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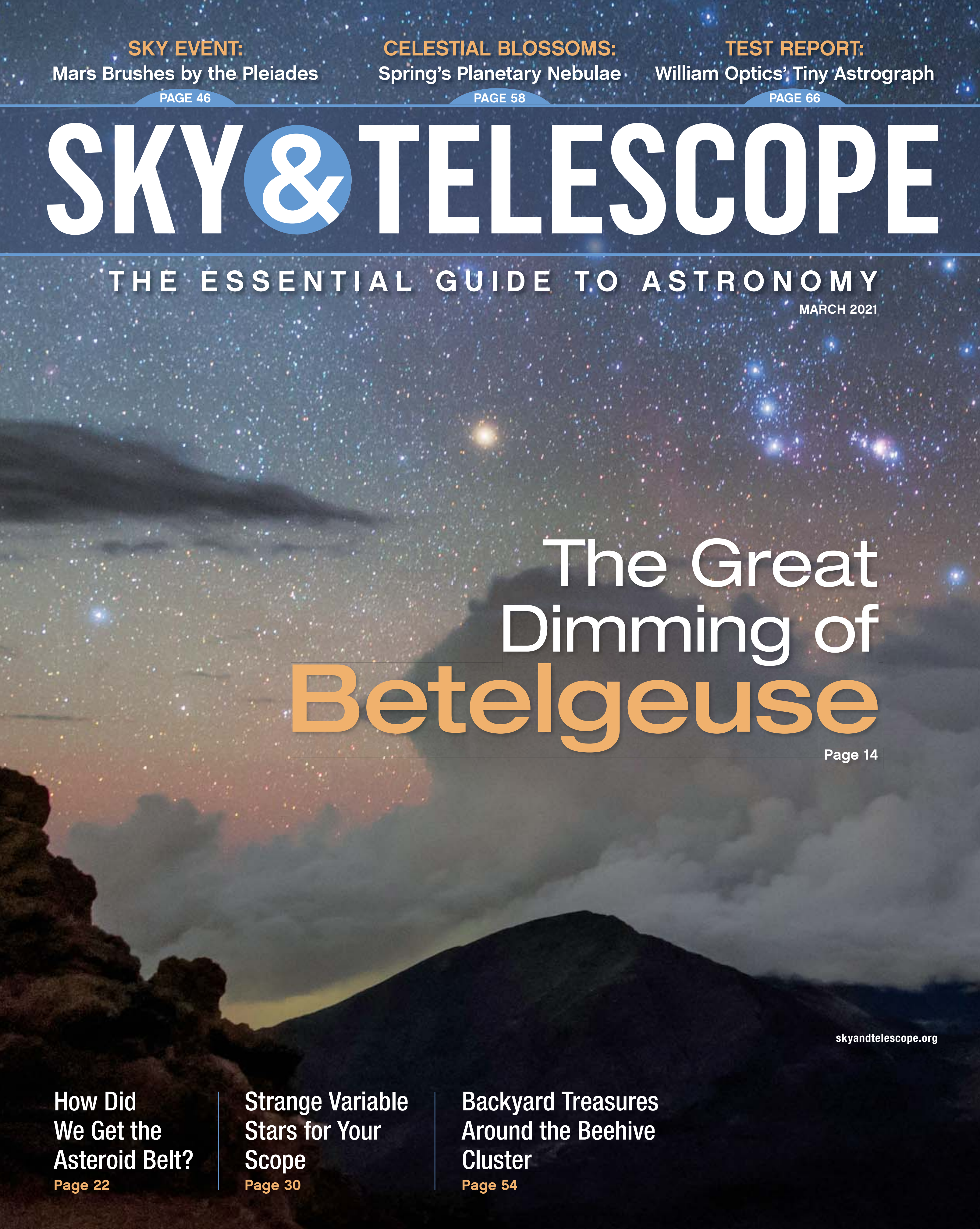
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

MARCH 2021



The Great Dimming of Betelgeuse

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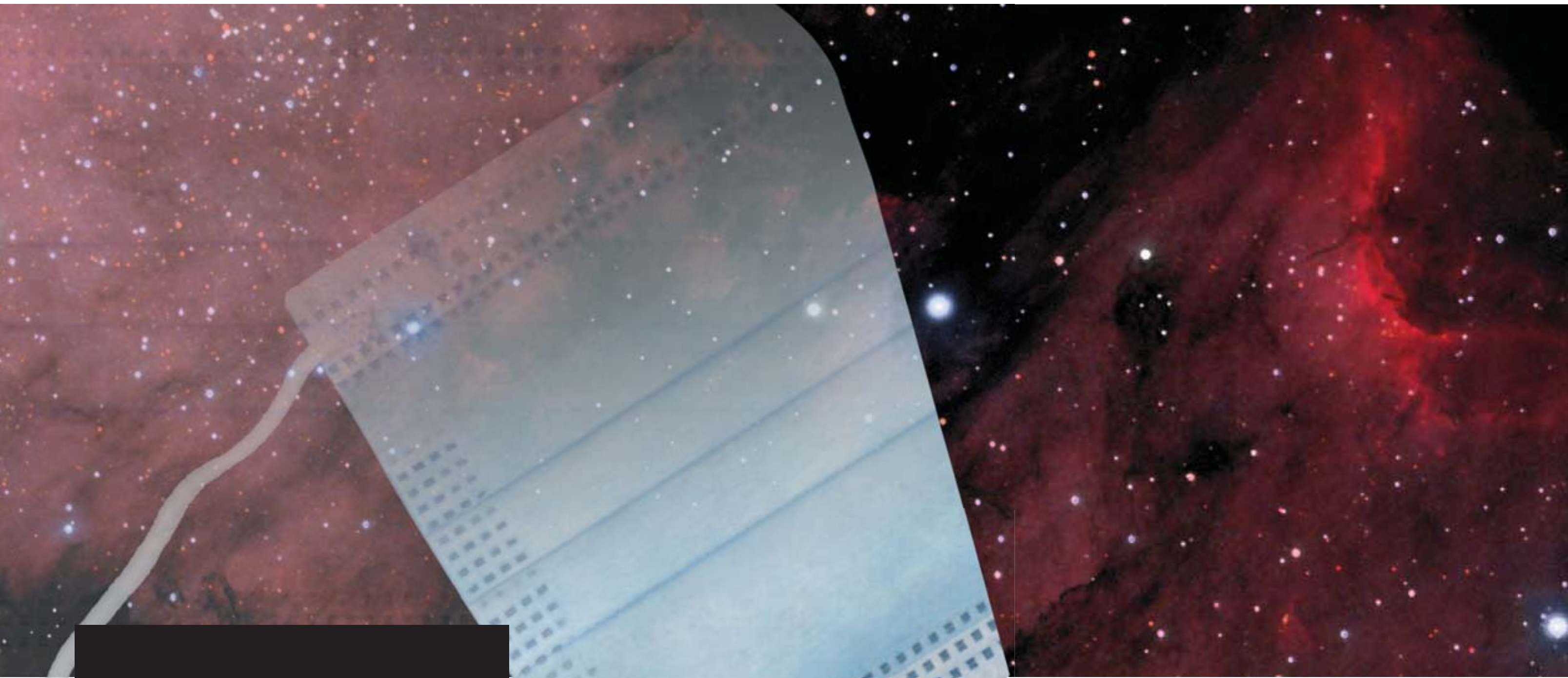

Pelican Nebula Image by Jim Burnell using NP127is. To see the unmasked original go to http://bit.ly/TVOUnmask

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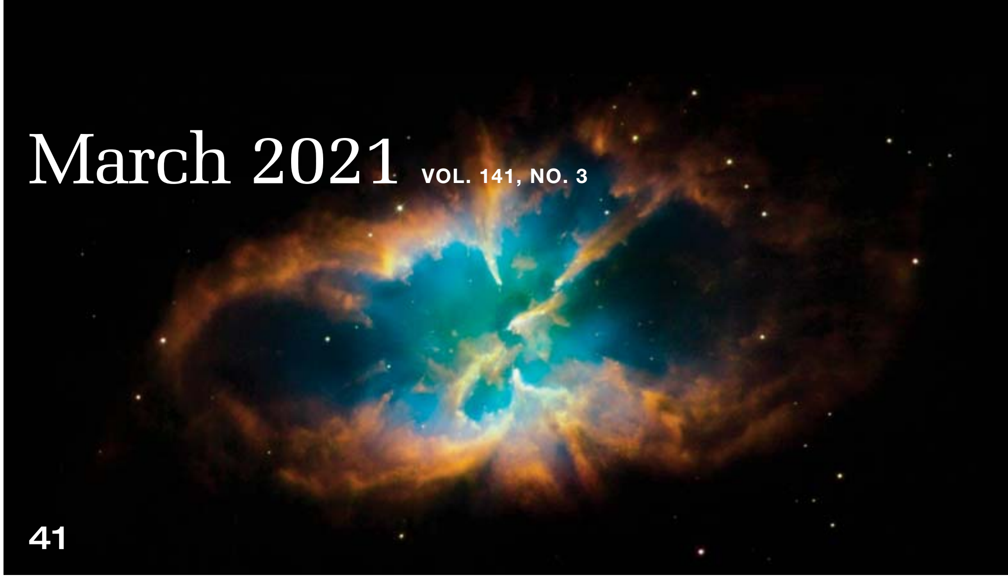

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ON THE COVER

Orion rises above Haleakala Crater in Hawai'i.
BABAK TAFRESHI

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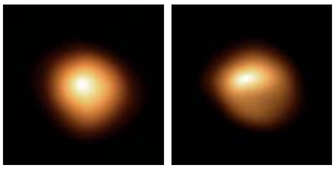
A Classic *S&T* Story

EVERY NOW AND THEN a story comes along that checks all the boxes in terms of what we seek to cover in *Sky & Telescope*. It's a prototypical *S&T* tale, just as a deep-dive investigative piece on China, say, is a quintessential *New Yorker* article, or a profile of a famous alpinist is an archetypal *Outside* vignette. As our cover story this month reveals, the mysterious dimming of Betelgeuse in late 2019 and early 2020 is one of those turns of events we just *had* to report on.

First off, it's a sizzler. Betelgeuse, the red supergiant that blazes like a fiery beacon in Orion, is many people's favorite star. Professional astronomers are as agog over it and its byzantine behavior as anyone, and they're as in the dark as any of us about when (even if) it might go supernova. Sure, it might be 100,000 years from now; then again, it might be tomorrow (or never). The dimming had many of us on edge. Was Betelgeuse about to blow? Most professionals didn't think so, but they, too, were flummoxed by the fading.



▲ Before and during the "Great Dimming": Betelgeuse as it appeared in January 2019 *(left)* and December 2019 *(right)*

ESO / M. MONTARGÈS ET AL.

Second, it's a story with appeal for everyone, from beginners in astronomy to those deep-rooted. In Tom Calderwood's feature on page 14, you can learn some basic science about aging stars, for example, or you can hone your understanding with arcane phenomena like the *mirror effect* and *rogue cells*.

What else makes it vintage *S&T*? The story is a perfect example of pro-am collaboration. Amateurs using backyard scopes contributed as vitally to the investigation of the "Great Dimming" as professionals operating the VLT and Hubble. It's an international narrative, with astronomers from around the world grappling with the enigma. It involves instruments operating across multiple wavelengths — ultraviolet, visible, near-infrared, and submillimeter radio among them — and it has stimulated both observation and modeling.

The story also allows for simple but powerful graphics, always important for a popular-science magazine. All can marvel, for instance, at the odd darkening in the star's southeast. (At less than 650 light-years away, Betelgeuse is so nearby that our biggest scopes can make out enough of the star's disk that we can actually use compass directions on it.) The light curves of the fading are instantly digestible as well, yet as fascinating to the expert as to the novice.

Lastly, the story of Betelgeuse's strange antics a little over a year ago leaves many lingering questions, with a clear need for more data and more analysis. The reader ends the piece wanting more — especially with the potential for a spectacular supernova still teasing us.

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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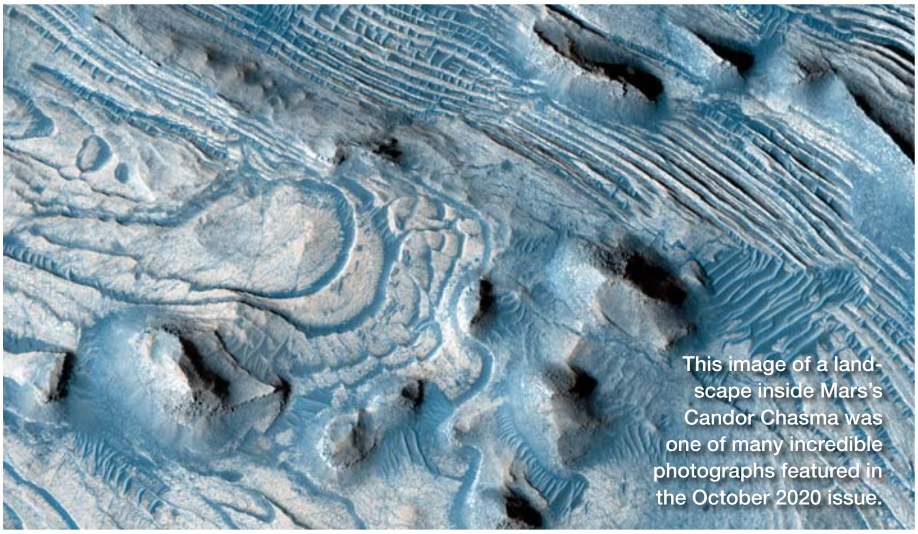

This image of a landscape inside Mars's Candor Chasma was one of many incredible photographs featured in the October 2020 issue.

The Beauty of Mars

In my 50 years of reading *Sky & Telescope*, the images shown in "The Red Planet Revealed" by Peter Tyson (*S&T:* Oct. 2020, p. 12) were the most scientifically and artistically interesting I have seen. Well done.

Michael Michaud
Lawrence, Kansas

The photos of Mars in *Sky & Telescope*'s October 2020 issue were both stunning and fascinating.

Only one thing could have made them even better: scale bars to show the size of the natural features.

Cheryl Rofer
Santa Fe, New Mexico

Tracking by Hand

Not wanting to spend several hundred dollars on a new motorized camera mount to photograph Comet NEOWISE (*S&T:* Nov. 2020, p. 14), I decided to resurrect a 35-year-old technology: the barndoor tracker. I remember seeing an article in *S&T* about how to make one in the 1980s. I made this device before Halley's Comet came around in 1986 and used the tracker to take pictures of it, Comet Hyakutake (C/1996 B2), and Comet Hale-Bopp (C/1995 O1). I also used it to take 8-minute exposures of Orion that showed the Horsehead Nebula. This mount was pretty good for the slow-speed color film available then.

▶ This barndoor mount was built based on an article in the October 1985 issue of *Sky & Telescope*.

To those unfamiliar with this device, one aims the hinge edge of the tracker at Polaris and rotates the handle one turn per minute, so the screw moves the top board and compensates for Earth's rotation. I lay a small finderscope with crosshairs along the hinge to aid in alignment.

Maurice Snook
Athens, Georgia

An Astronomy Tool Chest

When a new issue of *Sky & Telescope* arrives, I look at three columns first: Deep-Sky Wonders, *S&T* Test Report, and Jerry Oltion's Astronomer's Workbench. While reading his "A Place for Everything" (*S&T:* Nov. 2020, p. 74), I had one of those "Why didn't I think of that?" moments. The idea of using a tool chest to store all my astronomical gear was brilliant. I used to schlep a portable computer bench, a toolbox, an eyepiece case, and a stool around and always forgot something in the garage or house. By the time I got everything together, it took nearly a half hour!

As soon as I read the article, I purchased a wheeled tool chest with four drawers. I put two pairs of binoculars and various star atlases in the top drawer. The second contains my connecting cables and miscellaneous paraphernalia. The third drawer organizes my eyepieces and various cameras and camera connectors. The fourth holds my Bahtinov focusing masks, a three-ring binder with all my manuals in it, and an extension cord to hook everything up. No more going back into the garage or house, no more hunting for everything in an eyepiece case, no more fumbling in the dark for something I misplaced.

Thank you for this article.

Peter Ponzio
Elburn, Illinois

The Unistellar eVscope

I was happy to see Richard Tresch Fienberg's review of Unistellar's eVscope (*S&T:* Dec. 2020, p. 66). I've been using one since early 2020. I head outside and within minutes observe something new and interesting on almost every clear night. It performs amazingly well in my light-polluted skies, too.

I think this categorically different smart telescope will also be a boon for educational programs and easy online sharing. The eVscope might seem expensive, but I would make the case that, over time, the cost will be quite low compared to the deep-sky object rate per observing session. I also feel that telescopes like this will open up a whole new market of deep-space gazers for our amazing hobby, and they will stay active longer, too.

This telescope has become a way for me to easily participate in amateur astronomy. My eVscope has brought me joy as I hop between a half dozen deep-sky wonders per session.

Jim Sweitzer
Oak Park, Illinois

NASA / JPL / UNIVERSITY OF ARIZONA; BARNDOOR MOUNT: MAURICE SNOOK

Observing Accessories

I really enjoyed Tom Dobbins's "Tips for Planetary Observers" (*S&T:* Nov. 2020, p. 52). His idea to place the diagonal mirror between the polarizing filters in a variable filter is brilliant! Rotating the eyepiece to adjust the brightness and reduce glare is a huge improvement for observing fine detail.

But dielectric mirror diagonals have an added benefit. While a diagonal with a metallic-film mirror preserves the polarization from the polarizing filter, a dielectric-film mirror does not. For a certain orientation of the first polarizing filter, rotating the eyepiece, and the second filter, results not in variable extinction of the brightness but instead variable color filtration.

On October 2nd, I was observing Mars, and with this hack, I could tune the color filtration of the planet from cyan through to magenta. So, one can adjust the color to improve the visibility of whatever feature they're interested in and still enjoy the benefits of glare reduction. Finding this specific orientation of the first polarizer is easy. It simply requires rotating the front polarizer incrementally and turning the eyepiece at that point. I found a position where I mostly get brightness extinction rather than color change. Then, to get the color variation feature, rotate this first polarizer 45° from that spot in either direction.

I've never seen such a dramatically clear view of Mars with any of my prior telescopes before using this setup. Thank you again for your wonderful column!

John Guerra
Concord, Massachusetts

The Goldilocks Zone

Monica Young's article "To Touch The Sun" (*S&T:* Nov. 2020, p. 20) captures my imagination and scaffolds my thinking and understanding, leaving me curious and on the edge of my seat for the next act! Thank you so much for adding another *S&T* article that is somehow both engaging and leaves me wanting more.

And thank you, *Sky & Telescope*, for consistently providing such a large variety and range of information, from tables regarding Jupiter's activities and moons to articles on pairing star diagonals to reorient stargazing and the many other wonderful topics over the years. It's difficult to imagine the editorial process that assures these articles are both receptive to the diverse interests of subscribers and provide high-caliber information without overwhelming.

That's the Goldilocks Zone for me!

Michael Robertson
Princeton, Minnesota

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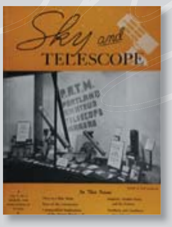
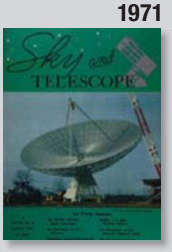
75, 50 & 25 YEARS AGO by Roger W. Sinnott

1946



1971



1996

◖ March 1946

Blue Moon "In his quiz column . . . Dr. L. J. Lafleur quotes an explanation found in the *Maine Farmers' Almanac* for 1937. In effect, this is that at one time the various full moons of the year were given names according to the order in which they occurred . . . But seven times in 19 years there were — and still are — 13 full moons in a year. This gives 11 months with one full moon each and one with two. This second in a month, so I interpret it, was called Blue Moon, and was considered unlucky and a real nuisance as it occurred at various times of the year and upset scheduling of church festivals."

This was the most consequential blunder ever to appear in the pages of S&T. *The key phrase is "so I interpret it." As Donald W. Olson discovered in 1999, writer J. Hugh Pruett had not seen the* Maine Farmers' Almanac *firsthand and guessed wrong, thereby planting the seed for today's most widespread meaning of Blue Moon.*

◖ March 1971

Touchdown "[The] Soviet spaceship Venus 7 arrived at that planet on December 15, 1970, after a 120-day flight. But the report that it apparently did not reach the planet's surface needs modification. . . . It now appears that an actual soft landing took place. On January 26th, the Moscow newspaper *Isvestya* published an announcement that computer analysis of the radio transmissions revealed weak signals continuing 23 minutes more, although at only one percent of the previous intensity. . . . Telemetry data after the landing revealed a temperature of 475° ± 20° centigrade, and a barometric pressure of 90 ± 15 atmospheres. . . .

"This is the first occasion on which scientific observations have been made from the surface of another planet."

The mission is better known today by its Russian name: Venera 7.

◖ March 1996

Quasar Homes "Extragalactic astronomers were astounded last year when the Hubble Space Telescope apparently failed to find some of the galaxies in which every quasar is thought to reside. Now two recent studies indicate that most, if not all, 'naked quasars' are indeed clothed — though scantily at times. . . .

"Kim K. McLeod (Harvard-Smithsonian Center for Astrophysics) and George H. Rieke (University of Arizona) . . . reanalyzed the Hubble images for a few of the nominally naked quasars by calculating a one-dimensional profile for the images that the orbiting telescope obtains of point sources. They then used these profiles to subtract the quasars' overwhelming glare from their far dimmer surroundings. . . .

"[They could also] detect the disputed quasars' hosts in near-infrared images taken with the 2.2-meter Steward Observatory reflector atop Kitt Peak."

◀ The 900-ton platform suspended above the Arecibo telescope fell 140 meters (450 feet), damaging the dish and surrounding structures.

OBSERVATORIES

Damaged Arecibo Telescope Collapses

AT 7:55 A.M. ON DECEMBER 1ST, a rumble echoed through the hilly terrain surrounding Arecibo, the iconic 305-meter (1,000-foot) radio telescope nestled in a natural sinkhole in Puerto Rico. The 900-ton receiver platform that had been suspended above the dish had come crashing down.

While no injuries occurred, the collapse ended hopes for a controlled dismantling of the telescope, which National Science Foundation (NSF) officials had announced less than two weeks earlier after two unexpected and devastating events that compromised the safety of the telescope.

First, an auxiliary cable, which helped suspend the receiver platform, tore out of its socket on August 10th, gashing the dish below. A redundant design transferred the load of that auxiliary cable to the four original cables and the remaining support cable. Engineers were called in to assess the damage and, after determining the structure was stable, to begin repairs.

Replacement cables were on order, but before they could arrive, one of the main cables from the same tower snapped on November 6th. This unexpected second break caused engineers to doubt the entire structure's integrity.

"Any engineering approach to better understanding the strength left in the main cables involves considerable risk for human life and could in fact accelerate the uncontrolled collapse of the structure," said Ralph Gaume, director of NSF's Division of Astronomical Sciences.

Engineers warned that another cable break would cause "catastrophic failure." A representative from the engineering firm Thornton Tomasetti wrote in support of dismantling the telescope: "We believe the structure will collapse in the near future if left untouched." Drone footage in the days following the announcement showed additional breakages in the remaining cables.

Ultimately, the uncontrolled collapse happened before engineers could devise a plan for controlled decommmissioning. A preliminary assessment indicated that the top sections of all three support towers broke off. Then, as the platform fell, the cables also dropped, causing significant damage to the observatory's learning center.

The loss of the 57-year-old observatory came as a shock to the astronomy community (see page 12). Arecibo's huge collecting area, incredible sensitivity, and powerful radar capabilities enabled it to study everything from near-Earth asteroids to distant galaxies; scientists had also used the dish to investigate Earth's atmosphere.

▲ A ground view shows the suspended receiver platform in better days.

"I'm devastated," says Alessondra Springmann (University of Arizona), who had used the facility to characterize comets and asteroids. "There's nothing else like this in the world."

"Arecibo is so much more than a scientific instrument," says Edgard Rivera-Valentín (Lunar and Planetary Institute). "It has been an icon in Puerto Rico that has served to inspire generations of scientists."

"Pretty much every schoolchild on the island has been to Arecibo," Springmann says. "Everyone has had family who worked there, who helped build it. You can't have an observatory without the people, and the people also derive great benefit from the observatory being there."

Arecibo is also irreplaceable for scientists. "The Arecibo Observatory is the world's most powerful and most sensitive planetary radar," Rivera-Valentín explains. "This makes Arecibo invaluable for planetary defense."

Technically, Arecibo is the second-largest radio dish in the world — China's Five-hundred-meter Aperture Spherical Telescope, or FAST, recently broke the record that Arecibo had held for decades (*S&T:* Feb. 2017, p. 26). But FAST's suspended platform cannot hold the weight of radar instrumentation. Other radar-capable radio dishes, such as NASA's Goldstone, lack Arecibo's sensitivity and availability.

Over almost six decades, Arecibo survived multiple earthquakes, hurricanes, and funding struggles. Even upon the telescope's collapse, NSF officials have emphasized that they are not closing the Arecibo Observatory. The NSF continues to authorize repairs for the facility's 12-meter radio telescope and the roof of the LIDAR facility, used for geospace research. Both were damaged in 2017 during Hurricane Maria. The observatory's visitor center has managed to survive unscathed.

■ MONICA YOUNG

● **See drone footage of the collapse at https://is.gd/Arecibocollapse.**

ARECIBO: RICARDO ARDUENGO / AFP / GETTY IMAGES; RECEIVER PLATFORM: ALAN DYER

VENUS

Phosphine on Venus: A Calibration Error?

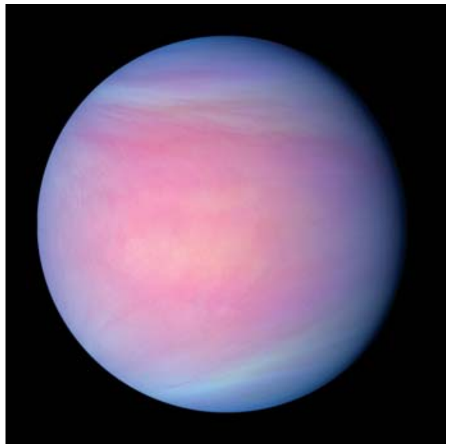
IN THE MONTHS AFTER Jane Greaves (Cardiff University, UK) and colleagues published the possible discovery of phosphine gas in the cloud decks of Venus (*S&T:* Jan. 2021, p. 10) using data from the Atacama Large Millimeter/submillimeter Array (ALMA), their study attracted a considerable amount of scientific scrutiny. Several groups had posted critical studies on the arXiv preprint server by mid-November.

But the biggest recent upset came from ALMA itself. “The publicity drew the attention of people with experience on other interferometers and ALMA experts specializing in other fields who made unexpected connections,” explains Anita Richards, the team’s ALMA liaison. “All of this has ultimately contributed to a new reduction.”

The problem arose because Venus is not a typical target for ALMA. The array of radio dishes spends most of its time looking at things that are far away and thus faint. But for this study, ALMA had to look for something barely visible (the phosphine absorption line) inside a large, bright, nearby object (Venus). Upon realizing an error had occurred with the way Jupiter’s moon Callisto was used as a calibration target, ALMA staff reprocessed the data.

After performing analysis on the recalibrated data, Greaves reported in a paper posted November 16th on the arXiv that the signal is now not quite five times the background noise, the “gold standard” for a detection.

However, the feature hasn’t disappeared and is still promising. So the team has come up with a new strategy: While their initial observations had some restrictions due to weather and the dish configuration at the time,



▲ False-color image of Venus

they now plan to use optimized settings, which will enable them to focus on distinct locations where they think phosphine is present. The team plans to re-observe Venus when ALMA, which has been closed for months due to the COVID-19 pandemic, reopens in 2021.

■ ARWEN RIMMER

STARS

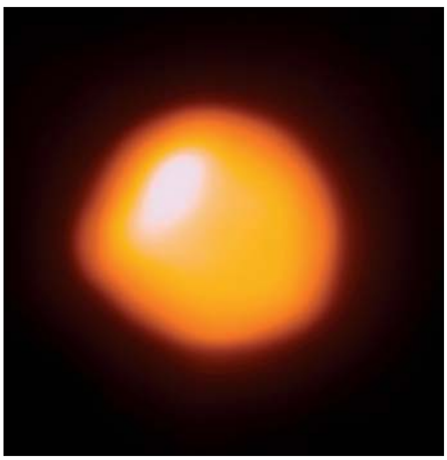
How Big Is Betelgeuse Really?

BETELGEUSE MIGHT ACTUALLY BE smaller, and therefore closer, than previously thought, Meridith Joyce (Australian National University) and colleagues report in the October 10th *Astrophysical Journal*. Knowing the star’s size is crucial to understanding its recent bizarre behavior (see page 14) — and predicting if or when it will finally explode as a supernova.

Using historical data collected by amateur astronomers of the American Association of Variable Star Observers, as well as archival observations from an imager aboard the Coriolis satellite, Joyce’s team assembled a light curve that shows how Betelgeuse’s brightness varies over time as the star pulses. The additional data enabled the researchers to newly identify a 185-day cycle produced by pressure waves (aka sound waves) slowly moving through the star’s outer layers.

By inputting this swell-and-contract rhythm into a computer simulation, Joyce calculated Betelgeuse’s average girth: between 702 and 880 times the Sun’s diameter. That’s smaller than previously thought: If Betelgeuse were put in place of the Sun, it would extend roughly two-thirds of the way to Jupiter instead of all the way.

Infrared detectors already resolved the star to a spot 42 milliarcseconds across, and if the distance to the star is known, then that angular diameter translates to its size. But Joyce and colleagues worked backwards: They compared the size calculated in their simulation to the angular diameter of the star, giving the distance to the star as between 500 and 636 light-years.



▲ The Atacama Large Millimeter/submillimeter Array captured this image of Betelgeuse.

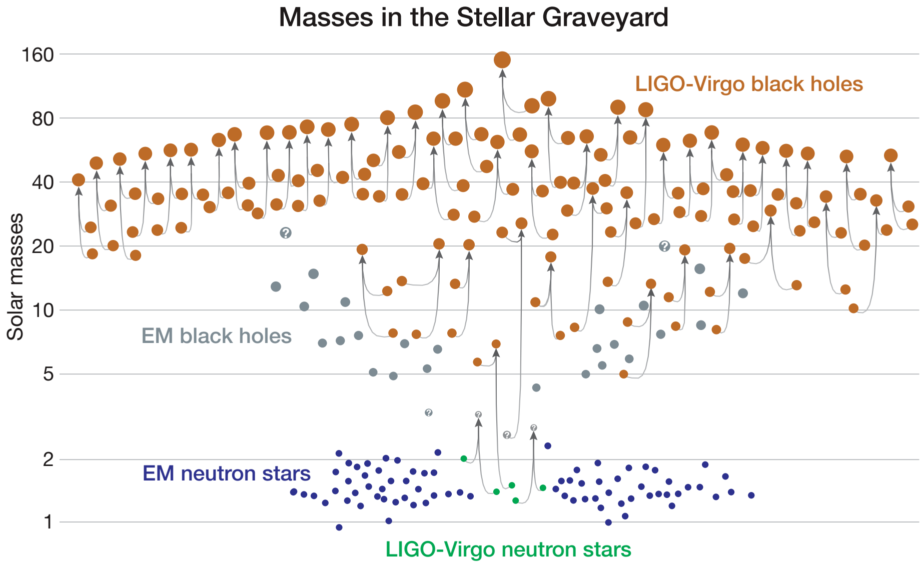
This estimated range just overlaps with previous calculations based on parallax measurements made with the Hipparcos satellite, which — when combined with additional radio data — had put the star’s distance between 620 and 880 light-years.

