in Cassiopeia. On the left, we see Caldwell 10 (west of an arc of three stars) and several other open clusters, while many reddish emission nebulae sprinkle the field. These include Sharpless 2-173 (floating by itself in upper right), NGC 281 (bottom middle right), and IC 63 and IC 59 above γ Cas at center. **DETAILS:** *Takahashi FSQ106N and FSQ106ED refractors, each equipped with Atik 11000 CCD cameras. Twenty-five-panel mosaic recorded through LRGB and narrowband filters totalling 350 hours.*

Pairing Crescents
Robert Horton
Crescent Venus appears just after emerging from behind the Moon as seen from North Sandwich, New Hampshire, on the morning of June 19th.
DETAILS: *8-inch f/4 Newtonian reflector with Canon Ra mirrorless camera. Total exposure: 1⁄250 second at ISO 800.*

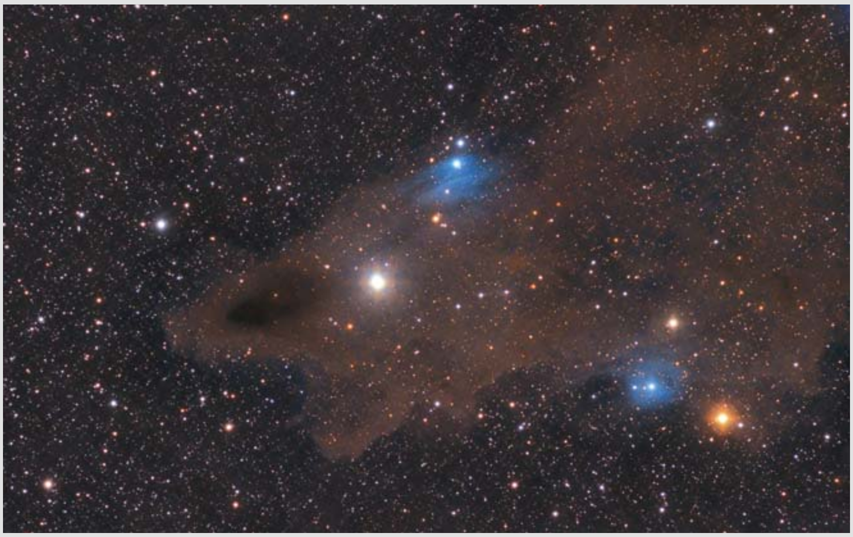


◁ NEARING NEIGHBOR

Oleg Bouevitch

Mars displayed a wealth of fine detail on August 1st, when the planet appeared 14.6 arcseconds across. The large, dark albedo marking Syrtis Major is well placed, with the lighter impact basin Hellas at lower left, leading towards the shrinking white South Polar Cap.

DETAILS: *Celestron EdgeHD 14-inch Schmidt-Cassegrain with ZWO ASI290MM video camera. Stack of multiple video frames taken through RGB filters at approximately 9:43 UT.*



◁ THE DARK SHARK

Kurt Zeppetello

Designated LDN 1235, this dark nebula in Cepheus surrounds the 6th-magnitude star HR 8493. It also contains the bluish reflection nebulae vdB 150 (top) and vdB 149 (lower right).

DETAILS: *Astro-Tech AT115EDT refractor with ZWO ASI1600MM-Pro camera. Total exposure: 9.95 hours through LRGB filters.*

◁ SONOITA SPLENDOR

John Vermette

The summer constellations Capricornus, Sagittarius, and Scorpius parade above a rustic stable at the Empire Ranch near Sonoita, Arizona. Jupiter is seen just above the tree at left.

DETAILS: *Canon EOS 6D DSLR camera with Rokinon 24-mm f/1.4 lens. Total exposure: 15 seconds at ISO 3200.*

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SKY & TELESCOPE Market Place

Your essential source for astronomical products

CLASSIFIEDS

AMATEUR OBSERVATORY FOR SALE: 12.5 Dall Kirkham (Coulter), excellent homemade mount, clock drive, corrector, all accessories, 8' dome with rotation system. Denver area. Price: $4,000. Tigers.paw@earthlink.net

ASTRO-PHYSICS 180 mm STARFIRE REFRACTOR: For sale is an Astro-Physics 180 mm EDT f9 Starfire refractor. Price includes refractor, guide scopes, other refractor accessories, eyepieces, and filters. Price, photos, and accessory list are available by emailing wallerfj@entermail.net