Nevertheless, Graham Harper (University of Colorado, Boulder) urges caution, because the results depend on simulations of the star’s structure and that is not yet well understood. “You always need a ground-truth when developing new techniques. All the assumptions and uncertainties (known and unknown) can add up.”

Yet the result has interesting implications if it pans out: A smaller Betelgeuse is likely at an earlier stage of its evolution, putting off any potential supernova. Joyce says, “We could be looking at around 100,000 years before an explosion happens.”

■ MONICA YOUNG

VENUS: PLANET-C PROJECT TEAM; BETELGEUSE: ALMA (ESO / NAOJ / NRAO) / E. O'GORMAN / P. KERVELLA



◀ Black hole (orange) and neutron star (green) mergers detected via gravitational waves between September 2015 and October 2019. Gray and blue denote black holes and neutron stars, respectively, known via emitted light.

GRAVITATIONAL WAVES

Big Black Holes Dominate New LIGO-Virgo Catalog

THE LIGO AND VIRGO collaborations have unveiled a new catalog of gravitational-wave detections from the first half of their third observing run (April to October 2019), which was posted October 27th on the arXiv preprint server. The 39 new detections raise the total number of collisions to 50 and reveal a surprising number of massive black holes.

Before LIGO, astronomers had predicted a dearth of black holes from about 50 to 130 solar masses. Such massive stellar cores ought to tear themselves apart, leaving nothing behind. But now, scientists have detected seven cataclysms involving a black hole of at least 50 Suns; one whopper tips the scale at about 90 solar masses.

That surprised LIGO scientist Maya Fishbach (Northwestern University). "It could be that there's a subpopulation that's actually contaminating the gap," Fishbach says. A previous generation of mergers, rather than dying stars, might have made these larger black holes.

Or, perhaps stars find various ways to stave off their explosive destruction. Stan Woosley (University of California, Santa Cruz) is among those diving into this second possibility. By making reasonable changes to stellar models, he says, it's possible to nudge the lower boundary up to about 65 solar masses — explaining all but one of the gravitational-wave sources. But no one knows quite what to do with the 90-solar-mass black hole. "That's right in the middle of the forbidden zone," Woosley says.

One way to find out the provenance of big black holes is via their spins. For example, black holes born in a binary should spin like tops around each other, while a pair that has adopted each other later on would be more likely to have a random assortment of inclinations. The catalog's spin data suggest that roughly a third of the black hole pairs were not born as binaries.

The new catalog also seems to show a gap at lower masses, Fishbach says. "But it's a messy picture," she cautions. "We're not sure where the gap is, and we're not sure if the gap is empty." This picture will become clearer when data analysis from the second half of the third observing run becomes available.

■ CAMILLE M. CARLISLE

THE MOON

China Launches Sample-return Mission to the Moon

A LONG MARCH 5 ROCKET roared to life in the predawn hours of November 24th (local time) as it launched China's ambitious sample-return mission, named Chang'e 5, to the Moon. The lander touched down in Oceanus Procellarum on December 1st. Beginning around local lunar sunrise enabled the solar-powered spacecraft to maximize its time during the lunar day, which lasts two Earth weeks.

The China National Space Administration chose a landing site near Mons Rümker, a young volcanic formation. The Rümker plateau rises as high as 1,300 meters (4,300 feet) above the surrounding lunar plain and contains basalts billions of years younger than those collected from the Apollo and Soviet landing sites. The lander carries a suite of scientific instruments, including cameras, a spectrometer, and ground-penetrating radar, to explore its environment.

On December 2nd, Chang'e 5's robotic arm drilled 2 meters into the lunar regolith for sample collection. The primary goal was to bring back at least 2 kilograms (4.4 pounds). Then, on December 3rd, the ascent vehicle launched from the Moon's surface, and on December 5–6, it transferred its sample to the service module in lunar orbit. This module will then bring back the sample for a touchdown on December 16–17 over Inner Mongolia. If all goes successfully, this will be the first lunar sample return in 44 years.

■ DAVID DICKINSON

MERGER CHART: GREGG DINDERMAN / *S&T*, SOURCE: LIGO-VIRGO / NORTHWESTERN UNIVERSITY / FRANK ELAVSKY / AARON GELLER; CHANG'E 5 LANDING: CNSA / CLEP

MILKY WAY

Stellar Fossils Reveal "Kraken" in Our Galaxy's Past

A RECONSTRUCTION of the Milky Way's history finds that our galaxy has absorbed at least five large satellites since its formation. Diederik Kruijssen (Heidelberg University, Germany) and colleagues pieced together the details in October's *Monthly Notices of the Royal Astronomical Society*.

Kruijssen and colleagues examined *globular clusters*, ancient balls of densely packed stars. A subset of these have trajectories that suggest they're strangers in a strange land. They also have a paucity of elements heavier than hydrogen and helium, indicating an origin in smaller galaxies. These globulars accompanied satellites as they were subsumed by our larger galaxy.

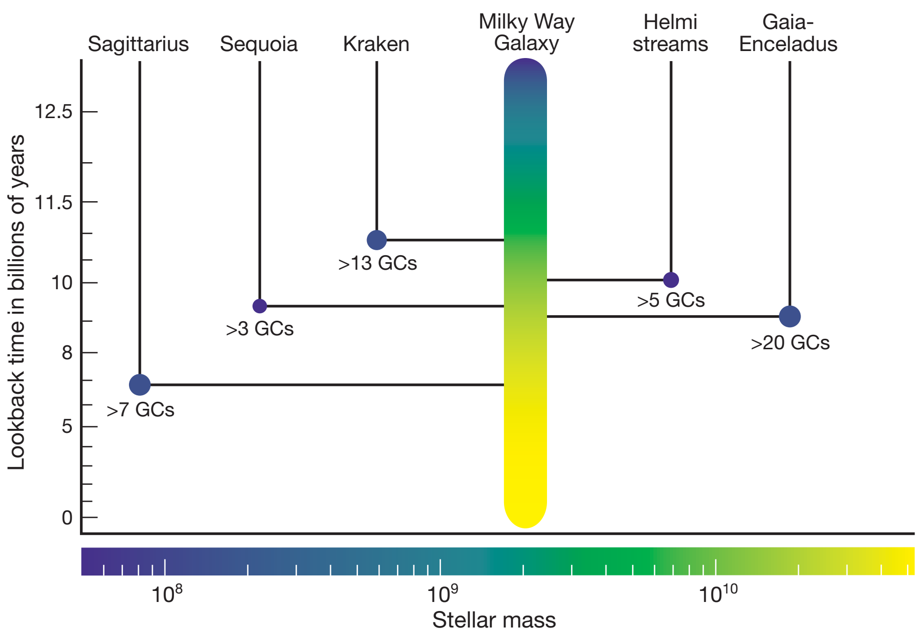
To understand where — and when — the Milky Way's globular clusters came from, Kruijssen's team turned to a set of zoomed-in cosmological simulations called E-MOSAICS. These simulations show the evolution of Milky Way-like galaxies as they cannibalize smaller satellites, subsuming their globular clusters. Kruijssen and his colleagues used E-MOSAICS to train an artificial neural network to relate globular cluster properties to their galaxy of origin. They then turned the neural network on our own galaxy's globulars.

The result is a history of our most significant mergers with other galaxies, starting with one dubbed "the Kraken," which collided with our galaxy around 11 billion years ago. A billion years later came a smaller galaxy whose remains appear as a rivulet of stars dubbed the Helmi streams. Two mergers followed with galaxies nicknamed "Sequoia" and "Gaia-Enceladus." The most recent acquisition was the Sagittarius dwarf, which joined us 7 billion years ago.

Gaia-Enceladus was the largest of the newcomers, but the Kraken came in when the Milky Way was four times less massive. "The collision with Kraken must have truly transformed what the Milky Way looked like at the time," Kruijssen explains.

Helmer Koppelman (Institute for Advanced Study) calls the study "fascinating" but says there are caveats associated with using simulations of "Milky Way-like" galaxies. "This 'average' galaxy might not exist," Koppelman says. Further observations will test these simulations' accuracy.

■ MONICA YOUNG



▲ This merger tree shows when five satellite galaxies collided with the Milky Way. Each one is labeled with the number of globular clusters (GCs) brought with it. Collision times are approximate.

LEAH TISCIONE / *S&T*, SOURCE: D. KRUIJSSEN ET AL. / *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY*

IN BRIEF

Streetlights and Pollution

A study led by Christopher Kyba (GFZ German Research Center for Geosciences) shows that while streetlights are an important source of light pollution, they're far from the only culprits. The city of Tucson, Arizona, has connected more than 19,000 LED streetlights in a "smart city" control system. From March 29 to April 7, 2019, Kyba and colleagues manipulated public lighting in Tucson, then took overhead images using the Suomi National Polar-orbiting Partnership satellite. They found that Tucson's streetlights contribute less than 20% of light escaping to space; the rest comes from other light sources such as parking lots and billboards. Tucson's streetlights have full cut-off shielding, which gives the city darker skies than most; nevertheless, the study, published October 28th in *Lighting Research & Technology*, suggests that fixing streetlights does not fix light pollution. John Barentine (International Dark-sky Association) and colleagues measured sky brightness from the ground, confirming these conclusions in the September *Journal of Quantitative Spectroscopy & Radiative Transfer*.

■ JAN HATTENBACH

"Minimoon" Is a Rocket

A piece of history has paid Earth a visit. In September the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) spotted a 6-meter object, designated 2020 SO. By November, Earth had captured this object as a temporary "minimoon." However, the object was unusual among natural near-Earth objects: Its solar orbit aligned with Earth's orbit, and additional observations showed that solar radiation pressure was pushing 2020 SO like an empty aluminum can on a windy day — indicative of a hollow object. Paul Chodas (Center for Near-Earth Object Studies) ran back the clock and found 2020 SO was last near the Earth-Moon system in late 1966 — timing that coincides with the launch of the ill-fated Surveyor 2 mission to the Moon. While Surveyor 2 crashed near Copernicus Crater, its spent Centaur upper-stage rocket missed the Moon and headed out into solar orbit. Follow-up spectroscopy using the Infrared Telescope Facility found the same specific type of stainless steel as rocket boosters were made of in the 1960s, confirming the identification.

■ DAVID DICKINSON

Adiós, Arecibo

On the painful loss of an iconic Space Age observatory

EVEN AS A KID I KNEW of a place called Arecibo, a mysterious facility in the jungle where astronomers peered into outer space and searched for alien transmissions. When I could understand basic geometrical concepts, I learned how a giant parabolic dish built into a sinkhole could gather and concentrate diffuse radiation from distant sources that would otherwise have fallen unseen in the surrounding rainforest, focusing it to a point where its power was sufficient to reveal the previously unseeable.

In the 1960s and '70s, as interplanetary craft were first setting out for our neighboring worlds, this magnificent instrument in northwestern Puerto Rico was also extending our human senses to heretofore hidden places and wavelengths. In magazine pictures, its perfect, curving dish and monumental support structure seemed like a futuristic synthetic eye of outrageous proportions. With it, we could seek answers for our nagging curiosity and antidotes to our cosmic loneliness.

As a young space geek, I learned that scientists had used Arecibo to determine the rotation rate of Mercury, discover the tallest mountain range on cloud-shrouded Venus, and, beyond our solar system, reveal neutron stars, binary pulsars, and other astrophysical marvels. I grew up on stories of Frank Drake, Carl Sagan, and Jill Tarter listening for alien signals there and sending out a few symbolic messages of their own. I admired Arecibo's role as planetary defense sentinel, identifying and tracking Earth-crossing asteroids.

▼ Puerto Rico's giant eye on the sky: Arecibo Observatory as it appeared during its heyday

ARECIBO OBSERVATORY / NSF

In short, for me as for so many others, Arecibo was iconic long before Hollywood filmmakers used it as a dramatic backdrop in *Contact* and *GoldenEye*.

Later in life, I made a pilgrimage there. I walked those vertiginous catwalks out to the receiver suspended 450 feet above the dish by 18 cables running from three giant towers. When I visited, in 2012, it wasn't shiny and new. The dish's surface looked a bit moldy, some of the hardware seemed a little rusty, and the surrounding jungle appeared ready to swallow the whole place up. The control rooms, with their huge transformers and racks of computer equipment, looked very mid-20th century, like something, well, out of a James Bond movie.

Yet scientists were still doing cutting-edge science there, and I shared the dismay of so many when I learned on December 1st that our beloved mystery portal, in desperate need of repairs and already teetering dangerously from two recently broken support cables, had suffered an irreparable collapse (see page 8).

Similar work will continue at other large radio dishes on Earth, but what we really want to know is if others exist elsewhere in the galaxy. Would minds evolving out there have converged on the same idea, to parabolically gather waves so that they may interrogate our shared galaxy and perhaps come to know us?

My whole life I've tried to picture those alien Arecibos and wondered if — like that transporter machine in *Contact* — ours might be an aperture across the galaxy to theirs. Now I wonder what will happen to Arecibo. Will the jungle reclaim it? Will it one day be an archeological site where visitors (Earthlings or otherwise) will marvel that there was once a civilization that valued science and exploration enough to build such a wonder but not quite enough to keep it going for more than two Saturn years?

■ Contributing Editor **DAVID GRINSPOON** is an astrobiologist and senior scientist at the Planetary Science Institute in Tucson, Arizona.

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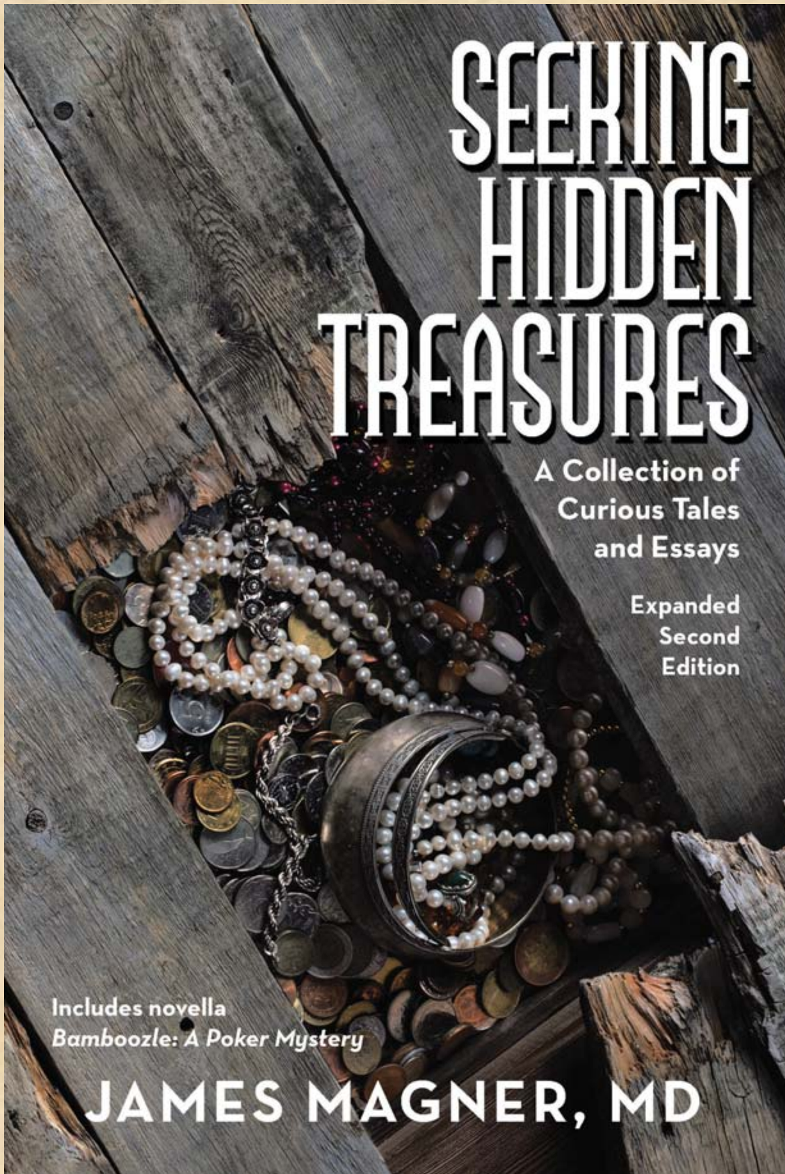

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– Leonard Engel, Professor Emeritus of English, Quinnipiac University

Photo by Peter Hvizdak, *Connecticut Magazine*

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Professional and amateur astronomers are working to understand why the famed red supergiant faded so dramatically.

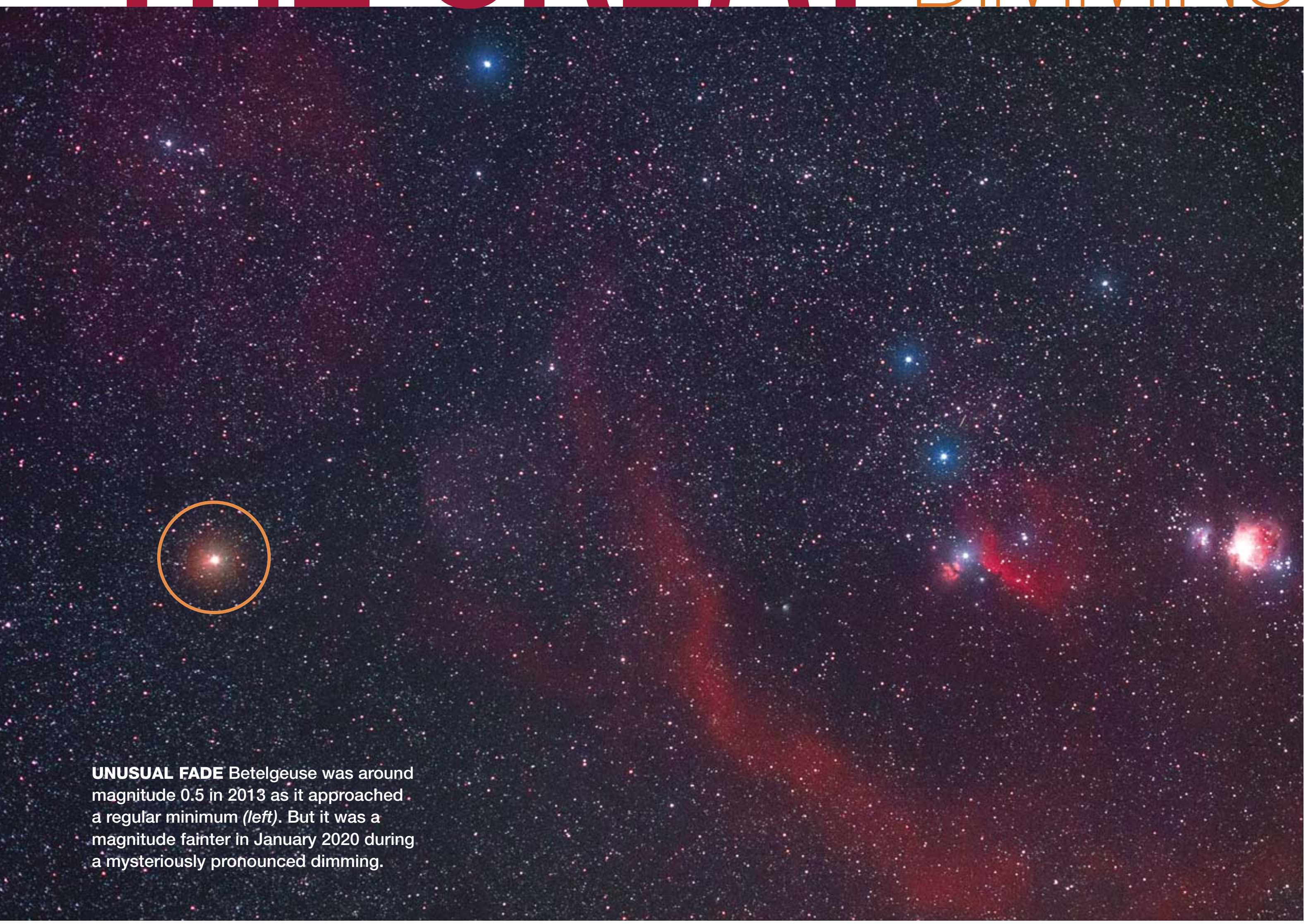
Betelgeuse has become a star — a media star, that is. Never in modern times has so much public attention been paid to a distant sun that *hasn't* exploded. Astronomers have been keenly interested in Orion's alpha star for some time (for example, *S&T:* May 2019, p. 34), but now it's a subject for the newspapers.

Betelgeuse is a *red supergiant* (RSG), a swollen, puffy star nearing the end of its life. These gigantic stars produce an abundance of dust, seeding interstellar space with various atomic elements. We still don't understand exactly how they disperse their chemical bounty. This is partly because red supergiants are so few, and so many of them are so far away. Betelgeuse, being nearby, is our backyard RSG laboratory.

But that's not what brought Betelgeuse into the spotlight. Between October and December 2019, the star's ruddy glow plummeted, then kept on fading. Popular speculation abounded that it was about to go supernova.

BABAK TAFRESHI (2)

THE GREAT DIMMING

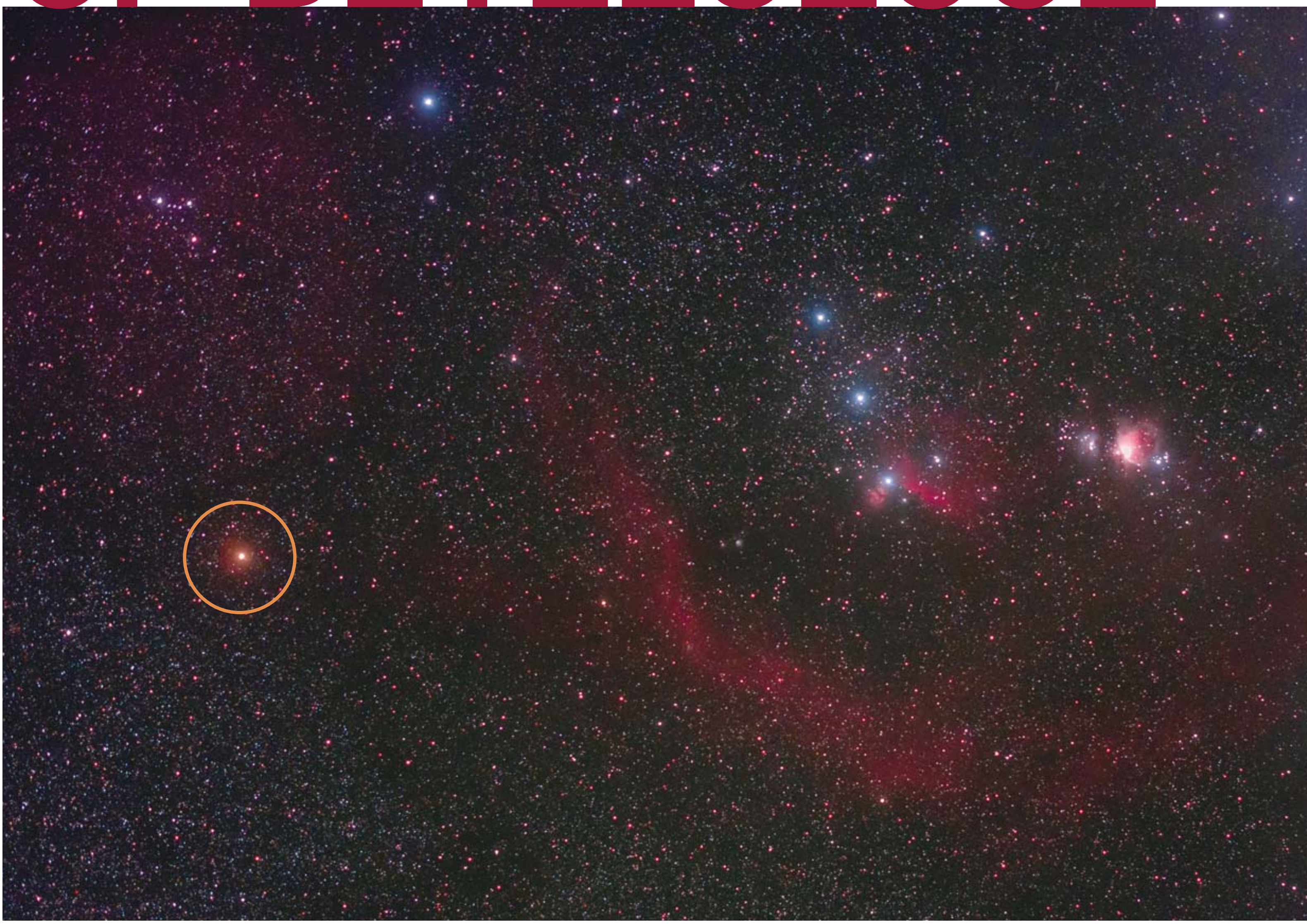


UNUSUAL FADE Betelgeuse was around magnitude 0.5 in 2013 as it approached a regular minimum *(left)*. But it was a magnitude fainter in January 2020 during a mysteriously pronounced dimming.

The "Great Dimming" electrified both amateur and professional astronomers. Members of the American Association of Variable Star Observers (AAVSO) have followed the star for decades, and professionals regularly refer to AAVSO's data to add context to their own investigations. With such instruments as Hubble, ALMA, and the Very Large Telescope (VLT) at their disposal, the pros can probe slivers of the Betelgeuse spectrum in exquisite detail. But for overall measures of brightness, they often depend on the modest tools of amateurs, whose instruments are not saturated by the star's intense light.

I lead an AAVSO observer group that was in on a campaign called the Months Of Betelgeuse, coordinated by Andrea Dupree (Center for Astrophysics, Harvard & Smithsonian). Known as the MOB, they are a loose association of professional astronomers in the Americas and Europe. Our group provided the MOB with precise brightness measurements throughout Betelgeuse's strange episode, using a technique known as *photoelectric photometry*. Together, the pros and amateurs saw the supergiant dim and recover, watching from vantage points on Earth and in space.

OF BETELGEUSE



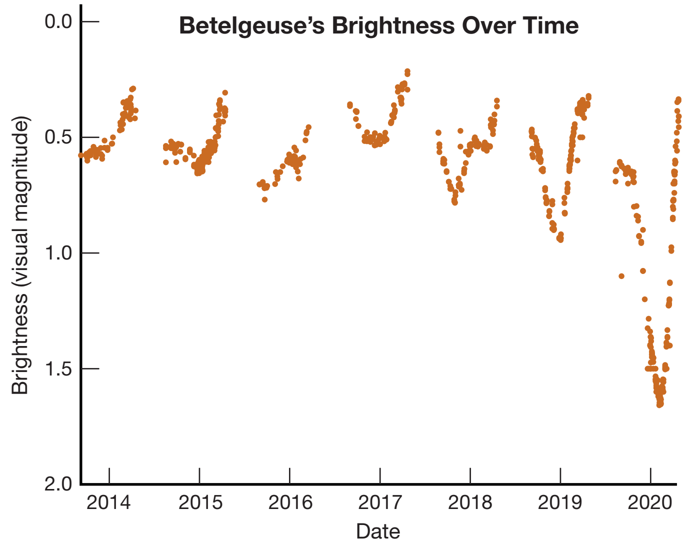
Inherently Inconstant

A red supergiant starts out with a mass about 8 to 40 times that of the Sun. On the main sequence, it furiously fuses hydrogen to helium for perhaps 1 to 10 million years. The core finally fills up with helium, and hydrogen fusion stops. No longer supported by an outward flow of energy, the core contracts and heats up dramatically.

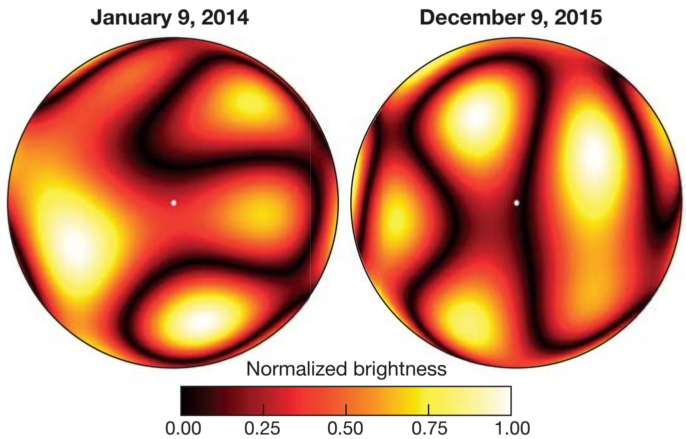
Around the outer core, the temperature rises high enough to restart hydrogen fusion in a surrounding shell. Within the core, the temperature will rise even higher, beginning the fusion of helium into carbon and then oxygen. As the core shrinks, the outer envelope expands to incredible proportions, a process — not fully understood — called the *mirror effect*.

We think Betelgeuse is in this helium-fusing stage. After its central supply of helium is exhausted, the core will go through a series of flameouts, contractions, and re-ignitions that finally create a nickel-iron center that can produce no more energy. A collapse will follow, and likely a fantastic explosion, treating earthlings to a spectacular sky show (see box below).

Almost all red supergiants are variable stars, changing in brightness over time. Some of them literally pulsate, expanding and shrinking over periods typically lasting hundreds of days.



▲ **ABNORMAL MINIMUM** Betelgeuse's brightness varies on multiple time scales, and its dips every 420 days or so are fairly predictable. But the fade it experienced in late 2019 and early 2020 was like nothing astronomers have seen from the star. These data from AAVSO observer Wolfgang Vollmann show about seven years' worth of photometric data.



▲ **GIANT CELLS** Based on polarization patterns in Betelgeuse's light, these simulated images show the star's slowly overturning surface in January 2014 and December 2015.

Betelgeuse currently pulsates over about 420 days, but its brightness also varies on a cycle of 2,000 days (5½ years). Many RSGs exhibit such a *long secondary period* (LSP), the cause of which is unclear. Repeated upwellings of hot material from deep inside the star may drive this slow variation. Giant, hot convection cells rise to the top, each one covering so much area that they collectively change the surface's temperature distribution.

Astronomers have indirectly detected convective cells on Betelgeuse. Using the 2-meter Bernard Lyot telescope in the French Pyrenees, Arturo López Ariste (University of Toulouse, France) and others studied Betelgeuse from 2013 to 2018. With specialized equipment, the researchers inferred the presence of huge regions of upwelling bright material edged by sinking, cooler material, and they mapped out these hotspots. Further evidence from Doppler shifts enabled them to also estimate the velocities of the updrafts and downdrafts — about 20 km/s (45,000 mph). The cells may take a few years to finish rising, much longer than the day-long time scales of similar motions in the Sun.

WILL BETELGEUSE EVER GO SUPERNOVA?

It might seem a silly question, but astronomers aren't certain Orion's red supergiant will have a spectacular demise. Observations haven't turned up clear examples of supernovae from red supergiants born with more than about 20 solar masses. (Betelgeuse is potentially below that limit, but astronomers don't know for sure.) It's possible stars above the limit instead implode directly into a black hole, perhaps due to how the star burns its carbon. Alternatively, the larger stars might lose enough material as they age that they evolve into hotter yellow or blue supergiants before exploding.

—CAMILLE M. CARLISLE

CONVECTIVE CELLS: A. LÓPEZ ARISTE ET AL. / *ASTRONOMY & ASTROPHYSICS* 2018; BRIGHTNESS GRAPH: *S&T* DIAGRAM, SOURCE: WOLFGANG VOLLMANN / AAVSO

The Data

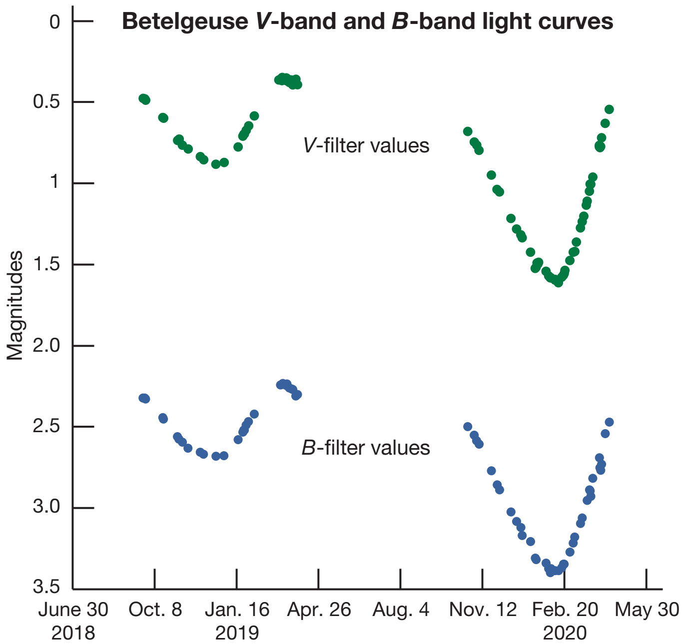
Between pulsation and convection, Betelgeuse has a long history of brightness variation. But the Great Dimming and the minimum it reached in February 2020 before rebrightening was extraordinary, causing much excitement in the scientific community.

The 2018 minimum of the 420-day cycle occurred near Christmas, so observers expected the next minimum about mid-February of 2020. But by the end of November 2019, the star had already broken through the 2018 low and was clearly headed lower. In early December, MOBster Ed Guinan (Villanova University) sent out an Astronomical Telegram to alert those scientists who had not already noticed.

The buzz grew. The American Astronomical Society (AAS) annually stages its big meeting for professional astronomers in early January. As attendees began gathering in Honolulu in 2020, I was getting urgent emails from the MOB: *Tom . . . What's it doing? . . . What's it doing?* The AAS conference held a special session to discuss the latest developments, and soon after, Betelgeuse was featured in the *New York Times*.

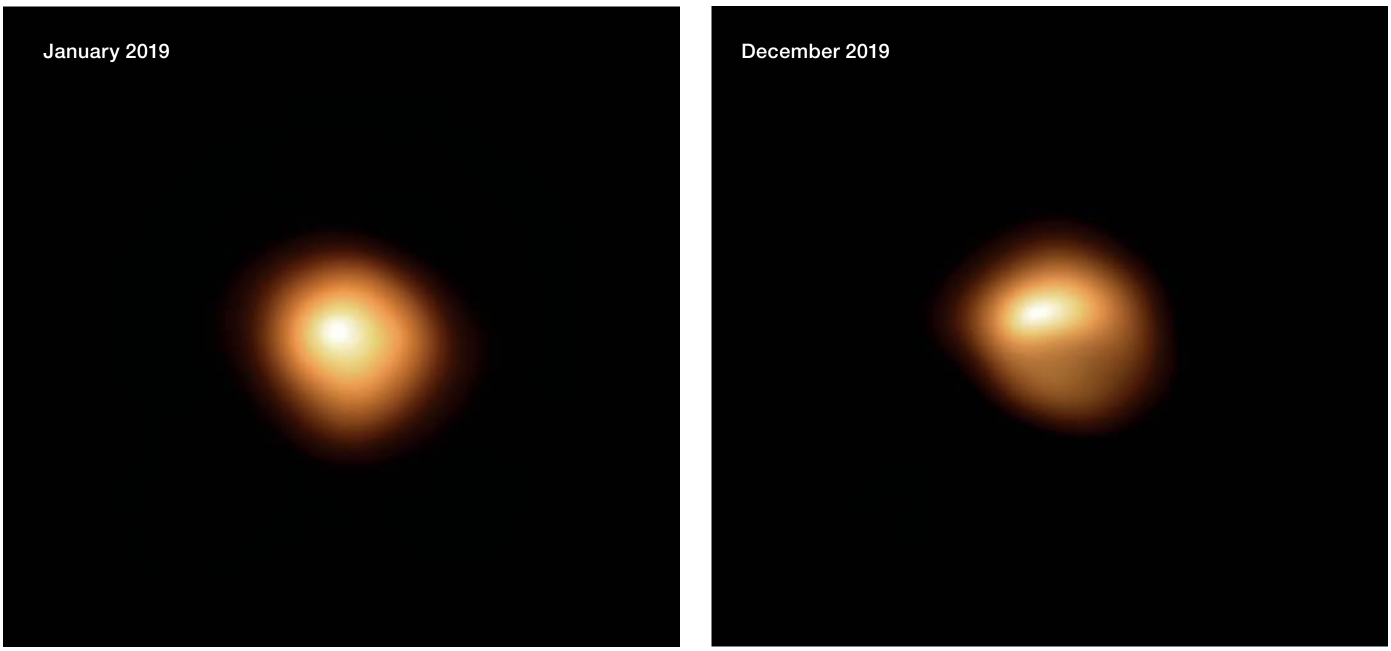
The iconic image of the Great Dimming was provided by Miguel Montargès (then of KU Leuven, Belgium) and others using the VLT. Taken in December 2019, it shows the southeast of Betelgeuse starkly fainter than the rest of the star. A similar picture from January 2019, when Betelgeuse was near its prior minimum, showed no such contrast.

But the Great Dimming is best summed up in a *light curve*, a graph showing the brightness of the star over time. Astronomers work with light curves taken through standard color filters that reveal how the star looks at different wavelengths. Here are *V* (green) and *B* (blue) light curves that I gathered with a photometer during 2018–2020. The *V* filter approximates the sensitivity of the human eye. In 2018, Betelgeuse dimmed to a *V* magnitude of 0.88, whereas in 2020, it bottomed out at 1.61 — an additional 50% drop in brightness.



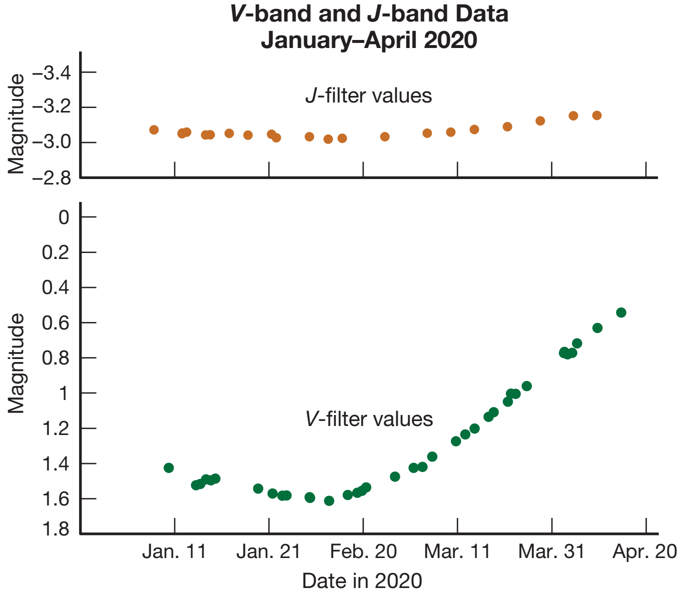
Why take data in different colors (known as *bands*)? Because the star's behavior may manifest differently at one wavelength compared to another, potentially revealing interesting information. For example, my group has photometers

▼ **PIECEMEAL DIMMING** These VLT images show Betelgeuse as it looked shortly after its 2018 minimum *(left)* and partway through its abnormal minimum in 2019–20 *(right)*.



LIGHT CURVES GRAPH: GREGG DINDERMAN / *S&T*, SOURCE: THE AUTHOR; BETELGEUSE BEFORE AND AFTER: ESO / M. MONTARGÈS ET AL.

that take data in the near-infrared (NIR). Compare the shape of the two light curves below, starting in January 2020 when we first began observing in the *J* band (1.25 microns) of the NIR. AAVSO member Jerry Persha took the *J*-band data.



While *V*-band brightness changed dramatically, the *J*-band data scarcely budged. Whatever affected the visible light had little effect on the infrared radiation, and that's a clue to the physics at work.

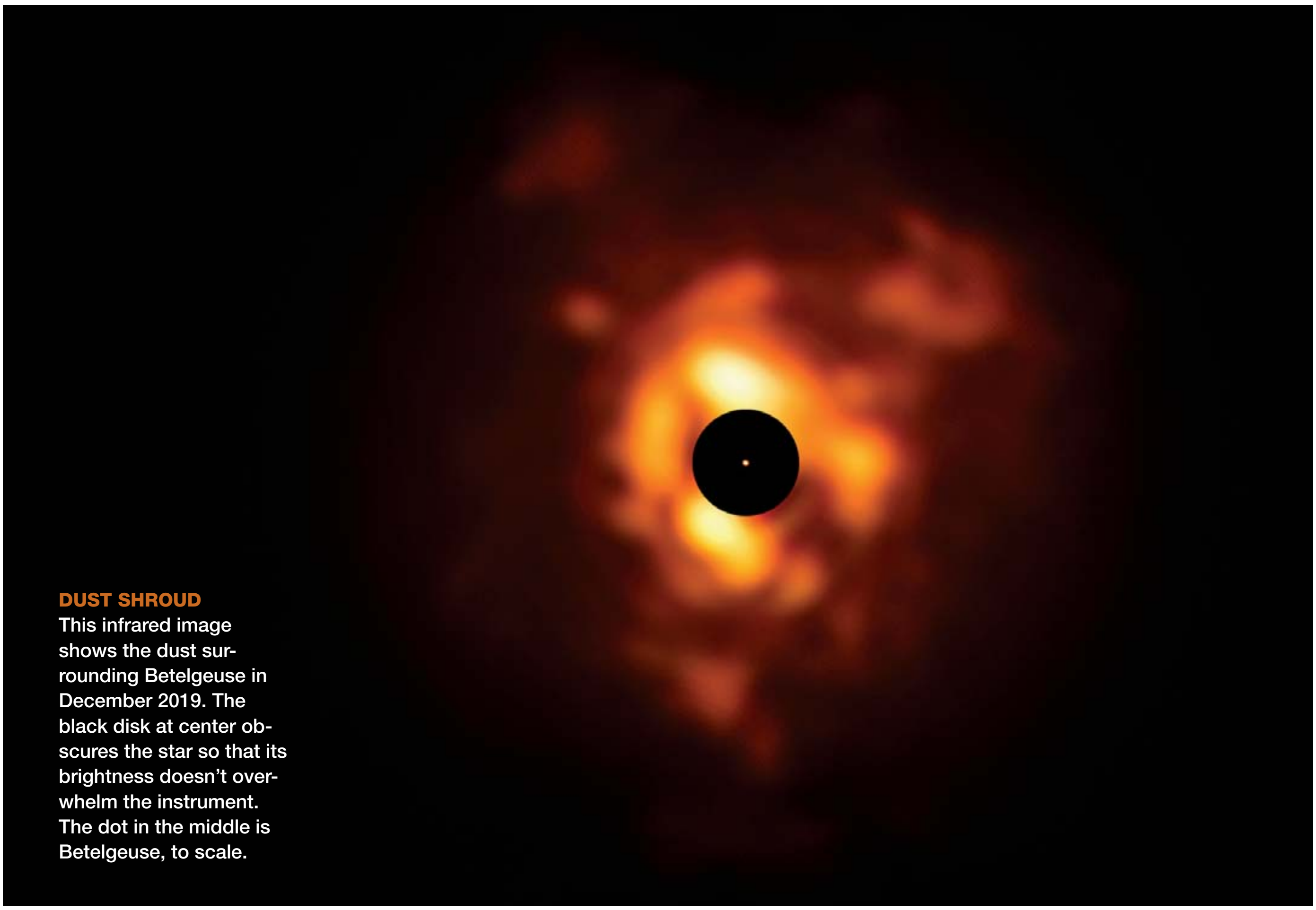
Based on the professional and amateur data in hand, two main theories are competing to explain the fade of Betelgeuse: a burst of new dust that partially obscured the star, or an unusual drop in its surface temperature.

Peeling the Onion

Before we explore these theories, let's have a look at the outside layers of Betelgeuse. The visible surface of a star is called its *photosphere*. In truth, it's not a surface at all (nothing could rest upon it). The photosphere is where the atmosphere of the star becomes opaque to our vision. It looks like a surface because we cannot see through it.

The photosphere of the Sun is about 5800 kelvin, so hot that barely any molecules can survive there. Betelgeuse, on the other hand, has swollen up so large — spreading its heat over so much area — that its surface is only about 3650K. The low temperature permits an assortment of compounds, such as titanium oxide (TiO), to exist in gaseous form.

Above the photosphere of our own Sun lies the *chromosphere*, a shell of very hot, very thin gas. But the chromo-



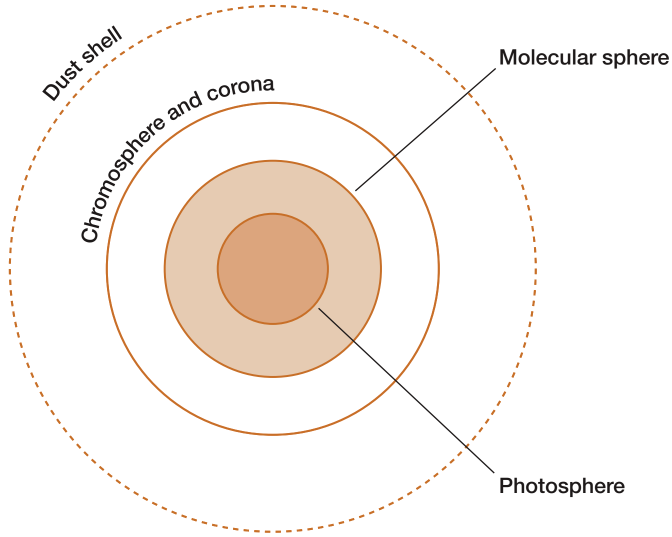
DUST SHROUD
This infrared image shows the dust surrounding Betelgeuse in December 2019. The black disk at center obscures the star so that its brightness doesn't overwhelm the instrument. The dot in the middle is Betelgeuse, to scale.

V- AND J-BAND DATA: GREGG DINDERMAN / S&T, SOURCE: THE AUTHOR; DUST SHROUD: ESO / P. KERVELLA / M. MONTARGÈS ET AL.

sphere of Betelgeuse is sandwiched between two layers the Sun lacks: a *molecular sphere* (or MOLsphere) below, and a dust shell above.

The MOLsphere is a recently discovered oddity of Betelgeuse, a region richer in gaseous molecules than the photosphere, which is how it gets its name. In our own Sun, it's a puzzle how the chromosphere becomes hotter than the photosphere below it. But in Betelgeuse the mystery is compounded, for the MOLsphere separating the photosphere and chromosphere is cooler than both of them.

The dust shell is the end-product of mass loss in an RSG. Astronomical dust is not the fluff under your couch. It consists of tiny solids that have condensed from material that has escaped from a star. Within the star, all material is gaseous, even metallic elements like aluminum and magnesium. On the surface of a cool star like Betelgeuse, the molecules, too, are in the form of gases. But if the atoms and molecules can leap off and migrate to a cooler area, they then have the chance to stick together and form grains such as silicon monoxide (SiO) or aluminum oxide (Al_2O_3). These grains are accelerated by unknown means and fly out to enrich the composition of interstellar space (*S&T:* Dec. 2020, p. 34).



▲ **EXTRA LAYERS** Betelgeuse's atmosphere has two regions the Sun's doesn't: a molecular layer and an outer dust shell. The perimeter of the real dust shell is highly irregular, and the different layers flow into each other as in a melting dessert. The diameter of the photosphere is about the size of Jupiter's orbit around the Sun.

GREGG DINDERMAN / *S&T*

Witnesses for Dust

In the temperature versus dust debate over the cause of the Great Dimming, Emily Levesque (University of Washington) and Philip Massey (Lowell Observatory) staked the first claim. Using a spectrograph on the 4.3-meter Lowell Discovery Telescope, they determined that the surface temperature in February 2020 was not much lower than it had been in March 2004, when the star was of normal brightness.

Earthbound astronomers cannot, of course, stick a thermometer into a distant star — the measurement was indirect. Levesque and Massey examined absorption features caused by titanium oxide (TiO) in Betelgeuse's atmosphere. TiO molecules start forming at about 3800K, and they become more prevalent as the star gets cooler, absorbing ever more light. The researchers didn't see big changes in the TiO lines compared to 2004, suggesting that the temperature had changed little since then.

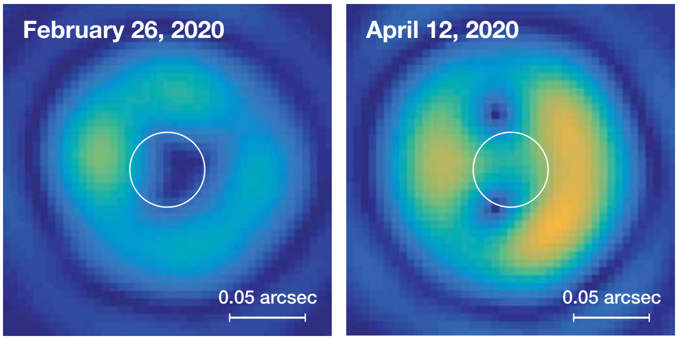
Professional astronomers also found evidence in support of dust by studying polarized light coming from the envelope around Betelgeuse. When sunlight reflects off the surface of a lake or the hood of your car, it becomes partially polarized, with the light waves vibrating at only certain angles. This is why polarized sunglasses are so helpful when driving or boating on a sunny day. Starlight reflecting off dust also becomes partially polarized. A team led by Boris Safonov (Lomonosov Moscow State University, Russia) imaged Betelgeuse with an instrument that picks out polarized light from an unpolarized background — sort of like sunglasses in reverse. Their data showed a big increase in polarized light as Betelgeuse recovered from its minimum. The interpretation was that, first, dense dust had formed, blocking light and causing the star to fade. Then, as the grains spread out enough for light to pass, a fresh wave of polarized reflections emerged from a newly enriched dust zone.

Observations suggest an ejection of material happened around the same time, which might be a source of dust. Betelgeuse has been shedding mass for eons, as we can see from the great cloud of dust that surrounds it. Dupree and others discovered signs of a recent expulsion by using Hubble's Space Telescope Imaging Spectrograph (STIS) to take ultraviolet spectroscopy of the chromosphere. The Hubble team scanned across Betelgeuse with the STIS, sampling narrow rectangles to build a kind of map of the star in UV. The spectra indicate that the southeast chromosphere experienced a shock throughout its levels during the fall of 2019. This is consistent with a burst of material passing through the chromosphere, material that could have condensed upon emerging and cooling.

But the ultraviolet data cannot reveal fresh dust, if any actually formed. And since we don't know how fast the material was moving through the chromosphere, we don't know when it would have reached a zone cool enough for condensation to occur.

Research is now turning toward *rogue cells*: unusually strong upwellings that could have the energy to push material off the photosphere. Rather than create a uniform circumstellar envelope, the result would be a kind of Swiss cheese, with pockets of new, hot gas injected into a generally cooler environment. The chromosphere does, in fact, appear to have regions of high temperature that occupy only a fraction of that layer. Dupree speculates that Hubble caught an outflow caused by a particularly powerful cell surfacing just as an outward pulsation peaked.

Cross Examination



◀ **POLARIZATION** Images reconstructed from polarized light data show that the amount of polarized light from Betelgeuse's dust-laden wind increased after the star's minimum in February 2020. The polarization intensity indicates how much light is scattering off dust. The change could be due to a change in the amount of dust, or in the illumination. The white ring shows the size of Betelgeuse.

But the dust explanation has some problems. The dimming of Betelgeuse aligned very nicely with the primary variation period of 420 days. How did a dust event synchronize itself with the pulsations? It is plausible that the star's regular expansion helped push material out of the star, but it's difficult to see how the dust would know to disperse right on schedule.

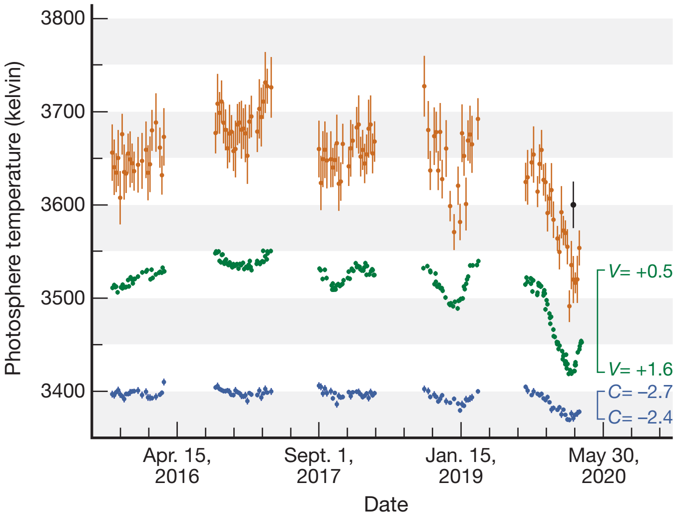
And if dust absorbed a great deal of visible light, where did that energy go? Dust that captures optical radiation should re-radiate some of it as infrared light, boosting the overall infrared brightness. Yet the near-infrared AAVSO data do not show this, nor do broader infrared data from the O'Brien Observatory of the University of Minnesota, taken by Robert Gehrz and others.

Lastly, Thavisha Dharmawardena (Max Planck Institute for Astronomy, Germany) and others observed Betelgeuse in submillimeter-band radio. That radiation would not be affected by dust and should stay fairly constant if the stellar temperature were stable. But they saw the brightness drop by about 20% compared to the pre-dimmed level.

These data raise the question of whether the near-constant temperature inferred from the spectrum is correct. The 2020 spectrum largely matches a computer-modeled spectrum for 3600K. This model assumes a uniform temperature across the disc. But what if the temperature distribution is uneven? Hot regions would be less affected by TiO absorption, filling the TiO bands of the whole-disc spectrum with light that would wash out deeper absorption features in the cool areas. Cool zones, by contrast, would radiate less total light than the average temperature would indicate.

Such a "dilution" of the light is the conclusion of Graham Harper (University of Colorado, Boulder) and others. Graham's team studied the TiO absorption using a different method. The average temperature of Betelgeuse they calculate is lower than that inferred by Levesque and Massey. Given that Levesque and Massey did detect emission characteristic of gas at about 3600K, a significant fraction of the surface must be substantially cooler — about 3300K. That would be sufficient to explain the dimming.

We can visualize the competing models by returning to the strange December 2019 image of Betelgeuse. In the dust model, the southeast is partly obscured by dust, while in the temperature-drop model, the southeast has cooled off. The results of Harper's team imply that the analysis of Levesque and Massey applies only to hot, bright areas of the surface, not the whole star.



▲ **TEMPERATURE FLUCTUATIONS** The amount of light absorbed by titanium oxide in a red supergiant's atmosphere is a good indicator of the photosphere's average temperature. Using a combination of near-infrared filters, Graham Harper and others measured TiO absorption (brown) in Betelgeuse's light over several years and found that the star's temperature dropped notably during the Great Dimming. Light curves in *V*-band (green) and an infrared band (blue) are also shown for reference, with the magnitude extremes for the 2019–20 event. (The TiO and infrared data are averaged into 7-day bins.) A study by Levesque and Massey used TiO absorption at shorter wavelengths to estimate a higher temperature (black dot). Perhaps regional temperature changes are at work.

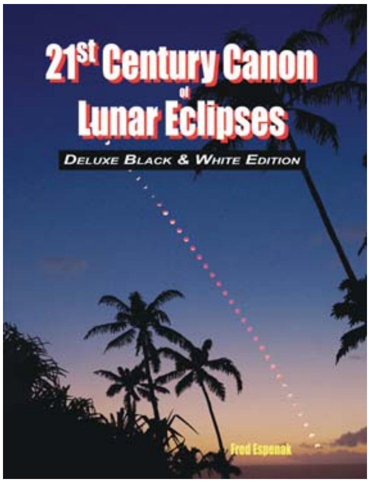
The Jury Is Out

The verdict on the Great Dimming remains under deliberation. Data from the last observing season are still under analysis, with more scientific papers in the publication pipeline.

Betelgeuse is a complex beast, and I have only scratched the surface of the story. The contention between various researchers using different instruments (more than are mentioned here) can feel like the story of the Blind Men and the Elephant. But although the men are always seen as comical characters, keep in mind that none of them is actually *wrong*. Each draws a conclusion based upon the best information he has. Their collective challenge is to synthesize a common explanation from everyone's data. That's how difficult science gets done.

■ **TOM CALDERWOOD** leads the AAVSO's photoelectric photometry ("PEP") section from the high desert of central Oregon. He can be reached at **pep@cantordust.net**.

POLARIZATION: STERNBERG ASTRONOMICAL INSTITUTE OF LOMONOSOV MOSCOW STATE UNIVERSITY; TEMPERATURE GRAPH: G. HARPER ET AL. / ARXIV: 2011.05982



◀ LUNAR ECLIPSE CANON

Astrophysicist and *Sky & Telescope* contributor Fred Espenak has released *21st Century Canon of Lunar Eclipses – Deluxe Edition* ($29.99 black-and-white, $49.99 full-color). The book contains maps and data for all 228 lunar eclipses occurring during the 100-year span from 2001 through 2100. Predictions are based on the Jet Propulsion Laboratory's precisely calculated coordinates of the Sun and Moon for hundreds of years into the past and future. *21st Century Canon of Lunar Eclipses* also uses a new elliptical model for Earth's shadow, producing the most accurate predictions to date. A series of 228 maps (arranged 12 per page) plot the visibility zones of every lunar eclipse this century. In addition, Appendix C features full-page maps for each eclipse, including detailed path diagrams, duration times, and contact times. 288 pages, 8½ by 11 inches, paperback.

AstroPixels Publishing
P.O. Box 16197, Portal, AZ 85632
astropixels.com/pubs/index.html

◀ IMAGING CONTROL CENTER

PrimaLuceLab unveils its latest version of its popular compact computer for imagers. The EAGLE4 advanced control unit for telescopes and astrophotography (starting at $1,095) is a Windows 10 Enterprise computer designed to control all your imaging accessories. The unit is housed in a CNC-machined aluminum enclosure that mounts directly to your telescope. Users access the operating system through a dual-band Wi-Fi connection to install their preferred camera-control software and device drivers. The EAGLE4 incorporates the new EYE sensor with a 5° field of view to monitor sky conditions where your telescope is pointing. Each unit incorporates four USB 3.0 ports, four USB 2.0 ports, four 12V power sockets, and three variable-voltage power-out ports to individually control up to three dew-prevention heaters.

PrimaLuceLab
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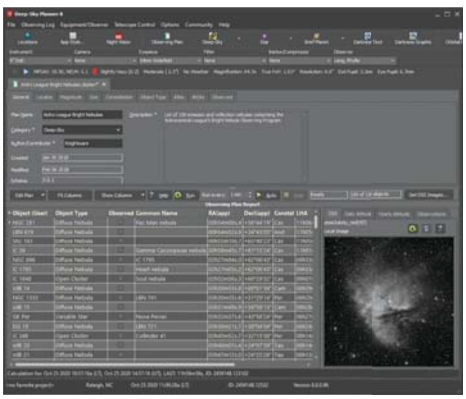


◀ OBSERVING PLANNER

Knightware announces the release of *Deep-Sky Planner 8* ($75 for digital download, $85 for a CD copy). This software lets you take advantage of cloudy nights and daylight hours to plan your evening observing sessions. Users can search through more than 1.6 million objects in the software's extensive database, which provides accurate positions for each object and computes the best time to observe it from your location. This latest revision includes numerous improvements to the user interface and support for high-resolution displays. *Deep-Sky Planner 8* allows you create and export customized observing plans directly to popular Go To navigation systems on PCs or smart devices, or print out your plans or save them as PDFs. The program can also directly control most ASCOM-compatible Go To telescopes and mounts.

Knightware
305 Evans Estates Dr., Cary, NC 27513
knightware.biz

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.

SOLAR SYSTEM RUBBLE by Nola Taylor Redd

HOW DID WE GET THE ASTEROID BELT?

The sparse swath of debris between Mars and Jupiter could tell us more about the solar system's earliest years than the planets themselves.

The asteroid belt divides the solar system in two, with rocky planets near the Sun and giants relegated to the outskirts. Most of the belt's mass is locked up in just four asteroids, massive objects whose origins are under investigation. But this strange dividing line itself holds clues about the early solar system.

Gas and dust left over from the birth of the Sun ultimately became the planets, though scientists are still struggling to understand the steps required (*S&T:* Dec. 2020, p. 34). Main-belt asteroids were long thought to either be a destroyed planet or one that was never born, thanks to interference from Jupiter's gravity. Both theories had the asteroids forming in their current locations.

The discovery of worlds around other stars helped to change that view, as scientists realized that planets didn't necessarily stick around the region where they were born. Suddenly, the early solar system became an interstate highway system where giant planets drove from place to place, pushing material ahead of them as easily as a plow shoves snow. The asteroid belt began to look less like a collection of rejects and more like a refugee camp of material ousted from elsewhere in the solar system.

CASEY REED

"The hard part is figuring out what came from where, because it is all jumbled together," says Sean Raymond (Laboratoire d'Astrophysique de Bordeaux, France). "It's not like a real refugee camp, where you can ask people or look at flags."

Still, the stirred-up mess may make understanding the first moments of planet formation easier. The processes that built planets are exceedingly complex, and it's virtually impossible to rewind the solar system to understand how everything fit together in the first billion years. The asteroid belt — which has remained relatively unchanged since that time — can provide the best look at what happened more than 4 billion years ago. Scientists are using several different frameworks to try to connect modern observations of the belt with its birth.

"It may be that our best hope to try to understand planet formation is to try to understand the composition and nature of all the things implanted in the asteroid belt," says Bill Bottke (Southwest Research Institute, or SwRI).

THE MAIN BELT

The main belt extends from about 2 to 3.3 astronomical units, between Mars (at 1.5 a.u.) and Jupiter (5.2 a.u.). The asteroids in it range in width from about 965 km (602 mi) to less than 10 meters (33 ft).

The Dance of Planets

When astronomers spotted 1 Ceres and its fellow large asteroids in the early 19th century, they quickly came to believe they had found the remains of a torn-up planet. For several decades, they argued about how the destroyed planet, Phaeton, had met its end.

Like the supposed planet, the theory of Phaeton eventually met its demise. As scientists discovered more asteroids, they realized that the asteroid belt had never been a planet. Instead of a destroyed planet, perhaps the belt was a failed one, kept from coming together by Jupiter.