DEEP SKY COFFEE: World-class coffee to fuel late night observation sessions! Veteran-owned; 35-year avid astronomer; 5% donated to Dark Sky Preservation and PTSD research. 20% off first purchase at: www.DeepSkyCoffee.com/astro

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

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

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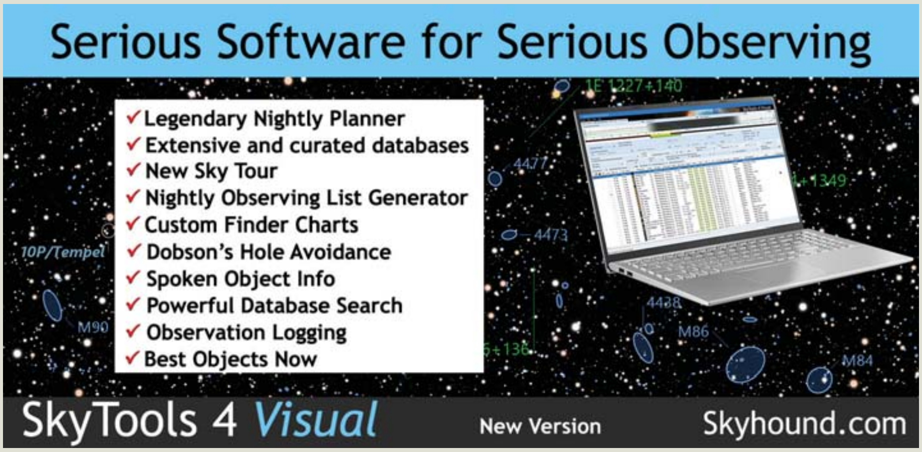

MISCELLANEOUS

OBSERVATORIES/DOMES

OBSERVATORIES/DOMES

OPTICS

TELESCOPES

skyandtelescope.org

SKY&TELESCOPE

INSIDE This Issue

Specialty astronomy equipment dealers and manufacturers are an important resource for amateur and professional astronomers alike — patronize our advertising dealers in this issue and enjoy all the benefits of their expertise.

Product Locator

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Sky-Watcher USA (Cover 2)
SkyWatcherUSA.com
310-803-5953

CAMERAS

Diffraction Limited (SBIG Aluma) (Page 57)
diffractionlimited.com/AC4040
613-225-2732

Planewave Instruments (Page 3)
planewave.com
310-639-1662

Sky-Watcher USA (Cover 2)
SkyWatcherUSA.com
310-803-5953

EYEPIECES

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FILTERS

Astro-Physics (Page 81)
Astro-Physics.com
815-282-1513

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Alluxa (Page 1)
alluxa.com

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omegon.com

MOUNTS

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iOptron (Page 57)
iOptron.com

Software Bisque (Cover 4)
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303-278-4478

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530-823-7796

Vaonis (Stellina) (Page 5)
vaonis.com/stellina
+33 (0)4 67 59 30 23

AD INDEX

Event Calendar

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

JACOB W. FRANK / NPS / WIKIMEDIA COMMONS / PUBLIC DOMAIN

~~September 11–13~~ **CANCELED**
CONNECTICUT RIVER VALLEY ASTRONOMERS CONJUNCTION
Northfield, MA
philharrington.net/astroconjunction

~~September 11–19~~ **CANCELED**
OKIE-TEX STAR PARTY
Kenton, OK
okie-tex.com

~~September 12–13~~ **CANCELED**
NORTHEAST ASTRONOMY FORUM
Suffern, NY
rocklandastronomy.com/neaf.html

~~September 16–20~~ **CANCELED**
ACADIA NIGHT SKY FESTIVAL
Mount Desert Island, ME
acadianightskyfestival.com

~~September 17–19~~ **CANCELED**
ILLINOIS DARK SKIES STAR PARTY
Chandlerville, IL
sas-sky.org

September 17–20
BOOTLEG FALL STAR PARTY
Harmon, IL
bootlegastronomy.com

September 18–20
IDAHO STAR PARTY
Bruneau Dunes State Park, ID
boiseastro.org/isp.html

September 18–20
ALBERTA STAR PARTY
To be held virtually at:
calgary.rasc.ca/asp2020.htm