In this picture, the belt started off as much as a thousand times more massive than it is today. Primordial worlds in the region crashed together, grinding one another down to create smaller asteroids and asteroid families. As they interacted with other protoplanets, gas giants, and one another, these asteroids found themselves ejected or destroyed. Some were hurled from the solar system by Jupiter's dominating gravity, while others were sent plummeting into the Sun. Only a fraction of the original asteroids born in the belt would have survived the chaotic first few tens of millions of years of planet formation and evolution.

But subsequent simulations of planet formation revealed that shedding that much mass was more challenging than astronomers originally suspected. In the last 15 years, two strong theories have emerged that may work together, or separately, to explain how to empty the belt.

A related conundrum that theorists had to also solve was the *small Mars problem*. According to classical planetary formation scenarios, Earth and Mars should be roughly the same size. Instead, the Red Planet has less than a sixth the mass of our own world.

"The low mass of the belt is linked to the low mass of Mars," says André Izidoro (Rice University, Texas). Because Mars sits so close to the asteroid belt, the same process that swept away the planet's initial reservoir of building material would also have removed part of the asteroid belt.

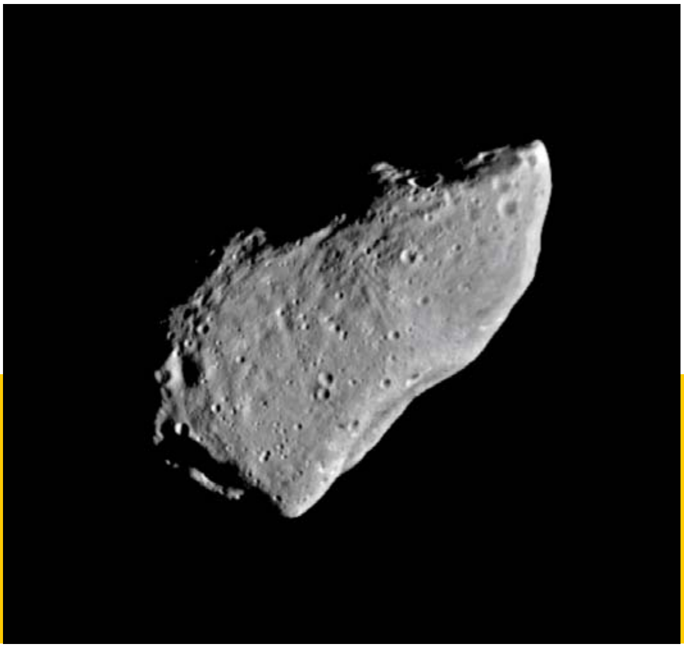
In 2011, researchers proposed the Grand Tack model as a solution to the small Mars mystery. The giant planets formed faster than the smaller terrestrial worlds, their increased mass allowing them to collect even more material in a case of the rich getting richer. According to the model, as Jupiter and Saturn gathered material from the dusty gas disk, they opened up gaps and launched spiral waves. These waves' gravitational influence then moved the two giant planets inward toward the rocky region of the solar system, shepherding icy material along with them.

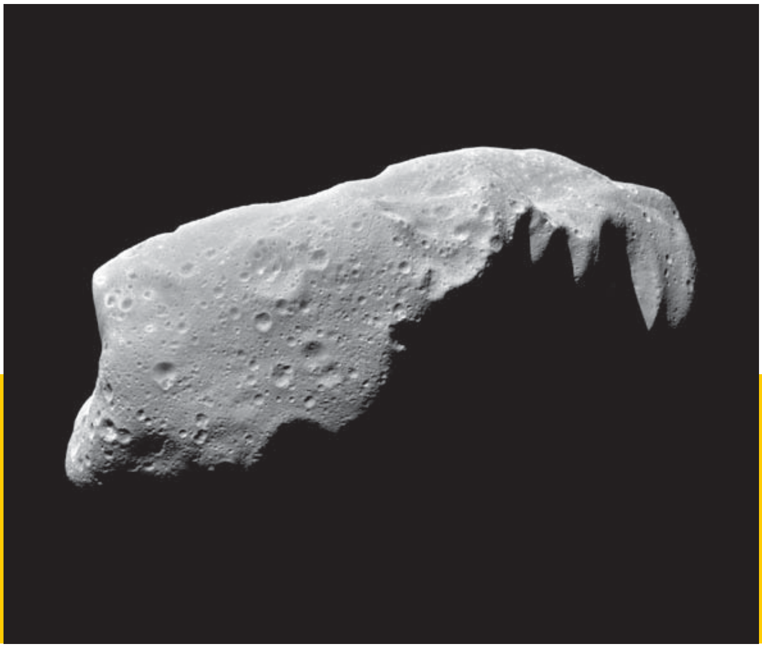
But it wasn't smooth sailing to the inner solar system. As the two worlds edged closer to the Sun, Jupiter encountered the original, more massive asteroid belt. Caught up in the giant planet's gravitational pull, the early asteroids found themselves flung helter-skelter around the solar system. Many were likely ejected, while others were cast into different regions. At the same time, material that would have fed

SPARSE NEIGHBORHOOD

The average distance between two asteroids is about 966,000 km (600,000 mi). That's 2.5 times greater than the distance between Earth and the Moon.

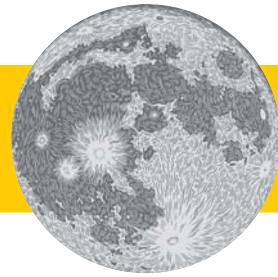
▼ **ODD SHAPES** Among the few asteroids we've imaged up close are *(left to right)* 951 Gaspra, 243 Ida, and 433 Eros. Ida (the largest here) is less than 60 km long. The Galileo spacecraft flew past Gaspra and Ida; Eros was the first asteroid orbited and landed on, by NEAR Shoemaker.





NASA / JPL (2)

The asteroid belt contains **less than 5%** the mass of the Moon.



Mars was tossed out of the Red Planet's reach. Some of the rocks traveled to the inner solar system and collided with the planets there. Eventually Saturn caught up to Jupiter and their two disk gaps merged, shifting the torques on the planets. The giants changed course, tacking like sailboats to return to the outer solar system, with both planets again tossing material willy-nilly.

The Grand Tack emptied the asteroid belt, leaving it an open reservoir for new material. Almost immediately, it began collecting refugees. As Jupiter and Saturn returned to the outer solar system, they interacted again with material they had tossed behind them on their journey in. Most was ejected, but a very small amount — a tenth of a percent — was hurled back towards the asteroid belt, refilling it.

Grand Tack isn't the only theory that explains the small Mars problem, but it is one of the strongest and most-discussed contenders. The model requires a very specific migration path for Jupiter and Saturn, one that strongly depends on the mass ratio of the two planets.

"If Grand Tack happened, then it's really powerful," says David Nesvorný (SwRI). He points out that the model not only covers many features of the asteroid belt and solves the small Mars problem, it also answers several other questions about the solar system, such as why it lacks the super-Earths abundant around other stars (*S&T:* Mar. 2017, p. 22). Determining whether Grand Tack did or did not happen, he says, is "the most important issue there is" in planetary science.

Grand Tack wasn't the first accepted theory to propose that the planets had moved. Early studies in the 1980s also suggested that the giant planets migrated, but astronomers later discarded those theories. In 2005, the Nice model of planetary formation emerged and has continued to evolve over the last 15 years. Named for the French city where the idea was born, the Nice model proposed that the solar system formed from the gas disk with a slightly different configuration. While Jupiter began slightly farther from the Sun, Saturn, Uranus, and Neptune were all closer than they are today, with Neptune closer than Uranus. A fifth world, another ice giant, may also have been present in the chain. Just past the giants sat a handful of planetesimals that weighed as much as 20 Earth masses. As the giants interacted with these planetesimals and one another, they triggered what scientists refer to as an *instability* that caused Jupiter to move, perhaps even jump, inward toward the Sun. The process scattered the other giant planets, perhaps ejecting one or even two ice giants and causing Neptune and Uranus to swap places as they moved outward.

"The composition of the asteroid belt in different places might tell you that a fifth planet existed, and you had to have it to get the asteroid belt," Bottke says. "It could be that having five giant planets is the easiest way to explain certain aspects of the asteroid belt."

But samples from the belt can be challenging to obtain. Most of the meteorites that have found their way to Earth are rocky or iron-rich. Carbon-rich samples from the outer solar system make up less than 5% of the meteorites that make it to Earth. And while there has been evidence that some meteorites once held ice, no frozen water has survived the brutal heat of Earth's atmosphere. That's one reason that the asteroid sample-return missions Hayabusa 2 and OSIRIS-REX are so important (*S&T:* May 2020, p. 14).

The planets weren't the only things moving around in this early era. The dance of the giants would have stirred up the icy objects in the outer solar system, too, pushing most of them out past Neptune to create the modern-day Kuiper Belt. A small percentage were hurled inward to make their new home deep in the asteroid belt. Others found their way into a shared orbit with Jupiter, creating a collection of more than 7,000 Jupiter Trojan asteroids (*S&T:* June 2016, p. 16).

Build-a-World

While some researchers have been probing the large-scale movement of the planets, others have been exploring how the solar system's raw material moves on a smaller scale. The question of how rocky planets coalesce has long puzzled scientists. Astronomers once envisioned a simple process of bigger and bigger rocks colliding with one another. But planetesimals growing from accumulating chunks hit trouble when they reach the meter-size level. Material of that size appears more likely to drift into the Sun than to form worlds, slowing and eventually stopping the movement as the planetesimals grow larger.

MOON: LEAH TISCIONE / S&T; EROS: NASA / JPL / JHU APL

Now researchers think they have the answer in the form of *pebble accretion*. It turns out that small bits sticking together can build a planet faster than large asteroids colliding. These "pebbles" are more easily captured by growing planetesimals than by larger objects simply whizzing by. Although pebbles only add a small amount of mass, they do so far more quickly than a single large collision that can blow a growing world apart.

The original assumptions behind the initial mass of the asteroid belt emerged during the era when scientists suspected high-speed planet growth and a fairly smooth distribution of material in the disk. Pebble accretion brings an alternative: Perhaps the collection of asteroids didn't start off quite so large, after all. After an initial burst of asteroid formation, small pebbles would have drained inward toward the Sun, emptying much of the belt region. But a growing Jupiter might have acted as a dam, keeping pebbles from the outer solar system from moving in to replace those that left. The result would have been a belt born with only a fraction of the previously predicted mass.

The idea that the asteroid belt could have started off less massive has been gradually gathering attention. Previous studies by Raymond and Izidoro revealed that it was relatively easy for material tossed into the asteroid belt during planet formation to stick around. That led them to speculate that, instead of starting with lots of mass and being whittled down, the region between Mars and Jupiter started off with no asteroids or planetesimals. Every object there today could have been hurled in from somewhere else in the solar system.

"It's certainly an interesting idea," says Bottke. "I suspect maybe it's too [extreme], but I like it because it gets you thinking."

A completely empty asteroid belt at the start of the solar system would change how modelers view the first few years around a newborn Sun. Models like Grand Tack and Nice might not be needed to explain the asteroid belt itself.

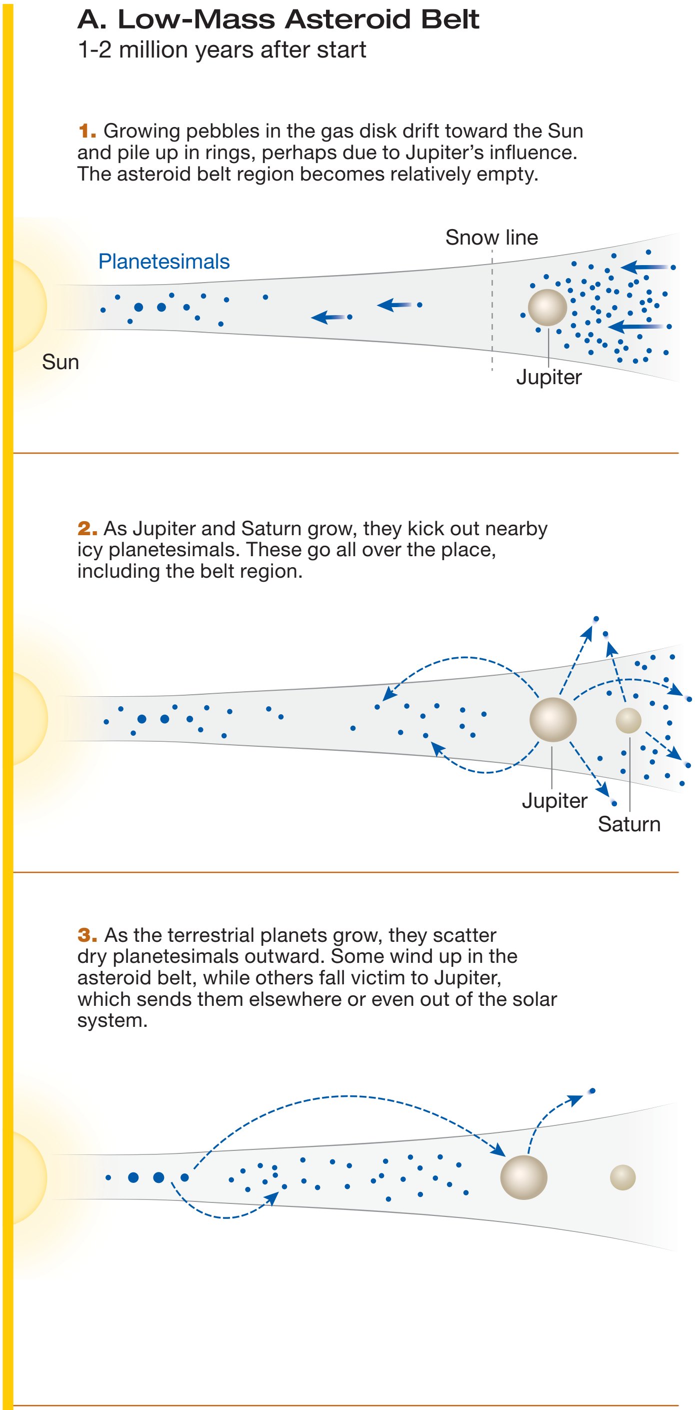
"If the belt was low-mass from the beginning, you don't need the dramatic migration history of the giant planets to explain the inner solar system," Izidoro says. "The giant planets could have stayed in their orbits during the early solar system days."

Ceres and Vesta

Whether it started off empty or full, the asteroid belt still appears to contain material from different parts of the solar system. Two of the most visible examples are Ceres and 4 Vesta, two of the largest objects in the asteroid belt. The pair are different not only from each other but also from many of their neighbors.

The largest object in the asteroid belt, Ceres, is a carbon-rich world whose mass makes up nearly a third of the mass in the belt. While most of the asteroid belt is filled with dry rocks, Ceres has long shown hints of being icy. Before NASA's Dawn mission arrived at Ceres in 2015, scientists suspected the dwarf planet could hold an ocean of water beneath its icy shell. The spacecraft identified bright spots on the dwarf planet and a smooth, constantly changing landscape that later revealed the existence of an extensive reservoir of subsurface brine (*S&T:* Dec. 2020, p. 8).

"Ceres, with its water and bright spots, is central to the general narrative we're coming up with for how the solar system formed and evolved," Raymond says.



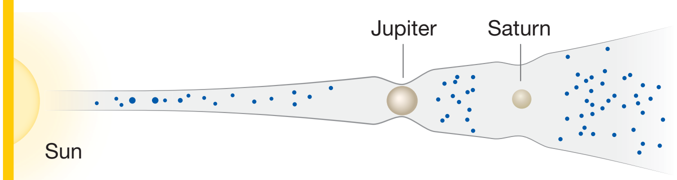
All diagrams, in all scenarios, are not to scale.

Bright salty spots and a young surface weren't the only surprises Ceres had. The spacecraft also found widespread *ammoniated phyllosilicates*, muddy minerals that resemble comet droppings. The ammonia indicates the dwarf planet couldn't have formed where it is now: Temperatures in the disk that formed the solar system meant that ammonia could only condense into ice in the outer reaches, farther from the Sun than the asteroid belt lies (*S&T:* May 2020, p. 34).

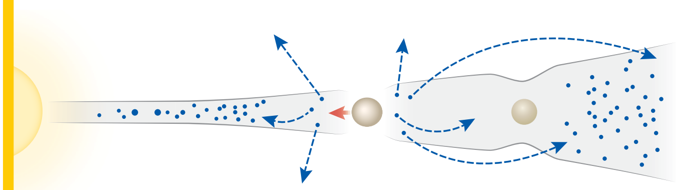
Ceres' icy composition isn't the only reason planetary scientists think the asteroid formed in the outer solar system. With its enormous size (for an asteroid), the dwarf planet has long stood out from its neighbors. In 2008, after the Nice model emerged, planetary scientist Bill McKinnon (Washington University) suggested that the dwarf planet could have

B. Grand Tack
3-5 million years after start

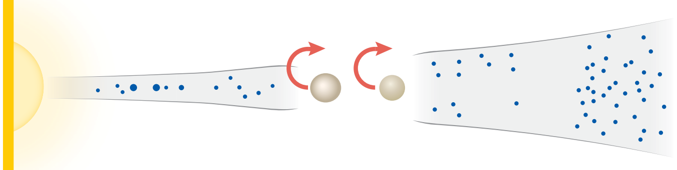
1. As Jupiter and Saturn form from the gas disk, they create gaps in the disk. Jupiter forms faster.



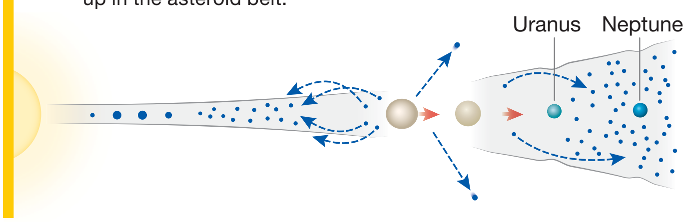
2. Jupiter's gap creates a torque in the disk that forces the planet inward, scattering planetesimals as it goes. Jupiter largely empties the asteroid belt.



3. Saturn then grows big enough to migrate inward and catches up to Jupiter. Their combined gap changes the forces on the giants and sends the pair back out of the inner solar system.

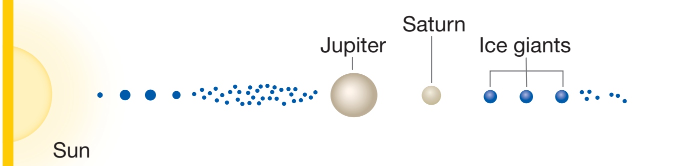


4. As they move out, Jupiter and Saturn again toss planetesimals out of their way. A small number wind up in the asteroid belt.

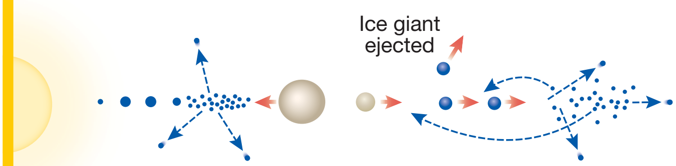


C. Early Instability
Within 10 million years after start

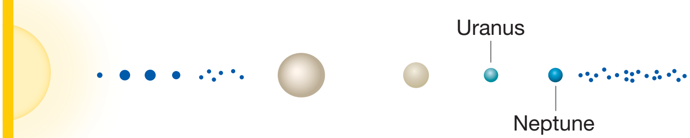
1. After the gas disk clears, Jupiter is a bit farther out than it is today; Saturn, Uranus, and Neptune are much closer, and there's a disk of icy planetesimals beyond. An extra ice giant might be present, too. This compact arrangement is unstable.



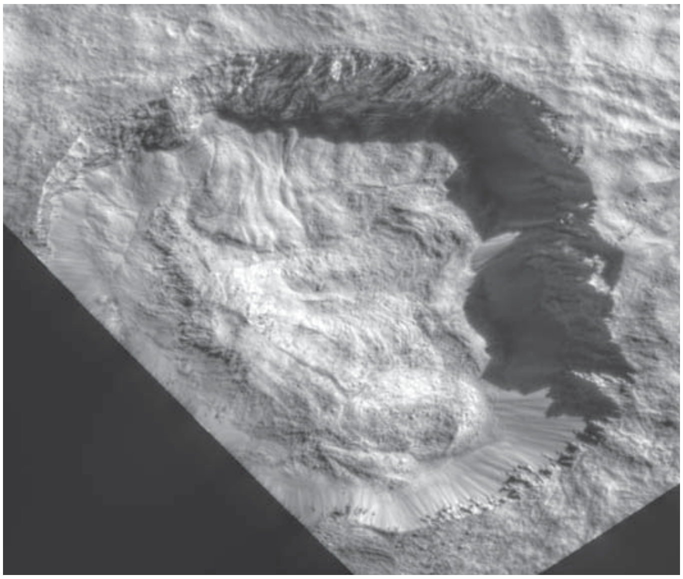
2. Interactions between the giants and the outer icy disk create orbital chaos: Giants cross paths and exchange orbital energy. Jupiter (or maybe Saturn) kicks out the extra ice giant. The giants spread out and clear out most of the icy planetesimals. Jupiter clears out much of the asteroid belt and Mars's feeding zone.



3. The planets stabilize, with Uranus and Neptune much farther out than they began and Neptune controlling the orbits of a large number of the remaining icy objects (today's Kuiper Belt). The remaining asteroids have orbits that are more oblong and tilted than before.



GREGG DINDERMAN / S&T



▲ **CERES** This view from NASA's Dawn spacecraft shows the floor of Ceres' Juling Crater. The crater floor shows evidence of the flow of ice and rock, similar to rock glaciers in Earth's polar regions.

come from the outer solar system. McKinnon later calculated that, as the giants danced their complicated steps, icy objects from the outskirts could have been hurled inward. Of them, only one would likely have been successfully implanted in the belt, while the others were ejected or tossed into the Sun.

Raymond says that as few as 10 Ceres-size objects in the outer solar system could explain Ceres' existence as the sole survivor. According to his simulations, roughly 10% of the planetesimals stirred up by Jupiter and Saturn under the Nice model should have wound up in the asteroid belt. Ironically, that makes things more difficult, because it suggests that the asteroid belt should have more carbon-rich asteroids than it currently holds. Why it doesn't remains a mystery.

According to Nesvorný, one of the best arguments for Ceres' implantation comes from meteorites. Rocky and carbon-rich meteorites are "different beasts," he says, that appear to have formed in separate places. C-type, carbon-rich meteorites best resemble Ceres and most likely come from the outskirts of the solar system. The parent bodies for these meteorites tend to orbit in the outer part of the asteroid belt, farthest from the Sun.

But they aren't the only asteroids making up the outer belt; stony S-type asteroids are also intermixed with their carbonaceous siblings. For years, scientists have recognized differences between C- and S-type meteorites. Now, new research has quantified those differences, revealing a gap in the isotopes found inside the meteorites themselves. The variations between the asteroids' isotopes indicates that they formed progressively farther out, with C-types placed firmly in the outer solar system.

"There has been this dichotomy between [meteorites] for decades," says meteorite scientist Conel Alexander (Carnegie Institution for Science). "What's changed is now these new isotope anomalies have been found in the system that hadn't been looked at carefully before. It all comes down to their isotopes."

Combined, the simulations, meteorite isotopes, and Dawn's observations make a strong case for Ceres having formed in the outer solar system.

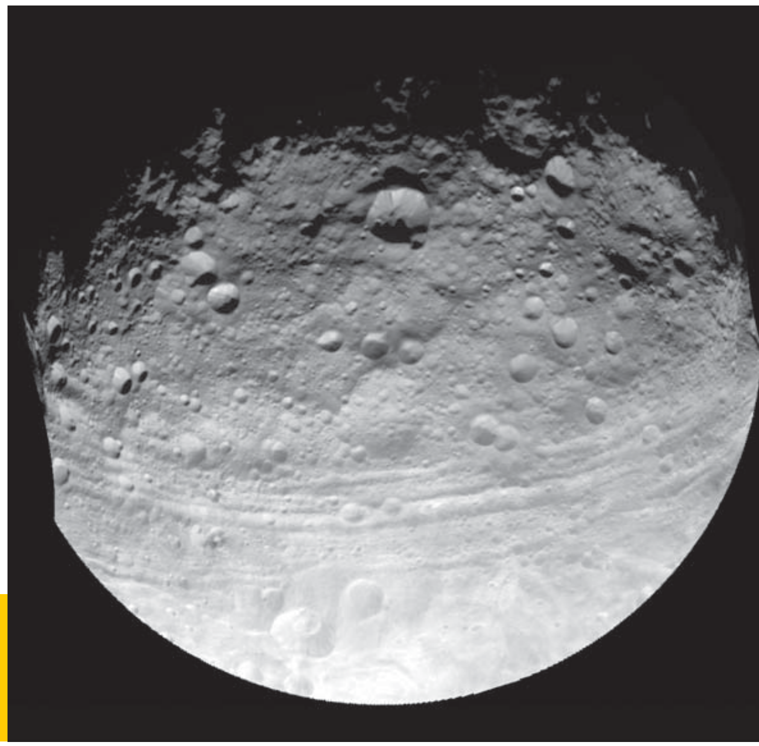
Vesta's origins are harder to pin down. The second most massive object in the belt, Vesta is differentiated, having separated into a crust, mantle, and core early in its lifetime. The fact that it has all three layers makes it fairly unique in the belt and might be key in solving an ongoing puzzle: the mystery of the missing mantle.

When newborn objects grow large enough, the heaviest elements in them sink to the center, while the lightest elements rise to the top. The result is iron-rich cores wrapped in rocky mantles. Astronomers have found iron-rich asteroids in the belt and collected iron-rich meteorites on Earth. But the lighter elements that would make up mantle material are surprisingly hard to spot in both.

One option, proposed by Bottke and his colleagues in 2006, is that differentiated asteroids formed closer to the

Four asteroids contain 55% of the main belt's total mass:
Ceres, Pallas, Vesta, and Hygiea

▼ **VESTA** Various craters and grooves along the equator stand out in this image from the Dawn spacecraft of 4 Vesta. The grooves may be due to a massive, glancing impact that made the interior crack and collapse.



CERES: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA / ASI / INAF;
VESTA: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

WHY IS THE ASTEROID BELT WHERE IT IS?

As the planets formed (and likely moved), they scattered smaller objects all over the early solar system. Some were trapped by Jupiter or Neptune; others ended up in the Kuiper Belt. Many wandered around until they were kicked out entirely. The few that landed in the region between Mars and Jupiter found a safe zone, a dynamically stable region where they could orbit the Sun for 4.6 billion years largely undisturbed. (No such region exists between Jupiter and Saturn, for example.) So it's not that the asteroids were preferentially put in the main belt — it's that, once there, they *stayed*.

terrestrial planets than they are today. There, collisions could have stripped off their mantles, leaving behind their denser cores. Interactions with planets and protoplanets then hurled the iron-rich meteorites outward toward the belt, leaving most of the lighter material behind to fall onto the terrestrial planets or the Sun. Because hurling material away from the Sun grows more challenging as you move inward from the belt, Vesta and its siblings most likely formed near Mars. Isotopes support this idea.

Another solution to the missing mantles is that the lighter material was more easily destroyed in collisions than the iron cores that remain today. "Vesta could be one of the asteroids that was just lucky and didn't suffer from a devastating collision," says Alexander.

While theorists try to rewind the solar system to understand how material was scattered, Alexander is turning to meteorites to try to figure out what happened.

Meanwhile, samples brought home by Hayabusa 2 and OSIRIS-REX from two carbon-rich asteroids should help to reveal more about the composition — and thus the origin — of these belt denizens. Launching in late 2021, the Lucy spacecraft should also provide insights, visiting several of the Jupiter Trojans in the late 2020s. Lucy's observations will tell astronomers how similar to Ceres these asteroids are.

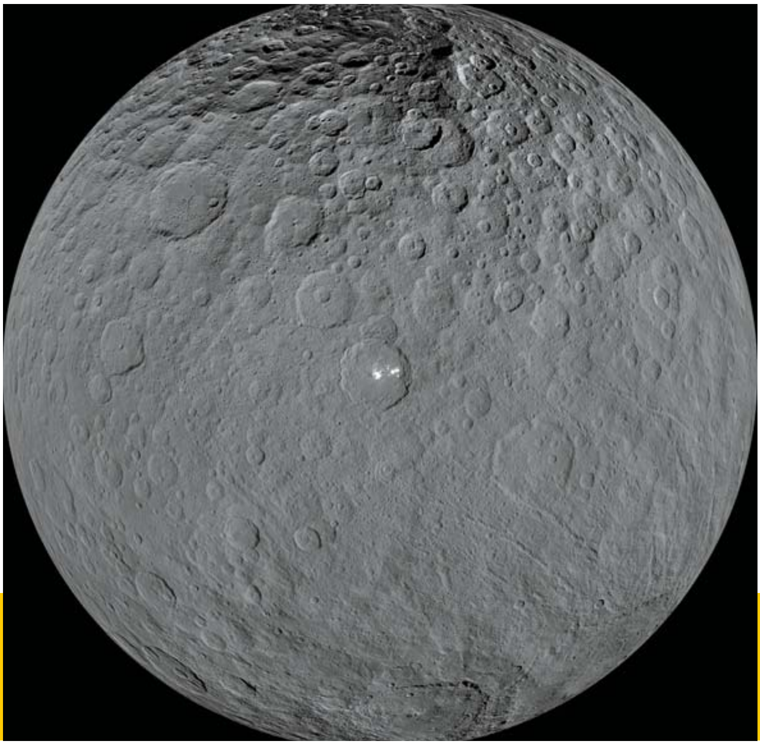
"There are a lot of dots to connect along the way to get from point A to B," Raymond says. "It's the funnest part of the game, to really build a story that's coherent."

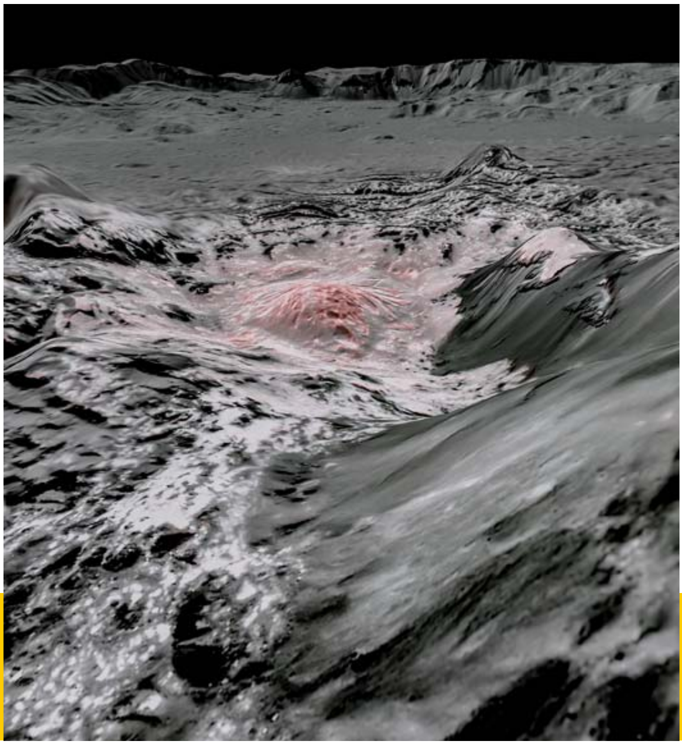
■ **NOLA TAYLOR REDD** is a freelance science journalist fascinated with space and astronomy. She has written for several publications, including *Scientific American*, *Science*, and *Smithsonian*.

Watch a video explaining the three early solar system scenarios: https://youtu.be/cSUrfEErhSE.

NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA (2)

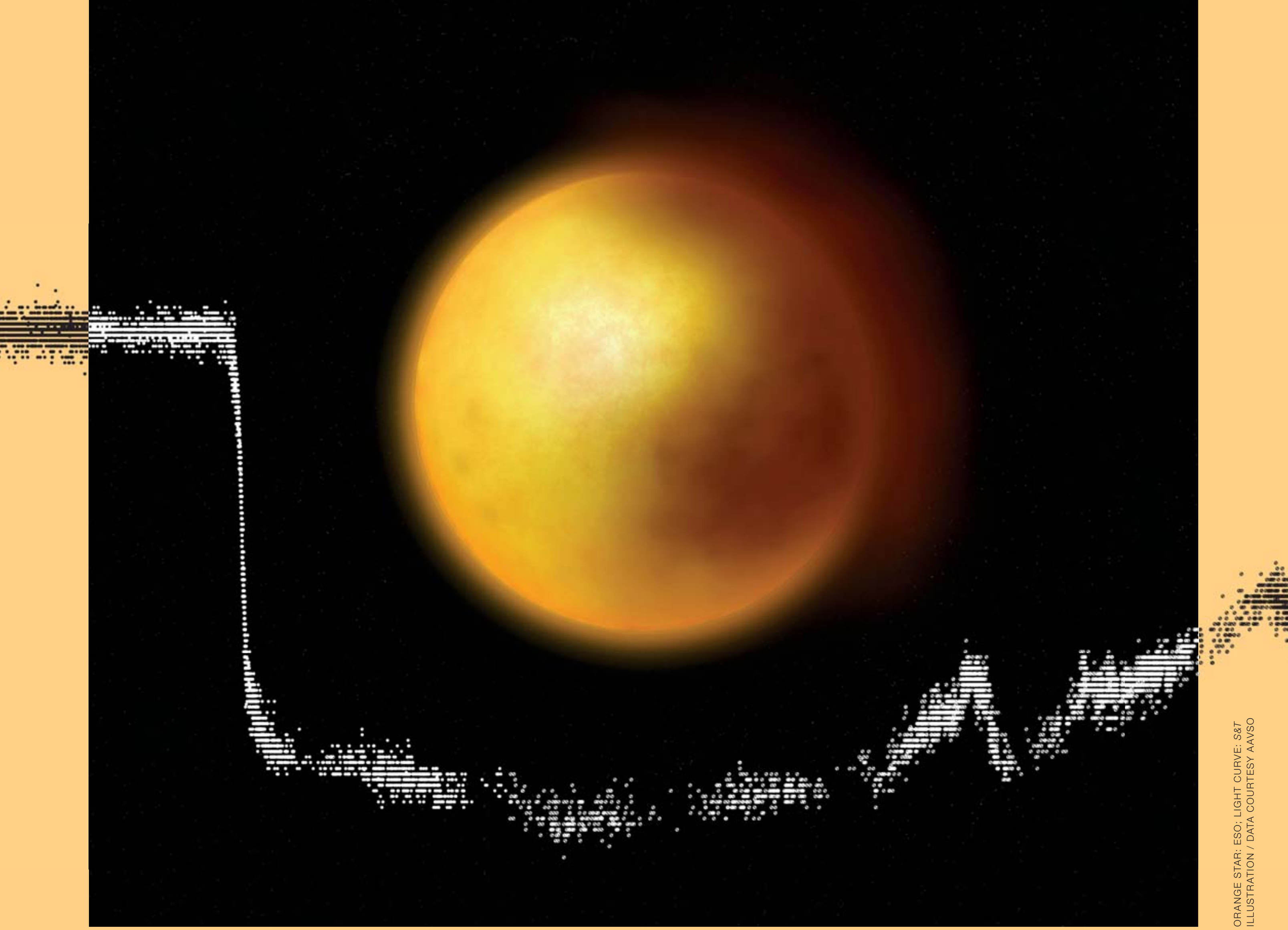
▼ **ASTEROID BRINES** Seen from afar, Ceres had multiple bright spots in Occator Crater *(left)*. Up close, these spots proved to be salty flows. The false-color mosaic at right combines visible and infrared images with topographic data, all taken by NASA's Dawn spacecraft, to show brine (pink) on Occator's floor. The foreground dome, Cerealia Tholus, is about 3 km tall and part of the bright region at Occator's center.





THE UPS AND DOWNS OF RCB STARS

These intriguing variables are as rare as they are fascinating.



ORANGE STAR: ESO; LIGHT CURVE: S&T ILLUSTRATION / DATA COURTESY AAVSO

In October 2019, Betelgeuse began a very unusual fade. Over the course of the next four months, Orion's red supergiant declined from magnitude +0.6 to below 1.6, after which it began to recover (see page 14). For a short time, Betelgeuse's surprising antics made it the most famous variable star in the sky. However, there's an entire class of extraordinary, rare stars that experience brightness drops many, many times greater. They are known as R Coronae Borealis (RCB) stars.

Meet R Coronae Borealis

As the 18th century neared its end, only a handful of non-nova variable stars had been identified: Mira (discovered in 1596), Algol (1667), Chi Cygni (1686), R Hydrae (1704), R Leonis (1782), Beta Lyrae (1784), Eta Aquilae (1784), and Delta Cephei (1784). The last two are Cepheid variables, stars that brighten and fade in a particular and predictable fashion. And though the variety is named after Delta Cephei, the variability of Eta Aquilae was actually discovered slightly earlier by English amateur Edward Pigott.

Born in 1753 and sharing the astronomical interests of his father, Nathaniel, Pigott became fascinated by variable stars. He suspected that there must be more than the handful known, and so he began to search. Eta Aquilae was his first confirmed find.

In 1783 Pigott observed the stars of Corona Borealis, and returning to the constellation the following year, he noticed a faint star that struck him as being "considerably brighter" than before. Pigott observed the star again in 1785 but didn't revisit it for a decade. When he did, in 1795, he found that it had faded almost beyond view.

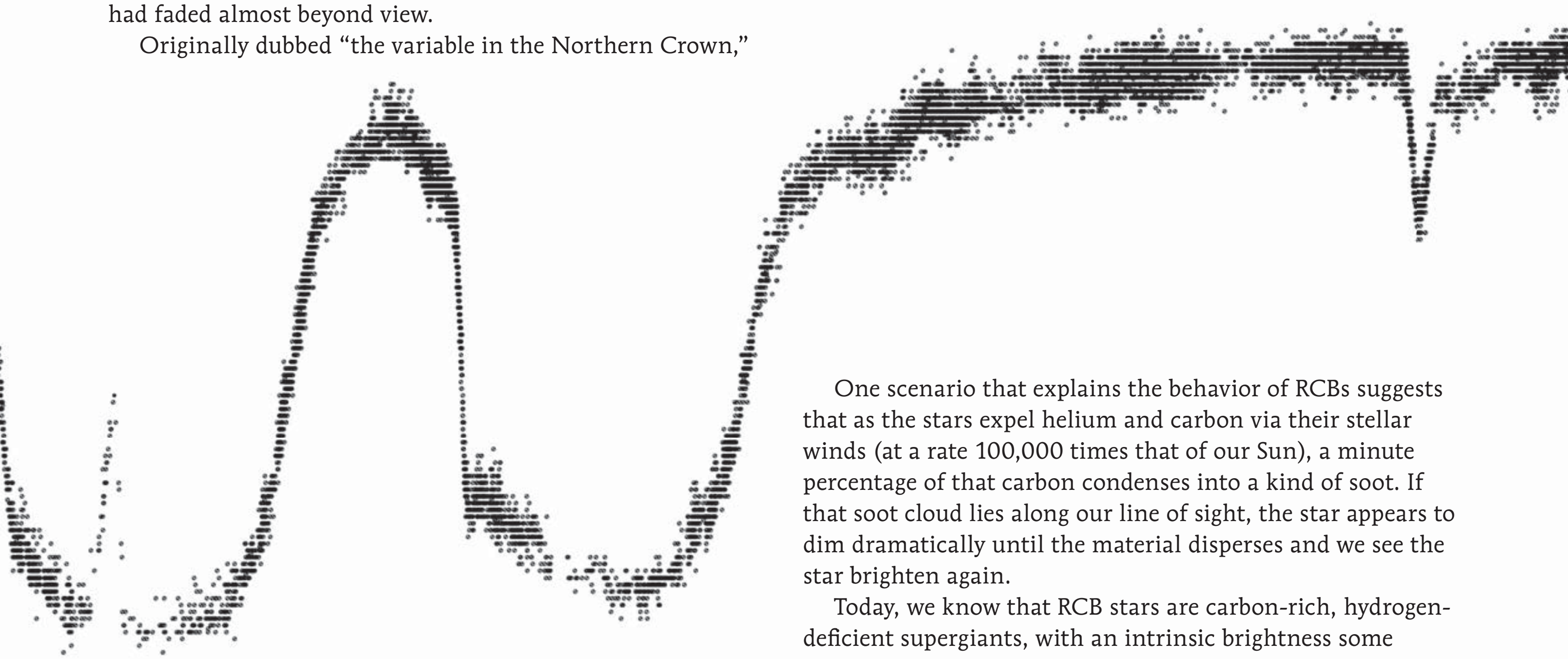
Originally dubbed "the variable in the Northern Crown," in 1850 the star was referred to as "Coronae R" by the German astronomer Friedrich Wilhelm Argelander. This was a precursor to its final designation, R Coronae Borealis. The "R" signifies it was the first variable star identified in the constellation. (Beginning the naming sequence with the letter R avoided overlapping with other designations then in use. Under this scheme, a constellation's second variable would be labeled S, the third T, and so on.)

In 1795 Pigott also discovered the variability of R Scuti, and William Herschel first noted the changing brightness of Alpha Herculis. These finds (along with R Coronae Borealis) brought the total number of variables known at the end of the year up to 11. That was just the beginning: In the next 100 years, more than 400 variable stars would be identified.

The Nature and Formation of RCBs

Monitoring of R Coronae Borealis has been ongoing since the discovery of its variability more than 200 years ago. The star shines somewhat steadily at around 6th magnitude for a few years or so, and then in the space of a few days to weeks, it plummets to around 14th magnitude, after which it begins a slow return to normal brightness. In the pantheon of variables, no other class of star behaves this way.

By 1935 astronomers realized that, compared to solar abundances, R Coronae Borealis lacked hydrogen — indeed, it was most unlike the Sun. That same year, they also concluded that thick clouds of carbon dust expelled by the star were causing the periodic large declines in brightness, though the exact mechanism was unclear at the time.



◀ **DUST STAR** This illustration depicts the R Coronae Borealis-type star RY Sagittarii enshrouded in a huge cloud of dust. It's such clouds of obscuring dust that are responsible for the irregular dimming episodes these fascinating variable stars undergo.

One scenario that explains the behavior of RCBs suggests that as the stars expel helium and carbon via their stellar winds (at a rate 100,000 times that of our Sun), a minute percentage of that carbon condenses into a kind of soot. If that soot cloud lies along our line of sight, the star appears to dim dramatically until the material disperses and we see the star brighten again.

Today, we know that RCB stars are carbon-rich, hydrogen-deficient supergiants, with an intrinsic brightness some 10,000 times that of our Sun. RCBs also exhibit an excess amount of infrared radiation arising from the heating of dust deposited in the circumstellar environment during previous dimming episodes.

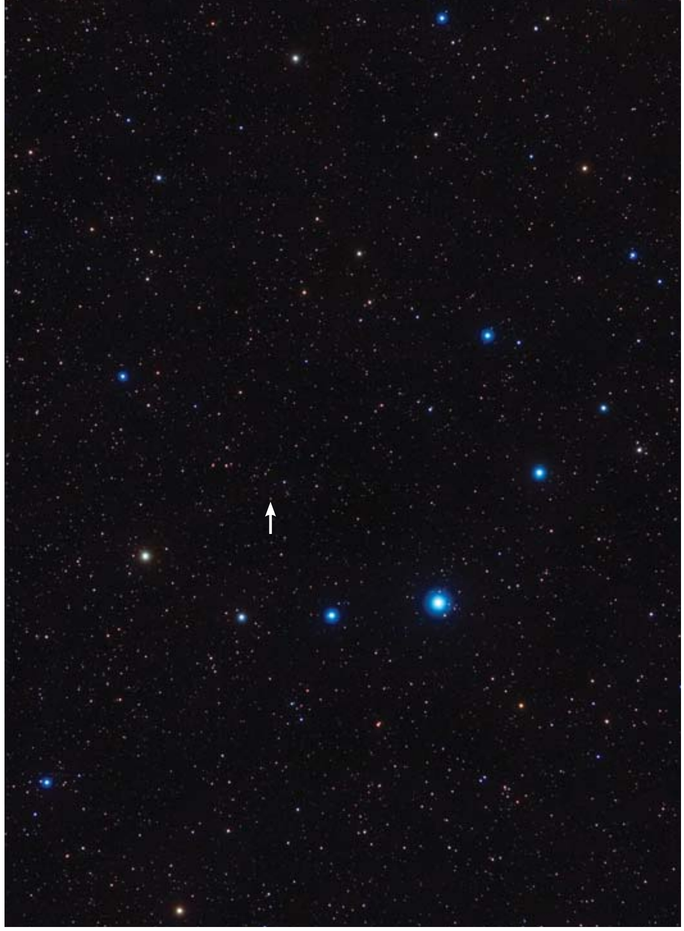
Just how these stars form remains a mystery. Over the years, astronomers have proposed two very different models to account for them. The first is the merger of two white dwarfs — and not just any two white dwarfs, but a carbon-oxygen white dwarf and a helium white dwarf. Most white dwarfs are composed of carbon and oxygen. However, very low-mass progenitors can't fuse helium, resulting in a helium white dwarf. As white dwarfs are also known as degenerate dwarfs, this model for RCB formation is sometimes called a *double degenerate merger*. On the other hand, if the white dwarfs are massive enough, then the merger leads to a Type Ia supernova instead.

The other competing, albeit less favored, model of RCB formation is the *final-helium-shell flash*, in which a star that's already in the planetary nebula phase rapidly expands and becomes a supergiant as its helium shell ignites. Thus far, three stars (Sakurai's Object, V605 Aquilae, and FG Sagittae) have undergone these final flash outbursts, and they all exhibit spectral characteristics similar to those of RCB stars.

An Unusual and Rare Variable

More than two million confirmed and suspected variable stars have been cataloged, according to the American Association of Variable Star Observers (AAVSO). And yet the RCB count hasn't kept pace, despite the prototype being one of the earliest variables found. It turns out that RCBs are very rare.

In a seminal 2012 paper, Louisiana State University astronomer Geoffrey Clayton noted that the list of known or suspected RCB stars stood at the modest total of around 90, with 65 lying within the Milky Way and 25 in the neighboring Large and Small Magellanic Clouds. Assuming that RCBs form from the merger of two white dwarfs, Clayton looked at the population of known RCBs in the LMC and extrapolated a total population of around 5,700 RCBs for the Milky Way. Taking a different approach, he also modeled the likely number of white dwarf mergers per year and the expected lifetime of RCB stars to arrive at an estimated population of 5,400 Milky Way RCBs — in line with his LMC extrapolation.

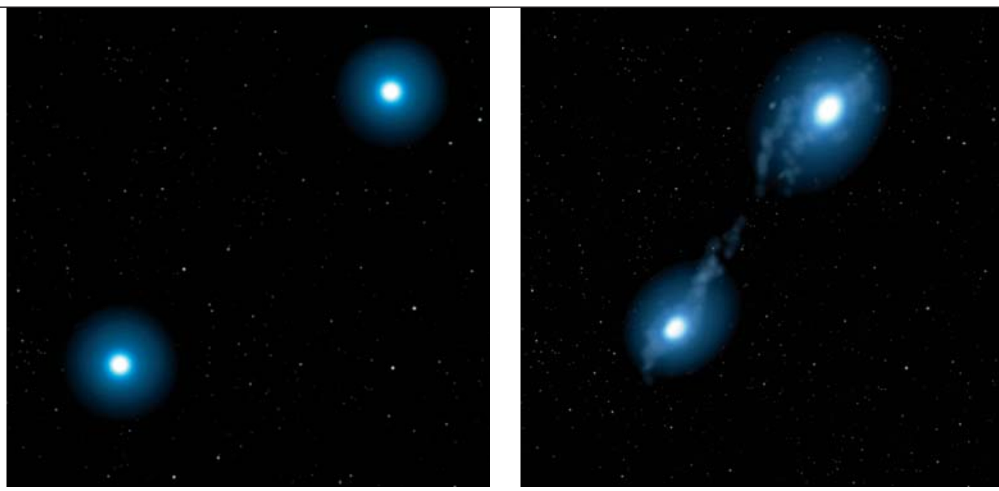


▲ **INCONSPICUOUS JEWEL** Corona Borealis, the Northern Crown, isn't a constellation most telescope enthusiasts spend a lot of time exploring. There are no bright clusters or galaxies within its borders, but it does boast R Coronae Borealis — one of the most interesting variable stars in the sky. The star (indicated with the arrow above) had dimmed to roughly magnitude 8 at the time this photo was captured.

Since then, astronomers have revised the estimated population downward to around 1,000. At the same time, ground-based and orbital surveys have increased the number of RCB finds. New results published in 2020 by Patrick Tisserand (Australian National University), Clayton, and colleagues have brought the count up to 147.

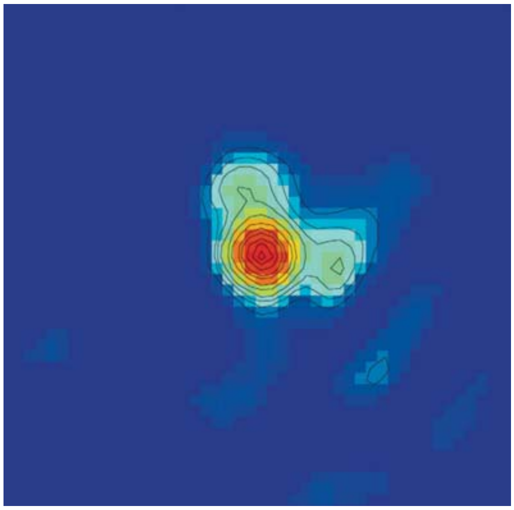
CORONA BOREALIS: AKIRA FUJII; RCB FORMATION SEQUENCE: GEMINI OBSERVATORY / JON LOMBERG (5)

▶ **A (VARIABLE) STAR IS BORN** This sequence of illustrations depicts the formation of an RCB star through the merger of two different types of white dwarf stars. The energy generated by their collision causes the merged stars to expand and form a supergiant with a diameter of around 100 million kilometers (62 million miles). This is the most widely accepted model explaining the formation of RCB-type stars.



Hot RCBs

Most RCB stars are cool, with temperatures in the range of 5000 to 7000 kelvin. (By comparison, main sequence stars range in temperature from 2000K to 50,000K, with our Sun registering a surface temperature of about 5800K.) However, four RCBs are considerably hotter, with temperatures ranging from 15,000K to 25,000K. This quartet of *hot RCB stars* (as they are collectively known) consists of V348 Sagittarii, MV Sagittarii, DY Centauri (all three in our galaxy), and HV 2671 (in the LMC).



◀ **DUST PUFF** In 2003, the European Southern Observatory's Very Large Telescope observed the RCB star RY Sagittarii at a wavelength of 4 microns to produce this image showing large clouds in the envelope of dust surrounding the star. This study helped confirm the "Dust Puff Theory" that explains the star's periodic dimming as a result of material expelled by the star itself.

ESO

In 2002, Orsola De Marco (now at Macquarie University, Australia) and her colleagues noted that the maximum brightness of the three hot Milky Way RCBs has declined over the last century. Five years ago, Bradley Schaefer (Louisiana State University) extended the study to include HV 2671 in the LMC. Schaefer also used photographic plates stored at Harvard College Observatory (covering the period from 1896 to 1989) to compile more complete light curves for all four hot RCBs. He was able to confirm that the stars were fading at a rate of around one magnitude per century.

De Marco also noted that the fading was related to the stars evolving to hotter temperatures. This heating up has been observed in DY Centauri, whose spectra show that the star's surface temperature has increased from 19,400K in 1987 to 24,800K in 2010. Schaefer modeled DY Centauri's evolution based on its changing brightness and determined that in 1906 the star was a normal RCB with a temperature of around 5800K. From there, its temperature soared to its present value. Interestingly, DY Centauri hasn't experienced any brightness drops since 1934, suggesting that the increased temperature shut down the mechanism that generates the star-dimming dust. Schaefer concludes that the time required for a normal RCB to evolve into a hot RCB is about one century, which explains why so few hot RCB stars are known.

R Coronae Borealis's Recent Performance

Although observers have watched it closely for more than two centuries, R Coronae Borealis can still surprise. Following a period of relatively steady brightness, in 2007 the star began to fade in an unprecedented manner. It first dropped to its usual minimum of around 14th magnitude, then hovered there for several months, before dimming even further beginning in 2008. In early 2009 it reached an all-time low of 15th magnitude — and it wasn't done yet. The star's return to maximum was also unusual.

The star climbed to 12th magnitude in late 2011, before dipping again to 14th magnitude. Then, as 2011 was ending, the star resumed its recovery, this time nearly reaching 10th magnitude in early 2013 before plummeting a few months later to just a little brighter than 15th magnitude. R Coronae Borealis began to brighten yet again, this time punching through to 10th magnitude in late 2014 for the first time since 2007. It ultimately brightened to just better than 7th magnitude in 2015 before once again falling to 14th magnitude in early 2016. Soon, its long road to recovery began in earnest and the star eventually reached 6th magnitude in mid-2018 — some nine years after this incredible sequence of events began.

What caused this particularly dramatic episode? Clayton notes that the obscuring dust must have formed continuously over many years for the star to remain in such a deep, prolonged decline.

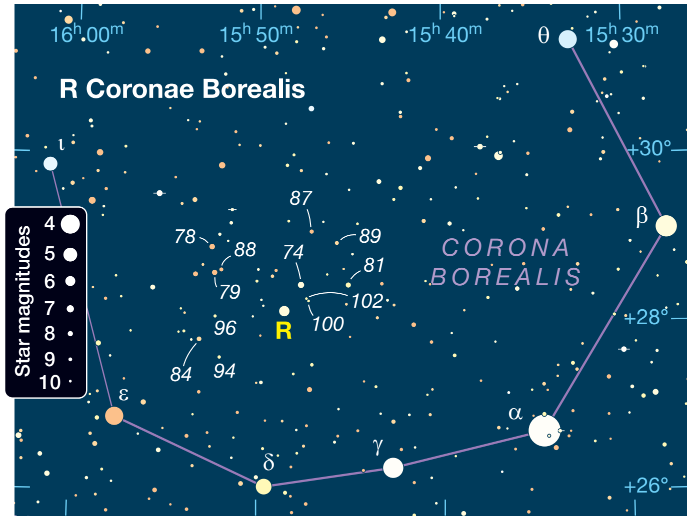
Three to Watch

R Coronae Borealis, along with RY Sagittarii and V854 Centauri, are the easiest RCBs for observers to follow. All three reach binocular visibility (R Coronae Borealis and RY Sagittarii can even climb to naked-eye brightness), and each has exhibited unusual behavior recently. The AAVSO recommends checking these stars once a week when they're at their brightest, and then nightly once fading has begun.

R Coronae Borealis lies within the horseshoe-shaped curve of Corona Borealis, about 2° north of 4.6-magnitude Delta Coronae Borealis. A 7.4-magnitude star lies less than ½° northwest of R. During March evenings, Coronae Borealis rises late in the evening. R's last major decline was in 2016, though there was a minor fade to 9th magnitude in late 2019. It's been back at 6th magnitude since the beginning of 2020.

The second-brightest RCB variable is **RY Sagittarii**, discovered in 1893 by Colonel Ernest Marwick, an officer in the British army then serving in Gibraltar. RY lies 4½° degrees southeast of 3rd-magnitude Zeta (ζ) Sagittarii, part of the Teapot asterism. According to the AAVSO, RY Sagittarii has a brightness range of magnitude 5.8 to 14.0. During March, RY Sagittarii is observable just before dawn, so you may wish to wait until later in the year when it's more favorably placed.

During the last 50 years, RY Sagittarii underwent declines exceeding four magnitudes in 1971, 1978, 1982, 1990, 1993, 1999, 2004, and 2008, before an 11-year gap to 2019. RY Sagittarii has not fully recovered from its most recent dimming and shines between 9th and 10th magnitude at the time of this writing.



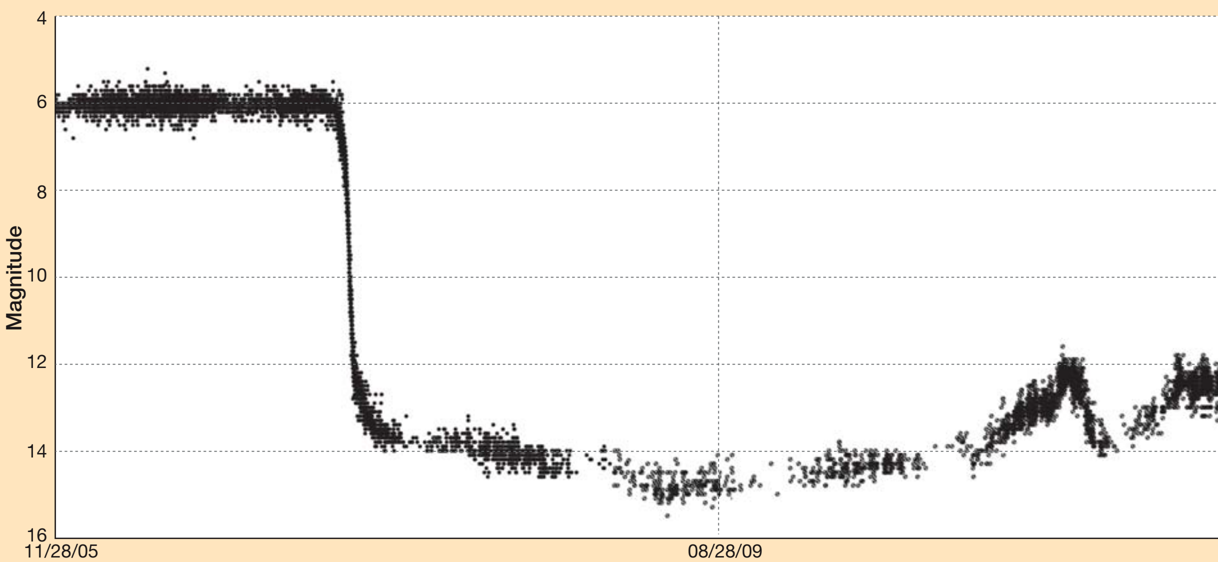
▲▶ **COMPARE AND ESTIMATE** Use this chart to locate and estimate the brightness of variable star R Coronae Borealis. On this chart and the ones that follow, the magnitudes of comparison stars are given with their decimal points omitted. So, for example, a magnitude-7.8 star is labeled "78" instead.

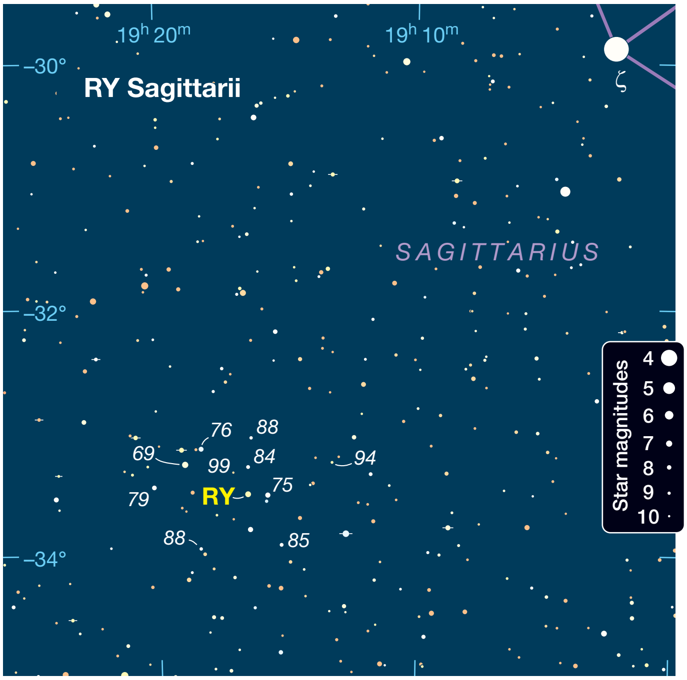
Our third RCB variable is **V854 Centauri**. With a declination of –39.5°, it's accessible to observers at locations south of roughly latitude 40° north. The star is found a little more than 2½° north of 2nd-magnitude Eta (η) Centauri. In March, the star's field is visible in the hours before dawn.

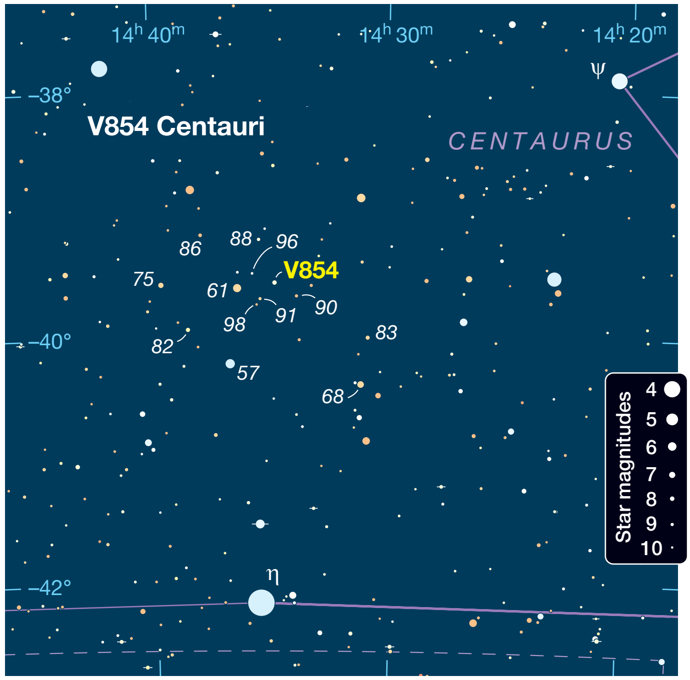
V854's variability was first detected in 1964, but its status as an RCB wasn't determined until much later. In July 1986, Australian amateur Glenn Dawes found a magnitude-7.5 star on a photographic sky patrol image. A previous photo he took in 1985 showed no star brighter than magnitude 11 at the position. Suspecting a possible nova, Dawes quickly alerted

LIGHT CURVE: *S&T* ILLUSTRATION / DATA COURTESY AAVSO

▶ **INCONSISTENT LIGHT** In the 200-plus years since its variability was first discovered, R Coronae Borealis has had its share of ups and downs. As this graphic illustrates, the star's brightness changes dramatically over irregular time spans.