~~September 18–20~~ **CANCELED**
BLACK FOREST STAR PARTY
Cherry Springs State Park, PA
bfsp.org

~~September 18–20~~ **CANCELED**
CONNECTICUT STAR PARTY
Goshen, CT
asnh.org

September 18–20
HIDDEN HOLLOW ASTRONOMY CONFERENCE
Mansfield, OH
wro.org/hidden-hollow-star-party

September 25–26
ASTRONOMY AT THE BEACH
To be held virtually at:
glaac.org/astronomy-at-the-beach

~~September 26~~ **CANCELED**
ASTRONOMY DAY
Events across North America
https://is.gd/AstronomyDay

October 13–18
ENCHANTED SKIES STAR PARTY
Pie Town, NM
enchantedskies.org

October 15–18
SJAC FALL STAR PARTY
Belleplain State Forest, NJ
sjac.us/star-party

November 10–15
DEEP SOUTH STAR GAZE
Sandy Hook, MS
stargazing.net/DSRSG

• **For an up-to-date listing, including coronavirus-caused cancellations, visit https://is.gd/starparties2020.**

My Time of Transits

Warning: Watching a planet cross the face of the Sun is highly infectious!

▲ Black-dot fever resulted in this image of Venus crossing the Sun on June 6, 2012.

SEAN WALKER / S&T

LAST NOVEMBER 11TH MARKS the end of a season in my life as an astronomer. As I'm a "senior" amateur, Mercury's passage across the Sun on that day may have been the last transit of a planet I'll experience in this lifetime.

I savor my two decades of transits, each of them infecting me with an incurable condition: black-dot fever. I've lived and observed in the western U.S. most of my life, which has longitudinally limited my interval of black dots to a half-dozen transits. Yet each event has its unique memories for me.

Mercury 1999: Wichita, Kansas. With the Sun low in the afternoon sky, the event would be a short passage, lasting less than an hour. I hoped for an impressive view, as some important visitors would be looking through my telescope. I rigged a small reflector to project the transit image onto a piece of white cardboard. My wife and son and a few friends made it to the event. They were quite intrigued with the setup and the spectacle. It was my first transit, and I immediately caught the bug!

Venus 2004: Filled with excitement after reading up on the history of this planet's transits, I traveled to Baltimore and set up a TV video system attached to a Meade 70-mm scope to easily share the view with passersby in the city's Druid Hill Park. It was a foggy morning, and anxious moments went by: Would it be clear enough to see Venus? Not only was it plenty clear, the fog was the perfect density to dim the sunrise, showing a large black spot visible without any filters or optical aid. After the transit ended, our small crowd had happy faces all day long.

Mercury 2006: What a beautiful setting for this one — the Point Vicente Lighthouse, atop cliffs overlooking the Pacific Ocean north of Los Angeles Harbor. Numerous visitors saw the event through my 90-mm Maksutov, and I captured some fine images of the planet's silhouette against the solar disk. It never ceases to amaze me how tiny a planet is compared to a star.

Venus 2012: Eight years after Baltimore found me in St. George, Utah, again setting up in a city park with several instruments. I assigned my C5 SCT to strictly visual observing. Park visitors came by and enjoyed a look. Two aspects were most thrilling to me: the rare privilege of seeing both Venus transits possible in a lifetime, and the even rarer sight of the arc of the planet's aureole through the C5's eyepiece during the last minutes of ingress. Sunlight shining through the atmosphere of another world!

Mercury 2016: Spreading the fever became my goal. Working as a ranger at Dinosaur National Monument allowed me to create and present a transit program for park visitors. Discouraged by rain at dawn, I set up the scopes on wet sidewalks near the monument's fossil quarry, in the Utah portion of the park. My black-dot luck continued to hold, with the skies quickly clearing, enabling 140 people to enjoy the program.

Mercury 2019: I found myself at sunrise within El Morro National Monument in New Mexico, with the transit already in progress. This time I set up a hydrogen-alpha solar scope along with my 5-inch Mak. I infected another generation of rangers while training them on the basics of safe solar observing. Fifty people watched the progress of Mercury across the Sun, some of us seeing the black-drop effect at third contact. What a way to end my time of transits!

■ DEREK WALLENTINSEN works as a National Park Service Ranger protecting federal lands and the dark skies above them. He lives in Albuquerque, New Mexico.

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