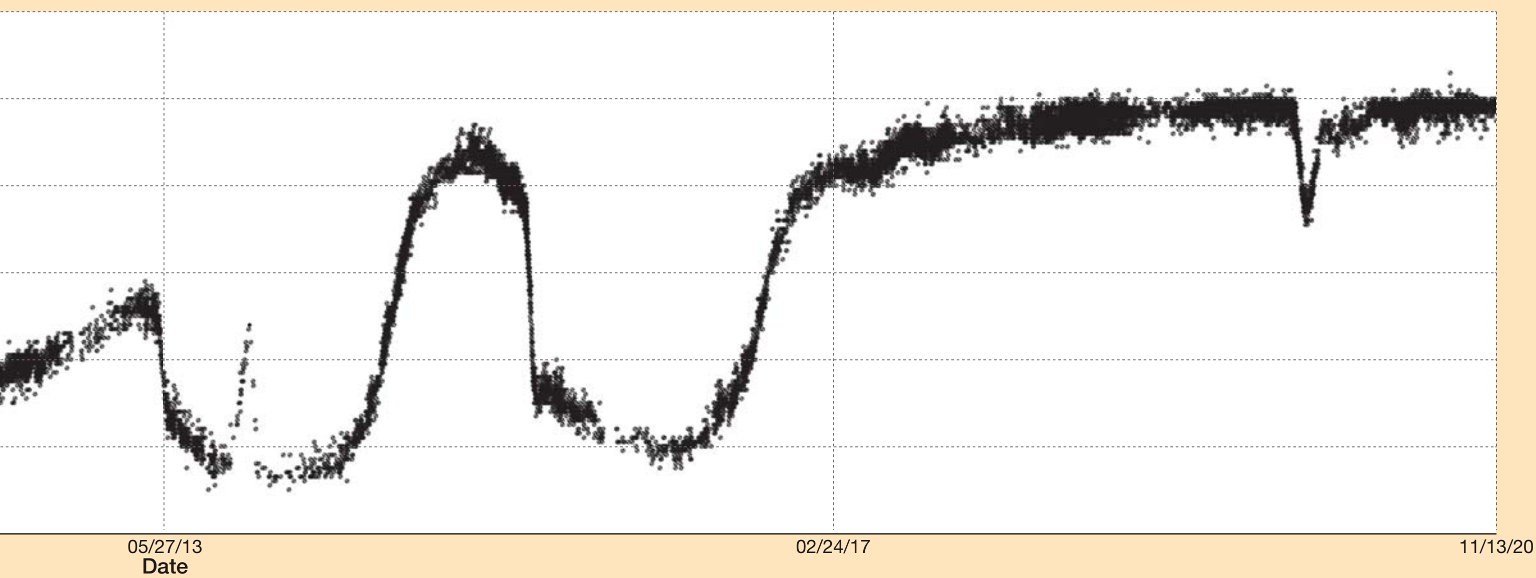
Robert McNaught at Siding Spring Observatory, who reviewed archival plates of the region and discovered the star ranged from magnitude 7 to 15, alluding to its RCB identity. In 1989 it was officially designated V854 Centauri.

The Centaurus variable is the third brightest RCB known and has been relatively active, going into decline on 16 occasions between 1987 and 2010. The most recent dip began in late March 2020. It still hasn't fully recovered and has been hovering between 8th and 9th magnitude, with another mini-decline to nearly 12th magnitude occurring in late August 2020.

The universe of variable stars is a fascinating one ripe with opportunities for amateur astronomers. You can find a wealth of helpful information, including detailed charts and light curves, at the website of the AAVSO, **aavso.org**.

How bright will our selected trio of RCBs shine by the time you read this? The best way to find out is to go outside on the next clear night and take a look!

Contributing Editor **GREG BRYANT** keeps an eye on the ever-changing sky from Sydney, Australia, where RY Sagittarii and V854 Centauri pass overhead.



 by Richard S. Wright, Jr.

Science with Astrophotography

Your pretty pictures can contain valuable information.

ASSIGNED COLOR Astronomers use false or representative color to help convey information in images of emission nebulosity, but that doesn't make the photo less useful. This narrowband composite photograph of the North America and Pelican nebulae (NGC 7000 and IC 5070, respectively) assigns images recorded through O III, Hα, and S II narrowband filters to the blue, green, and red channels in this picture to highlight the structure each gas contributes to the overall nebulous region. All photos courtesy of author unless otherwise noted.

If you've been involved in astronomy for any length of time, chances are you've encountered discussions on the value of amateur astrophotography. Often the phrase "It's just a pretty picture" is wielded like a cudgel by some who perceive themselves as the champions of science against many just getting started in the field. Science and art are often compared in a pejorative sense, and that's a pity. They both have value, and everyone seems to have their own definitions of what art or science actually is. If it's an image, and it doesn't meet someone's personal definition of science, then it must be "just" art. But the fact is, astrophotography is a very large part of the science of astronomy.

Amateur astronomers, including astrophotographers, are amateur scientists. After all, it's the passion for this branch of science that drives us into this pursuit and occasionally provides the fuel for a rich and fulfilling career in the sciences as well. But astro-imaging can also remain a hobby, and there is no shame in this. You can also be an amateur scientist and artist simultaneously — the two pursuits aren't mutually exclusive.

What Is Science?

One of the greatest misunderstandings about science among the general public is that it's nothing more than a body of knowledge — that there is a book of facts with the word "science" on the spine. Not quite. According to Merriam-Webster, science is "the state of knowing: knowledge as distinguished from ignorance or misunderstanding."

The route to this knowledge is known as the scientific method. It is a time-tested process involving careful observation, skepticism, and measurement-based testing that inevitably leads to what is true. "Trust your feelings" might make for great Jedi knights in *Star Wars*, but it makes for a poor scientist in the real world.

Some would argue that unless you're using a camera and contributing carefully calibrated data to some important project, you aren't doing real science. Nonsense! Just looking through your telescope is observing and learning about real phenomena. Even if this is all you are doing, you are still learning to navigate the night sky and utilizing equipment that scientists have used for centuries. Indeed, the typical amateur equipment of today is far superior to the instruments that made groundbreaking discoveries just 100 years ago. In the early days of astrophotography, the scientific community scoffed at anyone taking pictures through a telescope. A skilled observer is always better than machinery or glass plates, or so they thought. But the photographic revolution quickly turned the tables. Today, few (if any) professional astronomers use anything but an imaging device to make observations.

In order to perform science, your personal projects don't have to change the world, be completely novel, or have value to anyone else to be valid science. If you're making observations and using them to better understand the world around you, you're doing science. If you're repeating the 2,000-year-old experiment demonstrating that the world is round (which seems to require proof these days), you're doing actual science. After all, the hallmark of the scientific method is reproducibility — repeating an experiment properly should give the same result every time.

Science in Pretty Pictures

The tools available to amateur astronomers today are truly amazing, and the hobby of recording splendid images of the night sky is flourishing, even in this period of COVID-19 and social distancing. Never before in our history have we had such capability to record and discover the wonders of the universe above us.

Regardless, if you travel in imaging circles, you've doubtless encountered individuals seemingly on a mission to ensure that you don't squander the awesome power of modern technology on pretty pictures. When I first took up astrophotography, I recall the pressure from some of my early mentors to engage in astronomy with all the seriousness it deserved. One of them would use the term "Pretty Picture People" — with all the contempt of someone saying "con-artist." I've long since come to terms with this quarrel.

In fact, there are two kinds of scientific data: quantitative and qualitative. Professional astronomers understand that both kinds have value. Quantitative data is measured data. Counting the stars in an image and stating "there are 4,328 stars in this image" is another example of quantitative data. "This is a spiral galaxy," is an example of qualitative data. It's a type of galaxy that we recognize and have categorized. While the statement about the spiral galaxy is more subjective, it's still true because that is our convention.

"This is an unusual-looking galaxy" would be an important qualitative observation — one that challenges our previous categorization schemes. Such a statement can cause

▼ **ASTRO ART** Images like this creative conception of M31 as seen through an opening in a brick structure are more art than science, though nothing in the galaxy was distorted or changed to produce this fanciful composite.

scientific upheaval as much as anything unexpected in the quantitative realm.

The one and only rule about gathering qualitative imaging data is that you can't fake it. For example, copying stars from one part of an image to fill an empty area distorts the quantitative information in the image. Selectively rotating a galaxy but not its surrounding star field or combining two nebulae to make a more creative image isn't science at all — it's purely art.

However, if you assign specific colors to particular wavelengths recorded, highlight only a particular color, or apply a non-linear stretch, that's not faking image data. Nor is applying noise reduction or sharpening. In the world of astronomy and science in general, skillfully applied image processing is done all the time to uncover subtleties that wouldn't be apparent otherwise. But be careful, because data can also be processed to the point of creating details that aren't really there.

If you've followed this simple philosophy and someone claims your image has no scientific value, what they really mean is it has no scientific value that is of interest to them. But that doesn't necessarily mean it has no scientific value or interest to others.

For example, let's say you take an image of your favorite galaxy. You process it, perform some noise reduction and non-linear stretching to produce an attractive picture. You then share it on social media for your friends and family to see. That photo is full of important qualitative data. It is, after all, a *real* galaxy. While its brightness has been modified, the structure you've enhanced is real enough. It may have four spiral arms — you didn't remove one of them or

◀ **LEARNING DEVICE** These two observers are learning about individual craters on the Moon by using a smartphone to share the view on the device's screen.

add a new one. "This galaxy has four spiral arms" is verifiable scientific data that you've captured with your non-linear processed, selectively enhanced pretty picture.

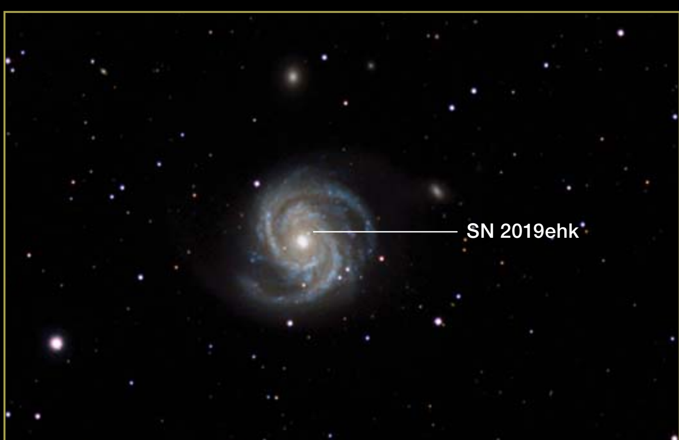
"Wait," a friend says. "Hey, I know that galaxy, but what's that bright star right there?" The next night your friend images the same galaxy, records the same star, carefully calibrates the data and measures its brightness using differential photometry. It's a supernova! Your friend gathered *quantitative* scientific data on the supernova by measuring its brightness, based on your *qualitative* data that there is a star there where there wasn't one before. And you just may have discovered a supernova with your own aesthetically processed image.

Doing More with Your Imaging

So, what if you'd like to do more quantitative work? Aesthetic astrophotography can be its own reward, but there are also many ways you can dig deeper. Amateur scientists occasionally make a groundbreaking observation or discovery, though this is a tremendous gift when it happens and not commonplace. Still, we sometimes play the lottery and hope we get lucky, so why not?

A great example of a collaboration between amateur astronomers pooling their resources and expertise is the MDW Hydrogen-Alpha Sky Survey described in this magazine's October 2019 issue, page 20, and online at **mdwskysurvey.org**. These amateurs (two are current and former

MOON: SEAN WALKER / *S&T*



▲ **SUPERNOVA SURPRISE** Aesthetic processing doesn't render an image scientifically useless. A good example is this photo of M100 in Virgo. The author imaged it in the spring of 2019, and after processing it simply to look good, a friend later noticed a new star in the galaxy, which turned out to be supernova SN 2019ehk.

▲ **REAL COLORFUL MOON** This photograph of the Moon may appear to some as garish art, but carefully increasing the color saturation on a picture of the Moon reveals true mineralogical differences in various regions of the lunar surface.

S&T editors) have set out to survey the entire sky with deep, hydrogen-alpha images. I find it wonderful that someone just thought such a thing as this ought to be. The imagery is stunningly beautiful and has contributed to several discoveries and scientific papers.

Tim Puckett, the most prolific amateur supernova hunter of all time, is another great example of an amateur scientist (**cometwatch.com**). Puckett is an amateur astronomer based in Georgia who began his supernova-hunting program in 1994. With the help of other amateurs, he's discovered hundreds of supernovae. While supernova searches today are highly automated, amateurs can still contribute occasional discoveries, and that includes you.

If you have your own research interests or projects, you can join the American Astronomical Society (**aas.org**) as an amateur affiliate member. (Note: The AAS owns *Sky & Telescope*.) This membership class is for those who aren't employed as astronomers, but nevertheless may be working on research that they wish to report on, or who may take advantage of the society's resources for their work.

While you certainly can create your own scientific observing program, many organizations have structured scientific programs that amateurs can participate in. Joining one of these programs can provide you with a framework to follow and offer training and guidance. Sometimes they even have mentoring programs.

One of the best-known organizations for professional/amateur collaboration is the American Association of Variable Star Observers (AAVSO), found online at **aavso.org**. For more than a century this organization has helped amateurs learn the basics of photometry and how to make scientifically useful observations.

A great example of this occurred in 2010, when amateur astronomer Barbara Harris observed a sudden outburst of the variable star U Scorpii. Harris and other amateurs had enlisted in an AAVSO campaign to monitor this star for an eruption predicted by a professional astronomer. Harris got up to let her dog out, flipped on her telescope, and won the celestial lottery! Well, it wasn't quite that simple, but just like in all forms of photography, "being there" is the most important thing.

If variable stars don't interest you, the AAVSO also offers an exoplanet program in which amateurs can contribute follow-up observations of stars with orbiting planets

▲ **BIG PAYOFF** While methodically imaging the star U Scorpii every clear morning, AAVSO member Barbara Harris made the discovery observations of the variable star going into outburst.

WOMAN WITH TELESCOPE: BARBARA HARRIS

▲ **CONTRIBUTING TO DISCOVERY** There are still lots of things to find in the night sky, and some of them are within reach of amateurs with relatively modest equipment. The mosaic above shows a thin arc of nebulosity discovered in Ursa Major by a team of astronomers and verified by the amateur MDW Sky Survey using a pair of 5-inch refractors (*S&T:* Oct. 2020, p. 11).

discovered by the Transiting Exoplanet Survey Satellite (TESS) telescope. Making an observation that confirms the existence of a planet around another star would be a pretty exciting use for a backyard telescope, and it can be performed with photometry and telescopes as small as 6-inch aperture (see our December issue, page 60).

▶ **SOLAR SYSTEM DISCOVERIES** Many amateurs concentrate on studying the solar system. Christopher Go has made several important discoveries, including witnessing major changes in a large storm on Jupiter (seen here passing south of the Great Red Spot on August 25, 2020).

Solar System Studies

Closer to home, objects in our solar system exhibit a great deal of dynamic activity that we still have much to learn about. If this interests you, there are two organizations that you can get involved with — the Association of Lunar & Planetary Observers (**alpo-astronomy.org**), and the British Astronomical Association (**britastro.org**). Both have programs covering solar system objects, from the Sun, Moon, and planets to asteroids and comets. For example, amateurs can submit their images of sunspots to a repository that documents how these features evolve over time. Other examples include recording storms and weather events on Mars, Jupiter, Saturn, Uranus, and Neptune. These observations contribute to the pool of data and aid our understanding of the planets. Taking part in this research is within the reach of many amateur astronomers and imagers.

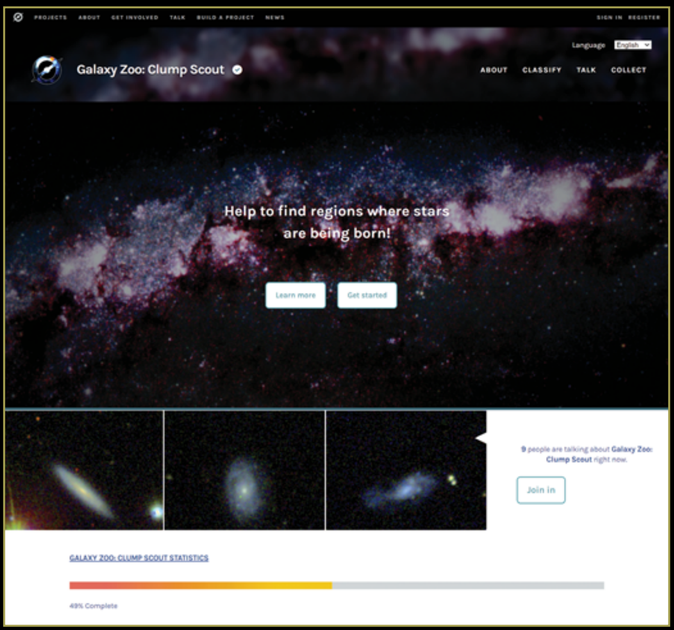
A great example of an imager making a name for himself in solar system studies is Philippine amateur Christopher Go — a man who runs a furniture company by day and methodically images the planets by night. Go has made several discoveries, including detecting a changing storm on Jupiter as well as recording an impact in the gas giant's cloudtops. Go is an excellent example of an imager whose passion blurs the lines between amateur and professional astronomy.

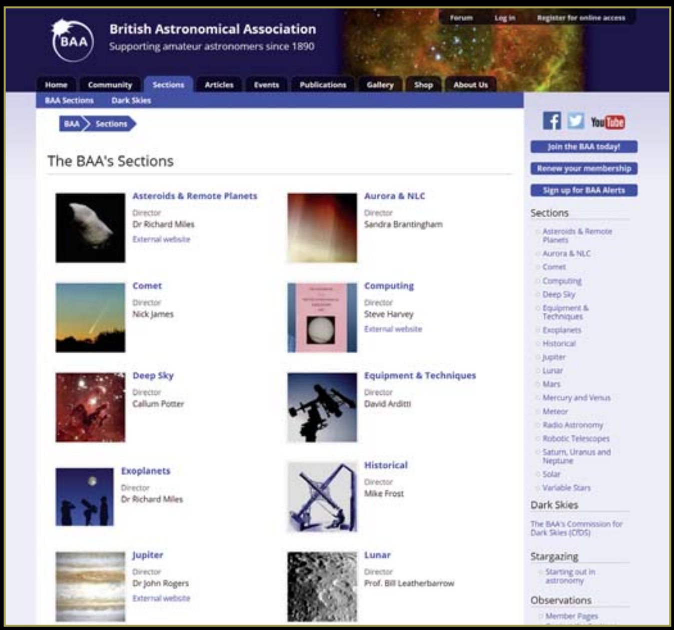
Even if you don't have any observing equipment, there are numerous citizen science projects you can participate in with just an internet connection. You can help classify galaxies with Galaxy Zoo (**zooniverse.org**) or classify craters on the Moon and map the extent of impact ejecta on asteroids at CosmoQuest (**cosmoquest.org**).

Whether you are an astrophotographer taking pictures for fun, performing your own research, taking part in an orchestrated scientific data-collection program, or participating in a citizen science project, you'll be spending your time in a wonderful way. Projects such as these build scientific literacy and appreciation while contributing to the world's astronomical and artistic richness. How deep you choose to delve into this fantastic hobby is completely up to you.

■ **RICHARD WRIGHT**, a lifelong amateur astronomer, is a software engineer specializing in computer visualizations and high-performance GPU technologies.

JUPITER: CHRISTOPHER GO





▲ *Left:* You can contribute to astronomical research without even owning your own telescope. Galaxy Zoo, for example, is a crowdsourcing program that uses the power of the internet to let you help identify star-forming regions in other galaxies and work on other big data projects. *Right:* Organizations such as the Association of Lunar & Planetary Observers (ALPO) and the British Astronomical Association (BAA) are made up entirely of amateurs who study objects in our solar system.

1 **EVENING:** The soft glow of the zodiacal light should be visible above the western horizon after sunset. Look for a hazy pyramid of light stretching up through Taurus into Gemini and beyond. From a dark viewing spot away from city lights, you could enjoy this sight for the next fortnight or so.

1 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:21 p.m. PST (11:21 p.m. EST; see page 50).

2 **DAWN:** Look to the southwest to see the waning gibbous Moon in Virgo, less than 5° above Spica.

2 **EVENING:** Mars glides past the Pleiades the next three evenings. About 2° separates the Red Planet from the Seven Sisters (see page 46).

4 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:10 p.m. EST.

5 **DAWN:** Look low above the east-southeastern horizon to spot Jupiter and Mercury (see page 46). A little less than 20′ separates the solar system's largest planet from its smallest. Saturn gleams upper right of the pair. Catch this sight before the Sun rises.

5 **DAWN:** Turn south to see the last-quarter Moon about 5° from the Scorpion's heart, the smoldering supergiant Antares.

14 **DAYLIGHT-SAVING TIME STARTS** at 2 a.m. for most of the United States and Canada.

18 **DUSK:** The waxing crescent Moon, Aldebaran, Mars, and the Pleiades are pleasingly arranged in a parallelogram.

19 **DUSK:** The Moon has hopscotched over the head of the Bull and forms a tidy triangle with Aldebaran and Mars.

20 **SPRING BEGINS** in the Northern Hemisphere at the equinox, 5:37 a.m. EDT (2:37 a.m. PDT).

22 **DUSK:** Continuing its climb along the ecliptic, the Moon, one day past first quarter, is in Gemini, some 5° from Pollux.

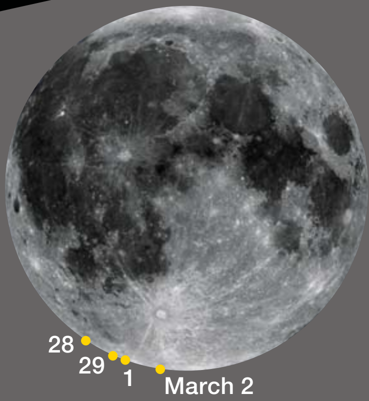
23-24 **ALL NIGHT:** The Moon visits the Beehive Cluster (M44) in Cancer. The pair move closer together as they sink toward the western horizon in the predawn hours (see page 47).

24 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 7:55 p.m. PDT.

25 **EVENING:** As it continues to wax, the gibbous Moon rolls into Leo, where you'll find it above the southeastern horizon, some 4° from Regulus.
— DIANA HANNIKAINEN

▲ NGC 2818 is located some 7,000 light-years away in Pyxis, the Mariner's Compass. This Hubble Space Telescope image highlights elements that contributed to the progenitor star's chemical makeup: nitrogen (colored red), hydrogen (green), and oxygen (blue). You'll need a telescope to spot this planetary nebula (see page 58 for more). NASA / ESA / HUBBLE HERITAGE TEAM / STSCI / AURA

MARCH 2021 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart



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

NASA / LRO

MOON PHASES

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

LAST QUARTER
March 6
01:30 UT

NEW MOON
March 13
10:21 UT

FIRST QUARTER
March 21
14:40 UT

FULL MOON
March 28
18:48 UT

DISTANCES

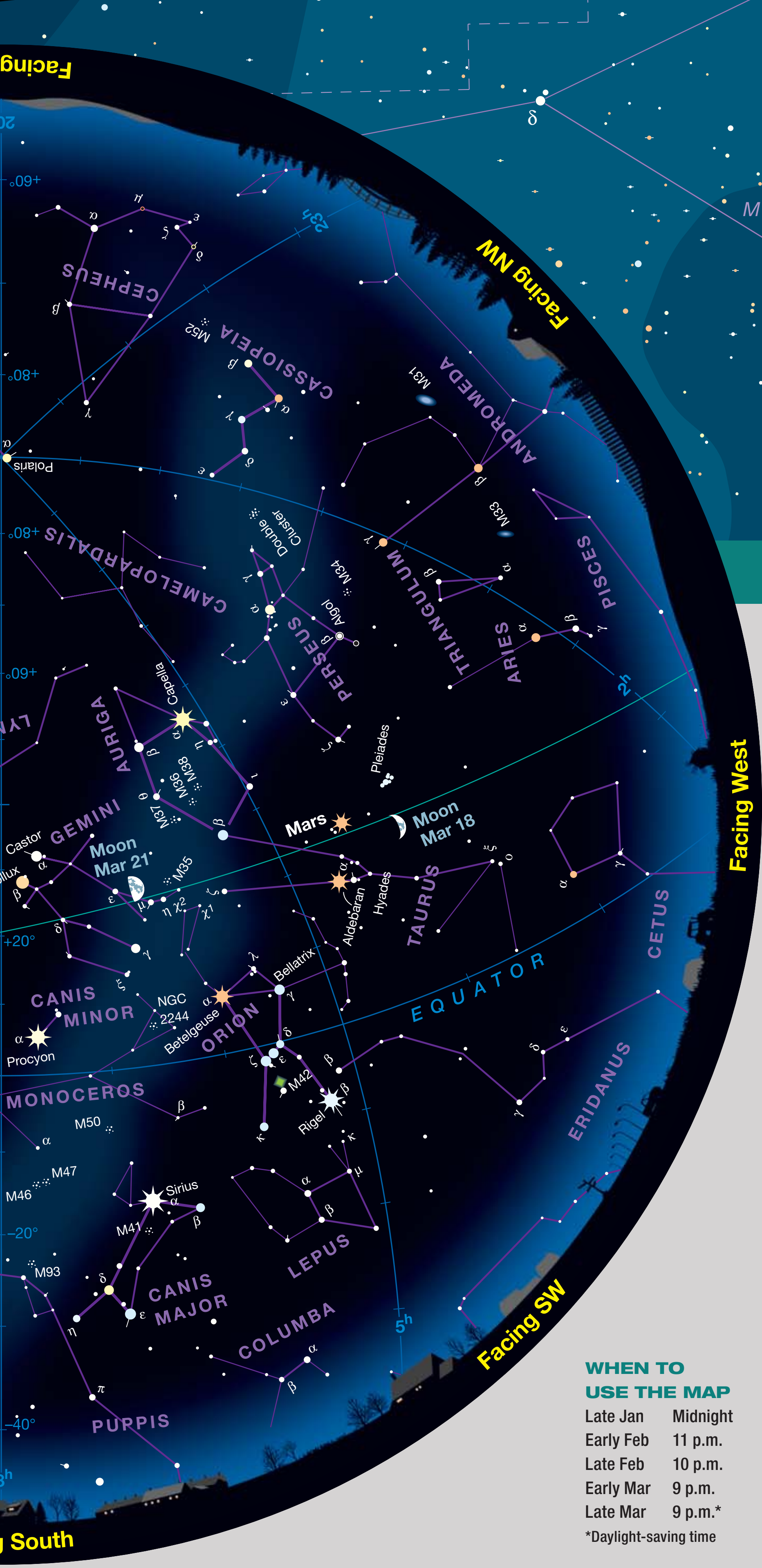
Perigee	March 2, 05^h UT
365,423 km	Diameter 32′ 42″
Apogee	March 18, 05^h UT
405,253 km	Diameter 29′ 29″
Perigee	March 30, 06^h UT
360,312 km	Diameter 33′ 10″

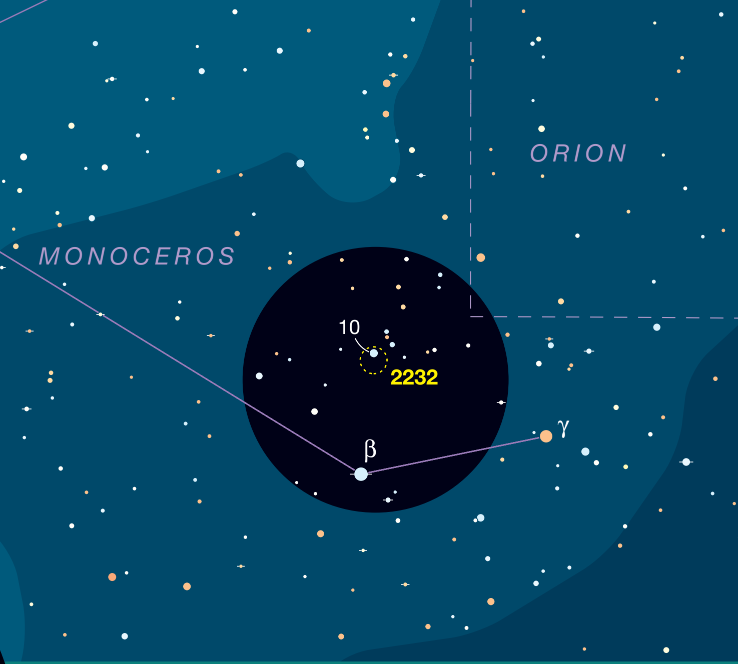
FAVORABLE LIBRATIONS

• Bailly Crater	March 1
• Drygalski Crater	March 2
• Pingré Crater	March 28
• Hausen Crater	March 29

Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

Birthplace of Worlds

One of my favorite objects in Monoceros, the Unicorn, is the open cluster **NGC 2232**. You'll find it 2° north of Beta (β) Monocerotis, which is itself a fabulous multiple star to revisit with a telescope. But back to NGC 2232: at magnitude 4.2 and almost a degree across, it's big, bright, and shows interesting detail even at binocular magnifications. In particular, look for the 5th-magnitude star 10 Monocerotis near the center, with lobes of stars extending to the northwest and southeast. We can see this level of detail because NGC 2232 is fairly close as open clusters go, just a little more than 1,000 light-years away. NGC 2232 is also a young cluster, between 25 and 30 million years old. That's almost half of the time that separates us from *T. rex*, but on an astronomical timescale, it's just a tick of the clock.

After the Sun formed, it may have taken 100 million years for the Earth and other rocky planets to coalesce. We might expect that after only 30 million years, planets would still be in the process of forming around the young stars of NGC 2232. And, in fact, that seems to be precisely the case. The Spitzer Space Telescope found evidence of debris disks around several stars in NGC 2232 that are thought to be related to the formation of new planets.

As observers we tend to get excited about stellar nurseries, like the Great Nebula in Orion (M42), where new stars are coming into being. Viewing NGC 2232 allows us to contemplate another stage in the life cycle of stellar systems: planetary nurseries. We can't see them with our binoculars, but new worlds are being born out there — something we clever primates just figured out this century. What will we learn next?

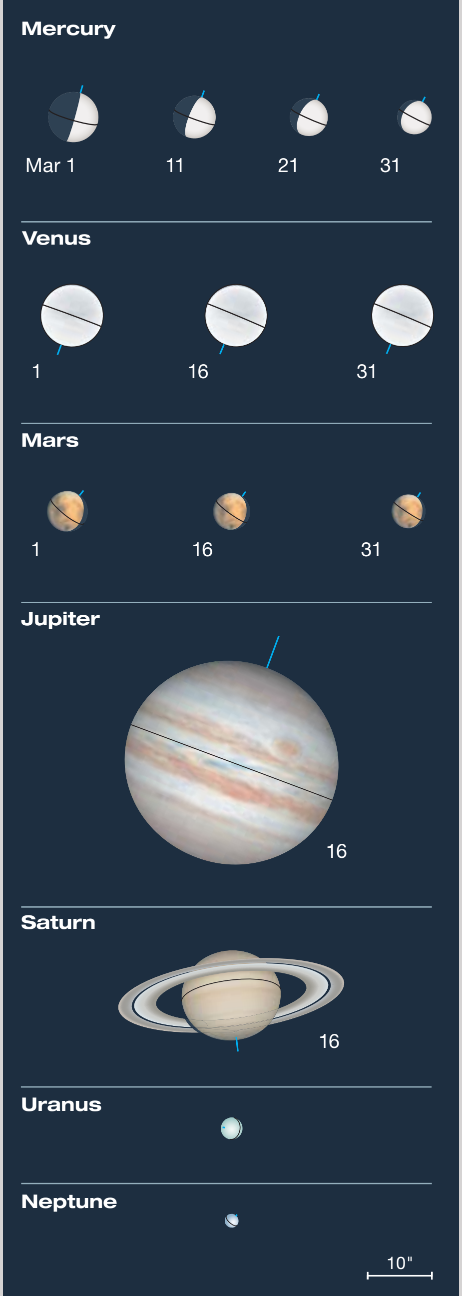
■ After 13 years of stargazing, **MATT WEDEL** is staggered by the thought that objects as vast and complex as planets and stars — and brains — can form at all.

WHEN TO USE THE MAP

Late Jan	Midnight
Early Feb	11 p.m.
Late Feb	10 p.m.
Early Mar	9 p.m.
Late Mar	9 p.m.*

*Daylight-saving time

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is visible at dawn through the 12th • **Venus** is hidden in the Sun's glare throughout the month • **Mars** is visible at dusk and sets after midnight • **Jupiter** and **Saturn** are visible at dawn all month.



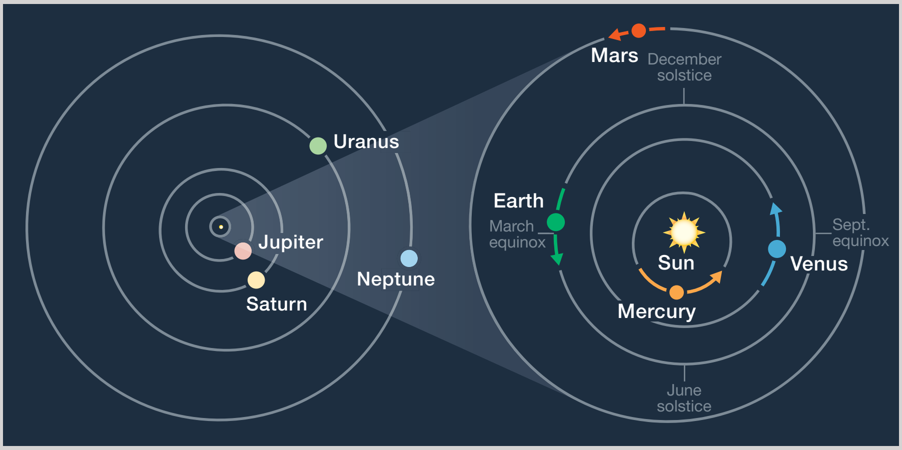
▲ **PLANET DISKS** have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

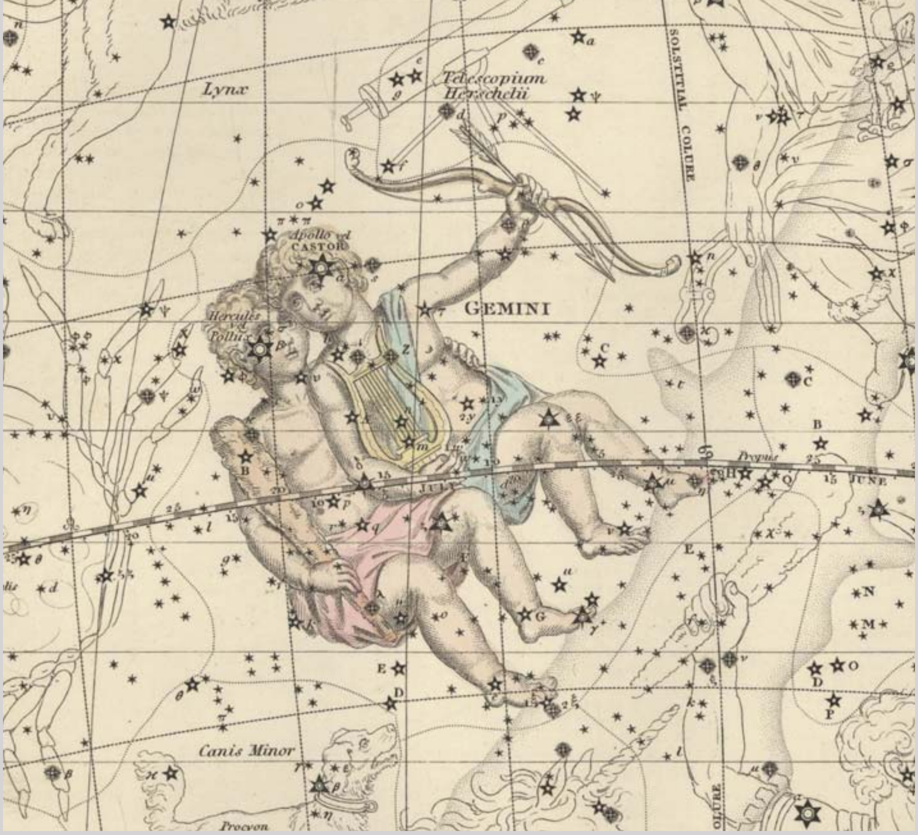
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during March. The outer planets don't change position enough in a month to notice at this scale.

March Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$22^h\ 47.4^m$	–7° 42′	—	–26.8	32′ 17″	—	0.991
	31	$0^h\ 37.5^m$	+4° 03′	—	–26.8	32′ 01″	—	0.999
Mercury	1	$21^h\ 04.5^m$	–16° 11′	27° Mo	+0.2	7.8″	47%	0.859
	11	$21^h\ 44.9^m$	–14° 45′	27° Mo	0.0	6.7″	63%	1.010
	21	$22^h\ 37.2^m$	–10° 59′	24° Mo	–0.1	5.9″	75%	1.141
	31	$23^h\ 36.2^m$	–5° 08′	18° Mo	–0.4	5.4″	85%	1.250
Venus	1	$22^h\ 25.7^m$	–11° 18′	6° Mo	–3.9	9.8″	99%	1.704
	11	$23^h\ 12.6^m$	–6° 39′	4° Mo	–3.9	9.7″	100%	1.715
	21	$23^h\ 58.5^m$	–1° 42′	2° Mo	–4.0	9.7″	100%	1.721
	31	$0^h\ 44.0^m$	+3° 20′	2° Ev	–4.0	9.7″	100%	1.723
Mars	1	$3^h\ 41.1^m$	+21° 05′	78° Ev	+0.9	6.4″	90%	1.466
	16	$4^h\ 18.1^m$	+22° 52′	71° Ev	+1.1	5.8″	90%	1.611
	31	$4^h\ 56.6^m$	+24° 08′	65° Ev	+1.3	5.3″	91%	1.751
Jupiter	1	$21^h\ 15.8^m$	–16° 30′	24° Mo	–2.0	33.0″	100%	5.965
	31	$21^h\ 41.2^m$	–14° 33′	47° Mo	–2.1	34.7″	99%	5.688
Saturn	1	$20^h\ 42.9^m$	–18° 40′	32° Mo	+0.7	15.4″	100%	10.802
	31	$20^h\ 54.4^m$	–17° 58′	59° Mo	+0.8	15.9″	100%	10.447
Uranus	16	$2^h\ 22.8^m$	+13° 46′	43° Ev	+5.8	3.4″	100%	20.483
Neptune	16	$23^h\ 26.9^m$	–4° 44′	5° Mo	+8.0	2.2″	100%	30.917

The table above gives each object's right ascension and declination (equinox 2000.0) at 0^h Universal Time on selected dates, and its elongation from the Sun in the morning (Mo) or evening (Ev) sky. Next are the visual magnitude and equatorial diameter. (Saturn's ring extent is 2.27 times its equatorial diameter.) Last are the percentage of a planet's disk illuminated by the Sun and the distance from Earth in astronomical units. (Based on the mean Earth–Sun distance, 1 a.u. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit skyandtelescope.org.





▲ **DYNAMIC DUO** Gemini, the mythological twins, are portrayed in this chart from Alexander Jamieson's 1822 *Celestial Atlas*.

Gemini's Like and Unlike Twins

Castor and Pollux share many similarities, but both stars are unique.

Two bright stars shine almost overhead on March evenings for observers at mid-northern latitudes. The fact that the stellar pair are only 4½° apart and similarly bright has brought them great attention throughout history. Their location in the zodiacal constellation Gemini further helps their recognition since they're near enough to the ecliptic that the Moon passes by fairly closely each month, and once in a while so does a planet.

Naturally, this pair of almost-twin stars are named after the most famous twins in history: the mythological brothers Castor and Pollux.

Compare and contrast Pollux and Castor. Stargazers often refer to the twosome as Pollux and Castor because Pollux is slightly brighter, but in mythology the tradition is to reverse the order to Castor and Pollux. This may explain why Castor received the Greek-letter designation Alpha Geminorum instead of its brighter brother, Pollux, which instead is the constellation's Beta star.

Pollux shines at magnitude 1.16 and Castor at 1.58. This latter places Castor in the category of 2nd-magnitude stars, albeit the second brightest, right after 1.52-magnitude Adhara (Epsilon Canis Majoris). If you look for it, you should easily note the brightness difference between Pollux and Castor, but with just a casual glance the pair seem equal.

However, the similarly bright duo have subtly different hues. Some people have more acute color sensitivity at night than others, yet I believe most observers can see the contrast between orange Pollux and white Castor. A few nights before writing this column, I stepped outside and easily discerned Pollux's warm tint. Astronomers use the B–V index to express star colors, and by that measure, Pollux is pegged about midway between yellow Capella and orange Arcturus. Where the Gemini pair really contrast is in their physical natures.

Pollux and Castor as suns. To compare actual stellar luminosity, astronomers refer to a star's *absolute visual magnitude* — how bright a star would appear if placed at the standard distance of 32.6 light-years (10 parsecs). Pollux is 34 light-years from Earth, so it would brighten imperceptibly from magnitude 1.16 to 1.09 if moved to the standard distance. On the other hand, Castor lies 52 light-years away, so moving it to 32.6 light-years brightens it from magnitude 1.58 to 0.59. That's still not tremendously brighter than Pollux.

There's a catch to this comparison in absolute magnitudes, however. Pollux is believed to be a single star. But as typical backyard telescopes show, Castor is a thrilling pair of white stars of magnitude 1.93 and 2.97, which appear very close (5.2″) together. Castor's two suns take about 445 years to orbit around each other and are accompanied by a third star, Castor C — a 10th-magnitude orange star. But that's not all. Spectroscopes reveal that each of the three are in turn double stars, so Castor is in fact a six-star system. We don't know if there are any planets orbiting these stars, but just imagine the sight of six suns rising and setting from the surface of such a world!

What about twin Pollux? In 2006 researchers found strong evidence of a planet circling the star. Designated Pollux b, the exoplanet is twice as massive as Jupiter itself, and it orbits Pollux once every 1.61 years at a distance somewhat greater than Earth is from the Sun. Pollux would be blindingly bright as seen from that planet, since the giant star is 33 times more luminous than our Sun.

■ **FRED SCHAAF** founded the South Jersey Astronomy Club on a spring day 32 years ago.

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

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

Red Planet Rendezvous

Mars has a close dusk encounter with the Pleiades, while Jupiter and Mercury meet at dawn.

THURSDAY, MARCH 4

Mars has been drifting closer and closer to the Pleiades, and this evening it's at its very closest — just a shade more than 2½° from the cluster's center. Shining at magnitude 1.0, the Red Planet has been within a 5° binocular field of the Pleiades since February 25th and remains so until March 11th. And though the sight can be appreciated with your eyes alone, binoculars or a small, wide-field telescope adds many more Pleiads to the mix and enhances the color contrast between the icy-blue cluster stars and the ruddy planet.

What's particularly notable about the March 4th encounter is that Mars hasn't been this close to the Pleiades since 2006, and you'll have to wait until 2038 to see it pass this near again. Look for both objects high in the southwest at nightfall. Mars and the cluster set around midnight, local standard time.

FRIDAY, MARCH 5

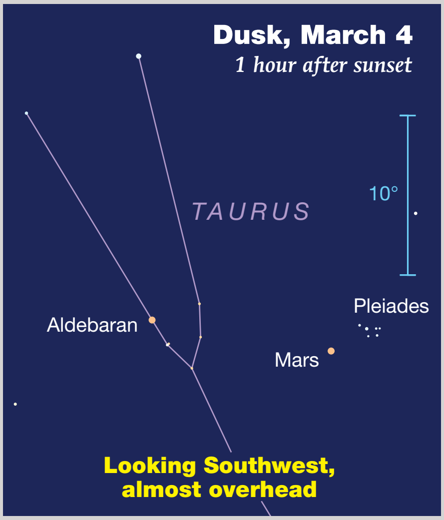
Early risers have an added incentive to get up before dawn today as fast-moving **Mercury** pulls up alongside lumbering **Jupiter** low in the east-southeast. The two planets will be nearest each other this morning at 5:55 UT, when they're separated by just a little more than 19′. By the time the pair rises for observers on the East Coast of North America, the gap between the planets will have widened a hair, to about 21′.

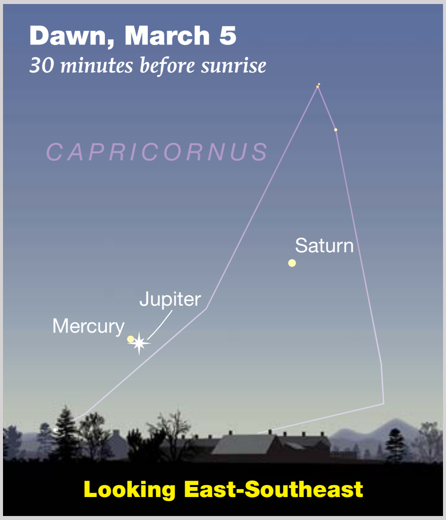
Mercury shines at magnitude +0.1 while Jupiter gleams at magnitude –2.0, ensuring a wonderfully eye-catching sight. And that's without taking into account **Saturn**, loitering 8½° to the upper right and shining at magnitude +0.7. Aim binoculars or a telescope (with modest magnification) at the tight twosome and you'll get to include a couple of Jupiter's moons in the view as well. If the weather doesn't cooperate on the 5th, bear in mind that Mercury is less than 1° from Jupiter on the mornings of the 4th and 6th as well.

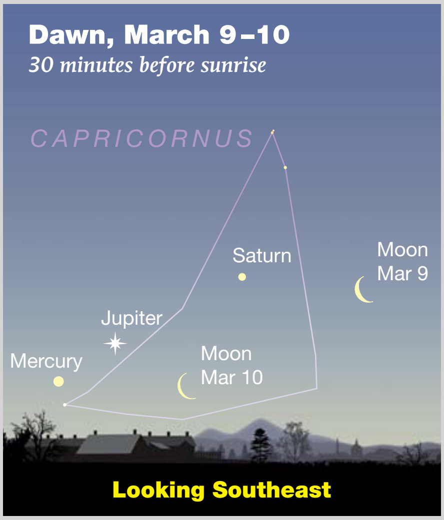
SATURDAY, MARCH 6

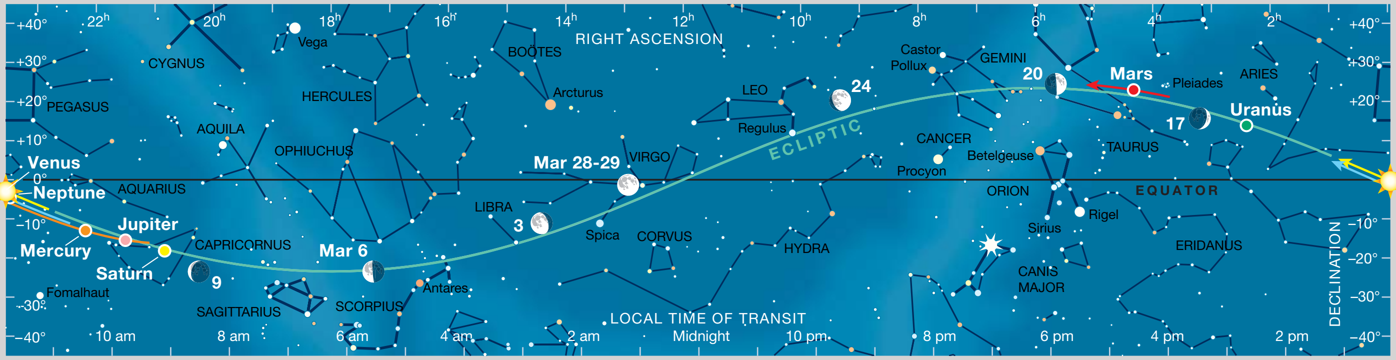
Today **Mercury** has its greatest elongation from the Sun, with the planet positioned 27.3° west of the solar disk. This is the biggest separation between the two objects for all of 2021, and yet the result is a decidedly mediocre showing for Mercury. It rises around one hour ahead of the Sun and was actually higher in the morning sky at the end of February. Why is that? It's because the ecliptic is canted at a rather shallow angle with the dawn horizon during spring for observers at mid-northern latitudes. Your best opportunity to catch Mercury in the morning sky occurs in October, even though the planet will then be nearly 10° closer to the Sun than on March 6th. You can

▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway.







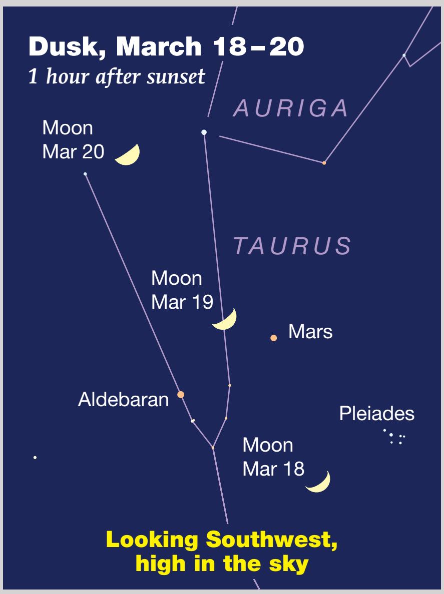


▲ The Sun and planets are positioned for mid-March; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

thank celestial geometry once again: During autumn, the ecliptic is nearly perpendicular to the eastern horizon at dawn.

TUESDAY, MARCH 9

The morning sky continues to be a hub of activity in Capricornus as the waning crescent **Moon** joins **Saturn**, **Jupiter**, and **Mercury**. At dawn today, the Moon is positioned roughly 7½° to the right of Saturn. The westernmost of the three morning planets, Saturn currently rises more than 1½ hours before the Sun but only about ½ hour ahead of brilliant Jupiter. On the following morning (March 10th), the Moon has shifted eastward to sit about 5° lower right of Jupiter.

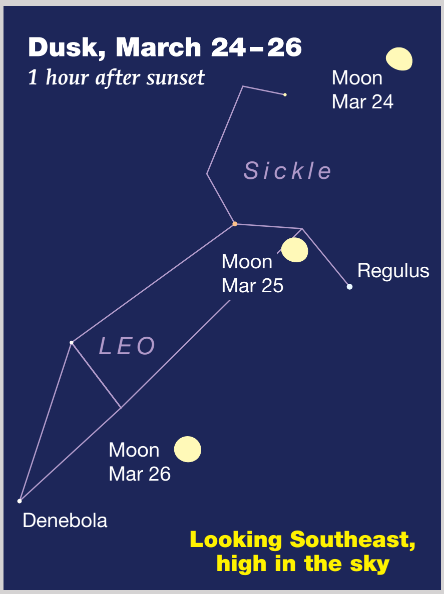


FRIDAY, MARCH 19

Continuing its eastward crawl along the ecliptic, **Mars** has moved away from the Pleiades and this evening finds itself joined by the waxing crescent **Moon**. The two worlds appear separated by roughly 3°, which means a pair of binoculars will nicely show them together in the same field of view. But the best perspective may be with your eyes alone since you'll be able to take in the entire Taurus scene, including the Hyades and Pleiades clusters and golden Aldebaran.

WEDNESDAY, MARCH 24

In the predawn hours, binocular observers on the West Coast will get to see the gibbous **Moon** due north of the Beehive Cluster, M44, in Cancer.



(Those farther east will see the Moon approaching near the cluster as the two objects set at around 5 a.m. local daylight time.) At its closest, the lunar disk will be roughly 1½° north of the cluster's center. Although glare from the lunar disk will extinguish the Beehive's fainter bees, the brightest members of the swarm are luminous enough to shine through the moonlight.

THURSDAY, MARCH 25

Look high in the southeast this evening to see the gibbous **Moon** (90% illuminated) about 4° above 1.4-magnitude Regulus, the brightest star in Leo. Fans of celestial symmetry will note that between 11 p.m. and midnight (EDT) the Moon is almost exactly midway between Regulus and 2.2-magnitude Gamma Leonis, also known as Algieba. Typical 50mm binoculars can show you the Moon and Regulus together or the Moon and Algieba together — but not all three at the same time.

FRIDAY, MARCH 26

Today **Venus** is in conjunction with the Sun — a milestone that marks the end of the brilliant planet's current apparition and the start of a new one. Venus reemerges as the Evening Star in mid-April and will be at its highest at dusk next autumn.

■ Consulting Editor **GARY SERONIK** has been watching the sky for five decades and considers the Moon a close personal friend.

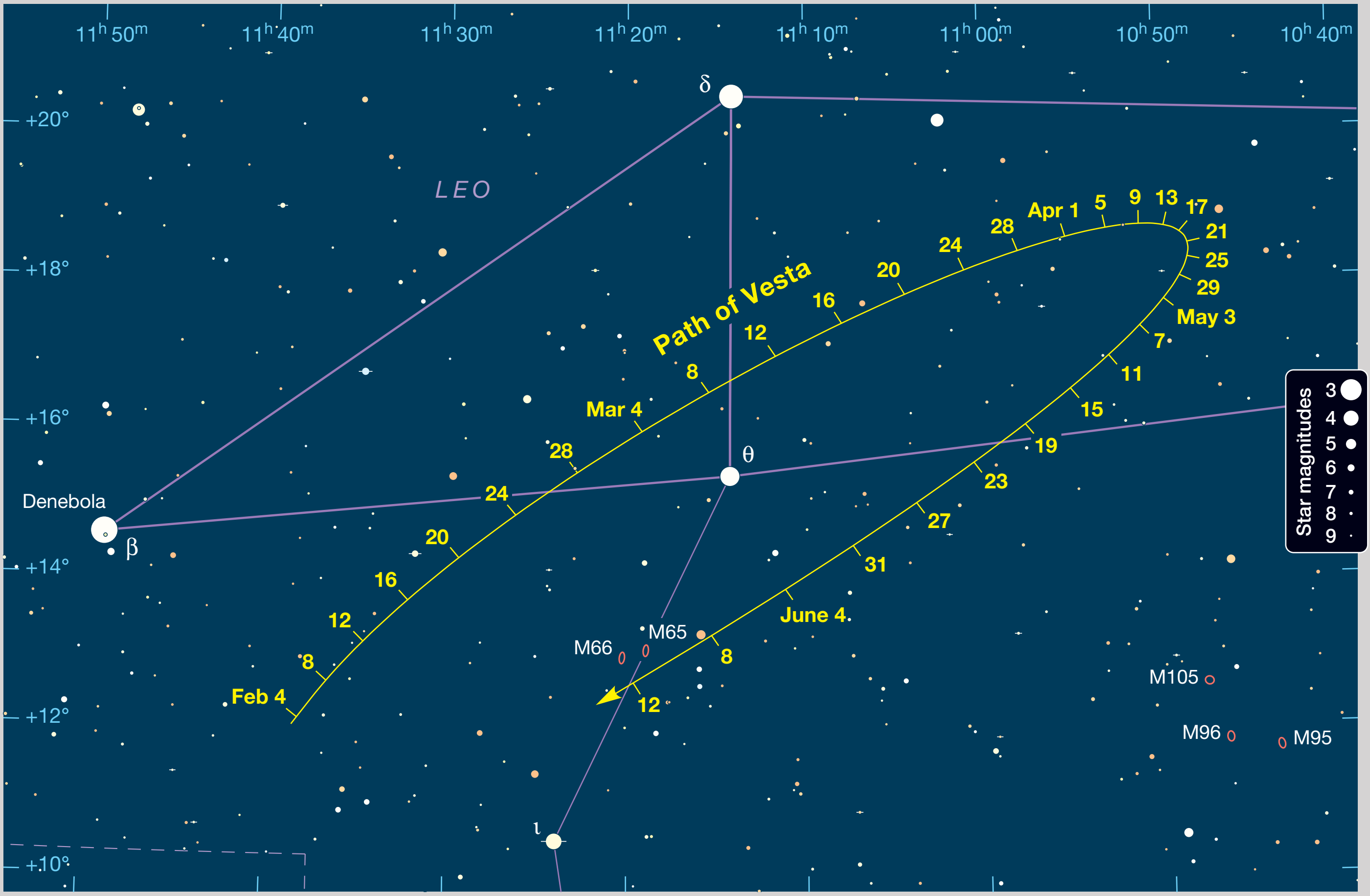
Vesta Reaches Opposition

The solar system's brightest asteroid is at its best as it loops through Leo.

With a mean diameter of 525 km (326 miles), 4 Vesta is not only the second largest main belt asteroid (after Ceres, 946 km) but also the brightest. If you swapped our Moon for Vesta, the asteroid would look like a baby white potato with an apparent diameter of 4.7′ — about half the width of the Moon's Mare Imbrium. But Vesta would shine spotlight-bright because it's nearly four times as reflective as our satellite neighbor.

Vesta reaches opposition on March 4th and is closest to Earth on the 9th, when it's at a distance of 204 million km. At its brightest, Vesta can reach magnitude 5.1, as it did in June 2018 and will again in July 2029. This year's apparition is quite favorable, with the asteroid brightening to magnitude 5.8, making it potentially naked-eye visible under rural skies, and an easy target for binoculars even from moderately light-polluted locations.

If you've never glimpsed an asteroid without optical aid before, this year's Vesta opposition provides a good opportunity. The asteroid's northerly declination (+16°) and proximity to 3rd-magnitude Theta (θ) Leonis both aid that goal. An additional plus is that no similarly bright stars are near the asteroid to confuse the sighting. During March, Vesta is well-placed in the eastern sky at around 9 p.m. local time and crosses the meridian around midnight. On the nights of March 20th and 21st, it passes close to the faint spiral galaxies NGC 3507 (magnitude 11.9) and NGC 3501 (13.0).



▲ **ASTEROID INSPECTED** The Dawn spacecraft captured this image of Vesta as it studied the asteroid from July 2011 to September 2012. The conspicuous mountain at the south pole (bottom) is the central peak of Rheasilvia, a 505-kilometer-wide crater excavated about a billion years ago.

NASA's Dawn spacecraft parked itself in orbit around Vesta from July 2011 to September 2012 to map and characterize the asteroid with a suite of instruments. Significantly, it found that the object is a differentiated protoplanet with an iron-rich core, silicate mantle, and basaltic crust. So far, Vesta is the only confirmed cased of a differentiated protoplanet — bodies like it were either incorporated into the newly formed planets or destroyed in collisions during the solar system's infancy. Vesta squeaked through intact, but barely. Two enormous impacts decimated its south polar region, excavating the 505-km-wide crater Rheasilvia and its older cousin, 395-km-wide Veneneia.

Fragments from the dual cataclysms are the likely source of both the Vesta family of asteroids and a subgroup of meteorites called howardites, eucrites, and diogenites — collectively known as the HED clan. Scientists had suspected a Vesta-HED connection for years based on spectroscopic similarities, but Dawn's in situ measurements clinched the relationship.

Incredibly, you can purchase a piece of an HED meteorite online. Imagine having one of those in hand as you spy Vesta in your telescope!

VESTA: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA; MUTUAL EVENTS: WINJUPOS

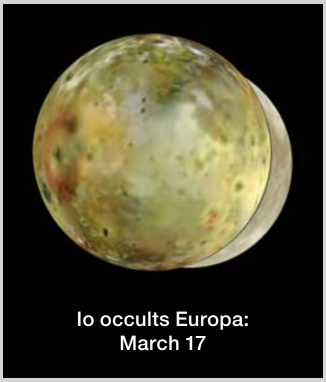
Mutual Event Season is Underway

EVERY SIX YEARS the orbital plane of Jupiter's four Galilean moons is edge-on with the Sun and Earth, and we enter mutual event season, when Jupiter's Galilean moons occult and eclipse one another. The current season began on January 3rd when Europa partially eclipsed Io and will wrap up on November 16th with a Ganymede-Io occultation. Jupiter's low altitude and proximity to the Sun precluded viewing the first part of this celestial hide-and-seek show, but by mid-March the planet is high enough in the early dawn for good views.

An *eclipse* occurs when the shadow of one moon lands on the surface of another. An *occultation* happens when the disk of one moon covers the disk of another. Eclipses and occultations can be partial to near-total. The greater the brightness drop, the more dramatic the event. During a deep eclipse, you can watch a moon nearly fade away. In central occultations, one moon approaches another and the two briefly merge into a single object before parting again. I always get a kick out of these temporary arrangements because they allow me to see the movement of the Jovian moons in near-real time.

Easiest to observe are events in which the brightness of the occulted or eclipsed moon dips by 0.3 magnitude or more. The table below includes the best ones visible from the Americas from mid-March through mid-April. (Note that some of these events may occur in daylight from your location.)

For a complete list of mutual events, or to generate predictions for your area, visit **https://is.gd/mutualevents**.



Io occults Europa: March 17

Ganymede eclipses Europa: April 15

▶ **MUTUAL EVENTS** These two simulations depict the circumstances of an eclipse and an occultation visible in the Americas. Both produce brightness changes great enough to be detected in amateur telescopes.

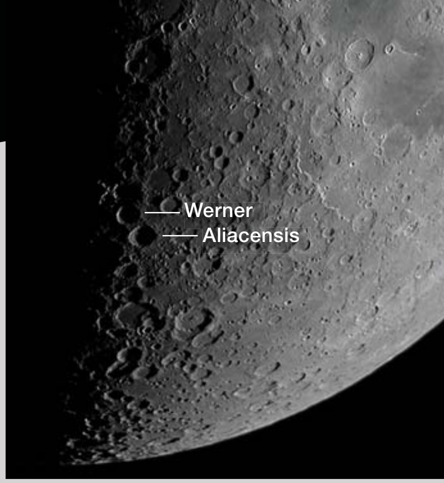
Selected Jupiter Mutual Satellite Events

Date	Time (UT)	Event	Mag change
March 17	13:04 – 13:08	Io occults Europa	0.6
March 29	12:06 – 12:14	Io occults Ganymede	0.4
March 30	9:30 – 9:35	Europa eclipses Io	0.5
April 1	13:17 – 13:23	Ganymede occults Io	0.6
April 6	11:46 – 11:51	Europa eclipses Io	0.3
April 11	10:01 – 10:11	Io eclipses Callisto	0.4
April 12	11:51 – 12:13	Io eclipses Callisto	0.5
April 15	10:08 – 10:16	Ganymede eclipses Europa	0.5

Lunar X Marks the Equinox

SPRING OFFICIALLY BEGINS at 5:37 a.m. EDT on March 20th. That evening, observers across North America can mark the occasion by sighting the Lunar X (also called the Werner X). The X is a trick of lighting that occurs around the time of first-quarter phase, as portions of three adjoining craters walls are illuminated to form a bright and striking letter X. The pattern should be most prominent from around 8 to 9 p.m. EDT.

To navigate to the X, locate the crisply defined, 70-km-diameter crater Werner and its neighbor Aliacensis (79 km) on the daylit side of the terminator, about a third of the way from the southern limb. Three craters immediately to the north and west of Werner — Blanchinus, La Caille, and Purbach — will still be partially steeped in shadow, but their adjoining walls are tall enough to catch the first rays of the rising Sun



▲ **EXCITING X** Henrik Adamsson captured the fleeting lunar X on February 22, 2018. For a couple of hours at first-quarter phase, the adjoining walls of three craters catch the first rays of light from the rising Sun to form a strikingly illuminated letter X just northwest of Werner.

and flash out a jaggedy letter X.

Because the Sun rises about 30 times slower on the lunar surface than here on Earth, the X pattern gradually emerges over a period of more than two hours. A peak on Purbach's southeastern wall is the first feature to appear out of the blackness, while the last is the hollow where the three walls join. The X boldly glows above the dark, shadow-filled interiors of the three craters for about 70 minutes before blending into the moonscape.

Sighting the X makes for a wonderful evening observing session accessible to anyone with a modest telescope.

Minima of Algol

Feb.	UT	Mar.	UT
1	12:07	2	4:21
4	8:57	5	1:10
7	5:46	7	21:59
10	2:35	10	18:49
12	23:25	13	15:38
15	20:14	16	12:27
18	17:03	19	9:16
21	13:53	22	6:06
24	10:42	25	2:55
27	7:31	27	23:44
		30	20:33

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**.

▲ Perseus is high in the northwest during evening hours in March. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

JUPITER WAS IN CONJUNCTION with the Sun at the end of January, rendering it essentially unobservable for much of February. (The list of Great Red Spot transit times below omits dates when the planet is out of view.) Jupiter returned to the dawn sky as a naked-eye object around February 19th and has been slowly gaining elevation ever since. By mid-March, it rises nearly 1½ hours before the Sun. On March 15th it shines at magnitude –2.0 and presents a disk 34″ in diameter.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. The moons orbit Jupiter at different rates, changing positions along an almost straight line from our point of view on Earth. Use the diagram on the facing page to identify them by their relative positions on any given date and time.

All the observable March interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for dawn 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.)

February 19: 0:42, 10:38, 20:34; **20**: 6:30, 16:26; **21**: 2:22, 12:17, 22:13; **22**: 8:09, 18:05; **23**: 4:01, 13:56, 23:52; **24**: 9:48, 19:44; **25**: 5:40, 15:35; **26**: 1:31, 11:27, 21:23; **27**: 7:19, 17:14; **28**: 3:10, 13:06, 23:02

March 1: 9:01, 18:57; **2**: 4:53, 14:48; **3**: 0:44, 10:40, 20:36; **4**: 6:32, 16:27; **5**: 2:23, 12:19, 22:15; **6**: 8:11, 18:06; **7**: 4:02, 13:58, 23:54; **8**: 9:50, 19:45; **9**: 5:41, 15:37; **10**: 1:33, 11:29, 21:24; **11**: 7:20, 17:16; **12**: 3:12, 13:07, 23:03; **13**: 8:59, 18:55; **14**: 4:51, 14:46; **15**: 0:42, 10:38, 20:34; **16**: 6:03, 16:25; **17**: 2:21, 12:17, 22:13; **18**: 8:09, 18:04; **19**: 4:00, 13:56, 23:52; **20**: 9:47, 19:43; **21**: 5:39, 15:35; **22**: 1:31, 11:26, 21:22; **23**: 7:18, 17:14; **24**: 3:10, 13:05, 23:01; **25**: 8:57, 18:53; **26**: 4:48, 14:44; **27**: 0:40, 10:36, 20:31; **28**: 6:27, 16:23; **29**: 2:19, 12:15, 22:10; **30**: 8:06, 18:02; **31**: 3:58, 13:53, 23:49

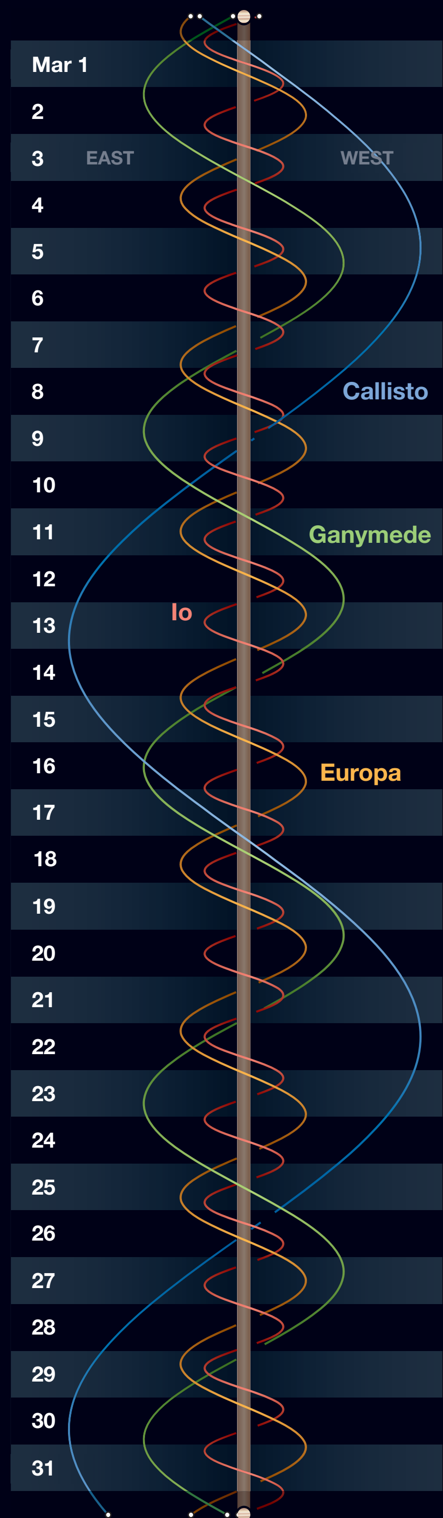
These times assume that the spot will be centered at System II longitude 355° on March 1st. If the Red Spot has moved elsewhere, it will transit 1²⁄₃ minutes earlier for each degree less than 355° and 1²⁄₃ minutes later for each degree more than 355°.

Phenomena of Jupiter's Moons, March 2021

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

◀ Atmospheric turbulence can vary greatly from night to night, or even hour by hour. This pair of of Mars images was recorded using the same telescope and camera on November 7th and 8th, 2020, as a high-pressure system settled over the northeastern United States, significantly improving telescopic views on the second night.

SEAN WALKER / S&T

Seeing for Planetary Observers

Knowing how Earth's atmosphere functions can improve your chances of experiencing good planetary views.

We live at the bottom of a turbulent ocean of air that is both the controlling and largely uncontrollable factor in determining the clarity of telescopic images. Unevenly heated from place to place, the atmosphere is filled with currents and eddies.

Warm, rarefied air refracts light less than cool, dense air. Astronomical "seeing" is caused by packets of thermally non-homogeneous air passing between the telescope and the object under scrutiny. These atmospheric "cells" typically range in size from 10 to 20 centimeters (4 to 8 inches) in diameter at most locations.

Each moving air cell acts like a weak lens, bending incoming rays of light. This has two distinct effects on a telescopic image, although they invariably occur in combination to some degree. Oscillation or "image excursion" displaces the image laterally, causing it to move randomly around a mean position in the field of view. Poor seeing also creates a defocusing effect, moving the image in and out of the telescope's focal plane, giving it an undulating appearance that's intermittently sharp.

The larger a telescope's aperture, the lower the probability that the air mass over it will be optically homogeneous. When the aperture is sufficiently large to receive light that has passed through a multitude of air cells, a blurred, washed-out image usually results. It's not uncommon for instruments of modest aperture to perform to their theoretical limits, but at most locations large telescopes rarely do so (*S&T:* Nov. 2018, p. 52). On most nights, only a patient vigil at the eyepiece allows the observer to enjoy those fleeting moments of supreme clarity that Percival Lowell called "revelation peeps."

Many novices imagine that crystal-clear winter nights with stars twinkling like flickering candles are best for telescopic observing. Such nights invariably disappoint with fuzzy, swollen images that seldom sharpen even momentarily, caused by turbulence in the jet stream at altitudes of roughly 9,000 to 18,000 meters. In fact, good seeing is often accompanied by the presence of haze, a thin deck of high cirrus clouds, or a temperature inversion. These all retard ground cooling and the turbulent convection it produces. Humid nights when the telescope drips with dew are usually excellent. Mist and fog are harbingers of superb views of the planets if the transparency doesn't suffer too much.

Virtually every location has its share of tranquil nights, but some areas have them more than others. On a global scale, the tropics and subtropics favor good seeing due to the more uniform atmospheric pressure at low latitudes.

The high apparent elevation above the horizon of the Moon and planets from low-latitude vantage points is also a considerable advantage. The thickest part of the Earth's atmosphere extends to a height of about 16 kilometers. The best seeing is found near the zenith, where the overlying blanket of air is thinnest and convective disturbances arising from the ground are minimized. The light from a celestial object 45° above the horizon passes through half again as much air as an object overhead, while the light from an object near the horizon must traverse a thickness of 160 kilometers or greater.

At temperate latitudes, the best seeing conditions generally occur from late spring through early autumn. Winter nights are frequently plagued by "fast" seeing when the jet stream is overhead.

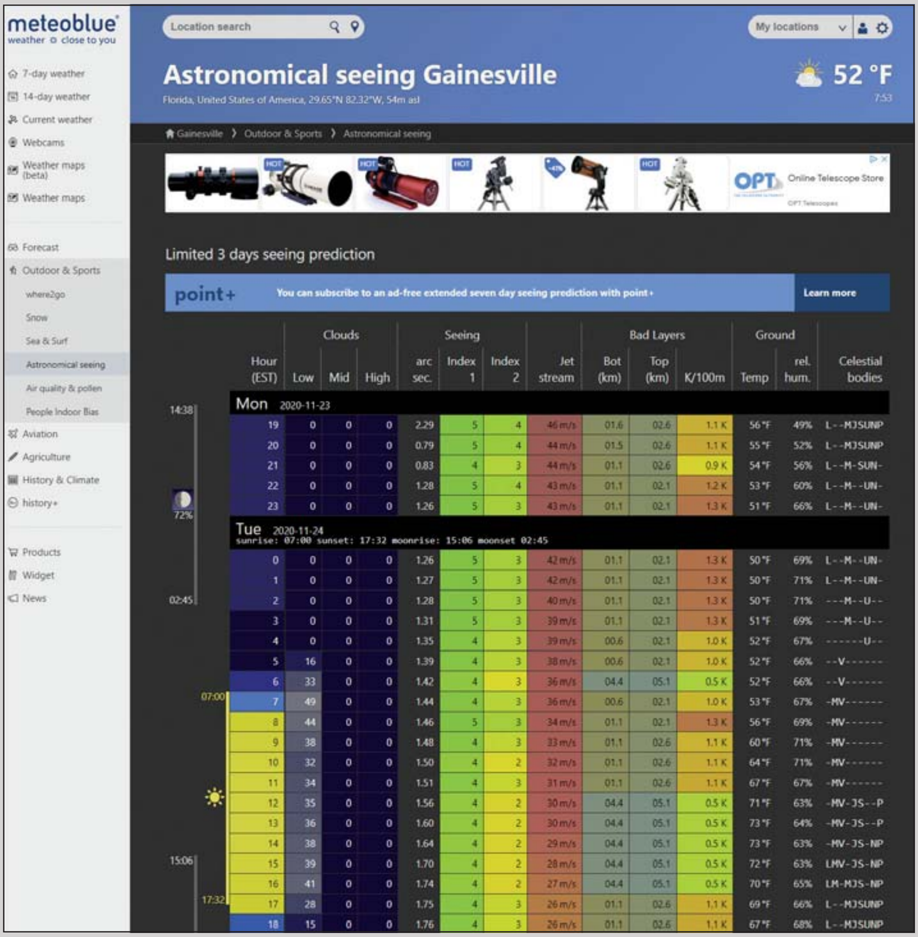
Isaac Newton suggested that mountainous regions would enjoy "serene and quiet air" because there would be less overlying atmosphere to degrade images. High elevation alone is no panacea, however, because wind blowing over peaks creates turbulent airflow. While conducting a site survey of the western United States in the 1890s, Harvard astronomer William Henry Pickering encountered chronically horrible seeing at the summit of Pike's Peak in the Colorado Rockies. Observing sites on the slopes of mountains and in valleys suffer from poor seeing produced when streams of cold air drain down from higher elevations.

Seeing is often excellent on isolated peaks, plateaus, and mesas that slope gently upward from windward to leeward. The leeward edges of these elevations tend to be especially good because cool air draining into the valleys below creates a laminar airflow.

Despite their low elevation, many coastal sites enjoy excellent seeing due to the modest diurnal temperature variation and the laminar airflow produced by onshore breezes. Both factors minimize convective turbulence. The Florida Keys are renowned for excellent seeing, as are Caribbean islands like Barbados and Jamaica.

In the Northern Hemisphere, poor seeing is almost always associated with winds from the north or northeast, while good seeing accompanies prevailing winds from the south or southwest. The air mass preceding a low-pressure system or cold front is often warmer than the underlying ground, creating a stable atmosphere for one to two nights before passage of the front. After the front passes, barometric pressure rises, and winds shift to the north or northeast. Skies become extremely transparent, but evening temperatures fall rapidly. The air tends to be colder than the ground beneath it, resulting in excessive convection and poor seeing.

▼ Several websites offer astronomical seeing predictions to help you plan your observing sessions, including Clear Sky Chart (**cleardarksky.com**) and Meteoblue (**meteoblue.com**, shown).



Hour (EST)	Clouds Low	Clouds Mid	Clouds High	Seeing arc sec.	Seeing Index 1	Seeing Index 2	Jet stream	Bad Layers Bot (km)	Bad Layers Top (km)	Bad Layers K/100m	Ground Temp	Ground rel. hum.	Celestial bodies
Mon 2020-11-23													
19	0	0	0	2.29	5	4	46 m/s	01.6	02.6	1.1 K	56 °F	49%	L--MJSUNP
20	0	0	0	0.79	5	4	44 m/s	01.5	02.6	1.1 K	55 °F	52%	L--MJSUNP
21	0	0	0	0.83	4	3	44 m/s	01.1	02.6	0.9 K	54 °F	56%	L--M-SUN-
22	0	0	0	1.28	5	4	43 m/s	01.1	02.1	1.2 K	53 °F	60%	L--M--UN-
23	0	0	0	1.26	5	3	43 m/s	01.1	02.1	1.3 K	51 °F	66%	L--M--UN-
Tue 2020-11-24 sunrise: 07:00 sunset: 17:32 moonrise: 15:06 moonset 02:45													
0	0	0	0	1.26	5	3	42 m/s	01.1	02.1	1.3 K	50 °F	69%	L--M--UN-
1	0	0	0	1.27	5	3	42 m/s	01.1	02.1	1.3 K	50 °F	71%	L--M--UN-
2	0	0	0	1.28	5	3	40 m/s	01.1	02.1	1.3 K	50 °F	71%	---M--U--
3	0	0	0	1.31	5	3	39 m/s	01.1	02.1	1.3 K	51 °F	69%	---M--U--
4	0	0	0	1.35	4	3	39 m/s	00.6	02.1	1.0 K	52 °F	67%	------U--
5	16	0	0	1.39	4	3	38 m/s	00.6	02.1	1.0 K	52 °F	66%	--V------
6	33	0	0	1.42	4	3	36 m/s	04.4	05.1	0.5 K	52 °F	66%	--V------
7	49	0	0	1.44	4	3	36 m/s	00.6	02.1	1.0 K	53 °F	67%	-MV------
8	44	0	0	1.46	5	3	34 m/s	01.1	02.1	1.3 K	56 °F	69%	-MV------
9	38	0	0	1.48	4	3	33 m/s	01.1	02.6	1.1 K	60 °F	71%	-MV------
10	32	0	0	1.50	4	2	32 m/s	01.1	02.6	1.1 K	64 °F	71%	-MV------
11	34	0	0	1.51	4	3	31 m/s	01.1	02.6	1.1 K	67 °F	67%	-MV------
12	35	0	0	1.56	4	2	30 m/s	04.4	05.1	0.5 K	71 °F	63%	-MV-JS--P
13	36	0	0	1.60	4	2	30 m/s	04.4	05.1	0.5 K	73 °F	64%	-MV-JS--P
14	38	0	0	1.64	4	2	29 m/s	04.4	05.1	0.5 K	73 °F	63%	-MV-JS-NP
15	39	0	0	1.70	4	2	28 m/s	04.4	05.1	0.5 K	72 °F	63%	LMV-JS-NP
16	41	0	0	1.74	4	2	27 m/s	04.4	05.1	0.5 K	70 °F	65%	LM-MJS-NP
17	28	0	0	1.75	4	3	26 m/s	01.1	02.6	1.1 K	69 °F	66%	L--MJSUNP
18	15	0	0	1.76	4	3	26 m/s	01.1	02.6	1.1 K	67 °F	68%	L--MJSUNP

When a high-pressure system stabilizes, an improvement in seeing can usually be expected for several days. However, as days become warmer following frontal passage, excessive ground heating may produce towering convective cumulus and cumulonimbus clouds during the afternoon. The presence of these clouds usually indicates that seeing will be mediocre well into the night.

The renowned British planetary observer William Frederick Denning claimed that he enjoyed his best views of Mercury, Venus, Mars, and Jupiter with the Sun just above the horizon. Images are often very sharp around sunset when there is a brief pause in the thermal balance between day and night and the atmosphere has not yet had time to radiate its heat into space. During this transient interlude, the atmosphere's temperature gradient (known as the *lapse rate* by meteorologists) is more uniform with altitude. Later, as heat is lost to space and terrestrial conductors, air masses begin to churn and seeing deteriorates. At most sites, turbulence begins to subside after midnight, with the best seeing usually occurring as dawn approaches.

The observer's immediate surroundings also have a profound effect on the clarity of telescopic images. A large expanse of lawn or a grass-covered field makes a good observing site. Whenever possible, avoid looking over rocky terrain devoid of vegetation, rooftops, or asphalt streets and parking lots. All of these features slowly shed the heat they accumulate during the day, producing convective turbulence long into the night. Although often impractical, viewing from a balcony or other elevated perch can improve viewing by avoiding the worst convection near ground level.

At the mercy of an atmosphere that may seem capricious and even cruel, every observer who hopes to glimpse the finest lunar and planetary details soon learns that patience and perseverance are indispensable virtues.

■ Contributing Editor **TOM DOBBINS** frequently enjoys good seeing conditions from his home in Gainesville, Florida.

All Around the Beehive

Don't bypass Cancer, a seemingly shy constellation trying hard not to be seen.

Early spring. Nightfall. Outside my suburban home, I'm gazing skyward at the barren area between Gemini and Leo, straining to identify Cancer, the Crab. Like its prominent neighbors, Cancer is a member of the exclusive zodiac club, yet the house of the Crab is barely visible. Within its boundaries, no stars shine brighter than magnitude 3.5.

Despite its low-key look, in terms of area Cancer ranks a reasonable 31st of the 88 constellations. Its 506 square degrees of celestial real estate contain targets well within range of backyard telescopes. So, grab some glass and join me as I explore the Cancer barrens.

Beehive in a Box

The top treasure in Crabland is **M44**, the Beehive star cluster. Relatively close at roughly 600 light-years, the big, bold Beehive sports a total visual magnitude of 3.1 and a diameter of 1½°. Its location in Cancer is readily ascertained. Two-fifths of the way from 1.2-magnitude Pollux in Gemini to 1.4-magnitude Regulus in Leo is a 4°-wide quadrilateral of stars reminiscent of the squarish pattern of the constellation Corvus, the Crow. I call it the Beehive Box because the Beehive Cluster is packed inside.

The Beehive Box, clockwise from its southeast corner, is formed by Delta (δ) Cancri, magnitude 3.9; Gamma (γ), magnitude 4.7; Eta (η), magnitude 5.3; and Theta (θ), magnitude 5.3. In my backyard sky I can spot only Delta and maybe Gamma. M44 is tougher still. Because its light is spread out so far, the cluster is very dim to the unaided eye. I can glimpse a ghostly grey patch in the right place slightly west of Delta and Gamma. My 10×50 binoculars morph the pallid patch into a glittering hive of roughly two dozen 6th- to 8th-magnitude "bees." Many of them are arranged in groups, the most dominant being a quadrilateral resembling (you guessed it) Corvus.

My 4¼-inch f/6 Newtonian is a great Beehive buster. A wide-angle eyepiece yielding 20× picks up at least five dozen cluster members. The scope also reveals that the northwest corner of the "Corvus quadrilateral" is marked by a tiny triangle of 6.4-, 7.6-, and 9.2-magnitude stars. The trio includes a double named **STF 1254 AB**. So, where's star B? Upping to 93× and focussing on the 6.4-magnitude leader, I notice a 10.4-magnitude companion 21″ to the northeast — the missing B in the Beehive.

▲ **THE BEE'S KNEES** The Beehive Cluster, M44, is one of the most celebrated northern deep-sky objects. From a rural observing site, the cluster and all four stars of the Beehive Box (see the chart on the facing page) are visible without optical aid. Stargazers through the ages saw M44 as Praesepe, Latin for manger. Delta and Gamma Cancri are Asellus Borealis and Asellus Australis — two donkeys feeding at the manger. Unaided suburban eyes can spot the donkeys but not the manger.

RON BRECHER

Outside the Box

Let's turn to Delta Cancri on the southeast corner of the Beehive Box, then drop down to Cancer's "other" open cluster. . . .

Whoa — not so fast.

It's good to stop and smell the roses — in this case, the rosy-red variable star

X Cancri, located less than 3° east-southeast of Delta. Lazily pulsating in semiregular fashion between magnitudes 5.7 and 6.9, the carbon-clouded red giant is an alluring sight in any telescope. Stars of similar magnitude dot the area, but ruddy X always stands out in my 4¼-inch.

After X Cancri I continue southward 5½° to 4.3-magnitude Alpha (α) Cancri, or Acubens. From Acubens, a westward 1¾° hike, past 5.4-magnitude 60 Cancri, arrives at the cluster **M67**. In physical terms, M67 is approximately five times more remote than M44; consequently, it looks dimmer (magnitude 6.9) and smaller (30′) than its glamorous cousin. Even so, this modest inhabitant of the Cancer barrens materializes in my 8×50 finderscope.

M67's eight or nine leading lights shine at 10th magnitude. The cluster seems elongated because of a clump of five stars on the southwest side, plus an unrelated, 7.9-magnitude yellow star just off the northeastern edge. In my 4¼-inch Newtonian at 27×, I count a dozen pinpoints, not centrally concentrated, spanning 15′ of sky. Pushing to 72× gives me nearly three dozen stars, including the yellow beacon.

My 7.1-inch f/15 Maksutov-Cassegrain provides a superb view of M67. Working at 90×, the long-focus reflector registers an attractive collection of maybe 50 faint stars. Doubling the magnification enhances the cluster's lozenge-like shape, loose layout, and its oddly asymmetric clump-of-five. M67 isn't glam; it doesn't gleam — it glows softly in a low-lit neighborhood.

Crab Couples

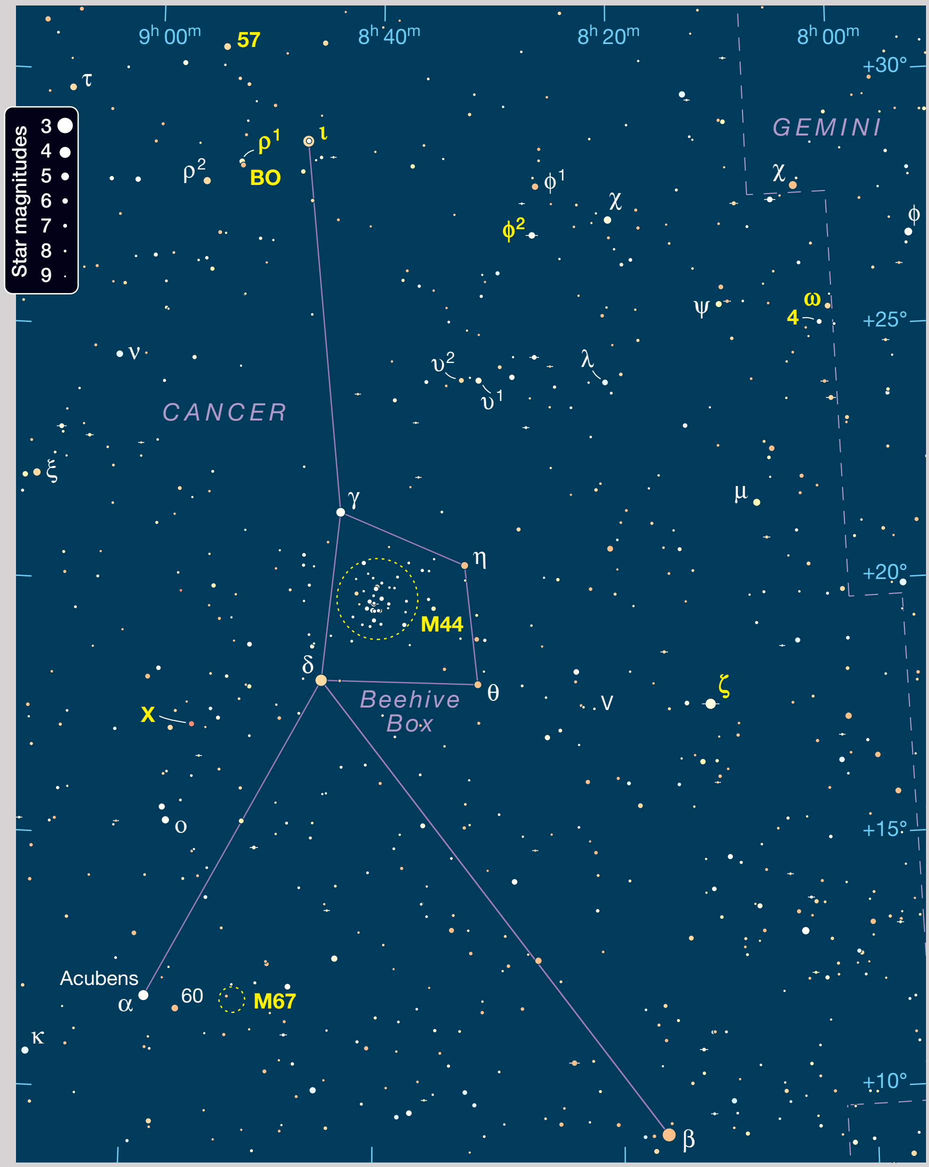
Several decent doubles reside in Cancer. The best-in-show award goes to colorful **Iota (ι) Cancri**, a little more than 7° north-northeast of Gamma (northeast corner of the Beehive Box). Iota features a 4.1-magnitude yellow star and a 6.0-magnitude blue star 31″ apart — easy pickings at 20× in my 4¼-inch reflector. Aimed at Iota, the view includes a bonus 1° to the east: the 6th-magnitude pairing of Rho¹ (ρ) Cancri and another variable star, orangey BO Cancri. A fine field!

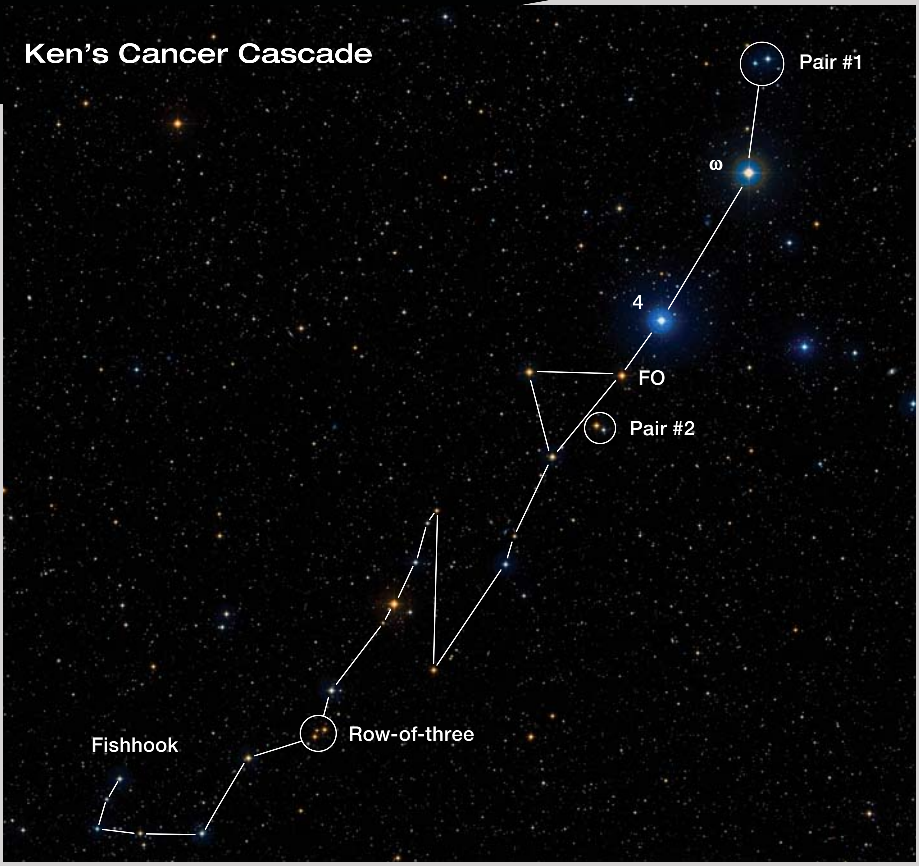
I suggest returning to Iota, then continuing 2½° further northeast to 6th-magnitude **57 Cancri**. The hop is aided by a few faint stars stretching northeastward, then curving northward into the target. This binary is tightly bound; its 6.1- and 6.4-magnitude components lie only 1.5″ apart. My little Newtonian kinda-sorta resolves them at 180×, but 232× is considerably better. The bigger Mak-Cass cranked up to 300× absolutely slays 57 Cancri.

Hop back to Iota Cancri, then swing 5° west-southwestward to a 1½°-wide triangle outlined by 5.1-magnitude Chi (χ), 5.6-magnitude Phi¹ (φ), and 6.1-magnitude **Phi² Cancri**. The fainter Phi boasts virtually identical 6th-magnitude siblings, 5.2″ apart. In the 4¼-inch reflector at 72× (less when the seeing is steady), they imitate a distant car's headlights. Simply put, Phi² is fab.

Back to the Beehive Box. A line drawn westward from Delta through Theta and extended a bit more than

▼ **CRUSTACEAN CONSTELLATION** Cancer, the Crab, is arguably the least conspicuous member of the zodiac, but it offers fine treasures for backyard telescopes. One unusual feature, dubbed the Cancer Cascade by the author, lies near the Cancer-Gemini border. As shown on page 56, the 2°-long Cascade is dominated at its north end by 5.8-magnitude Omega Cancri, which lies a bit more than one-quarter of the way from 1st-magnitude Pollux to the Beehive Cluster.





◀ **A CASCADE OF STARS** This Cancer asterism is a 2°-long string of 8th- to 10th-magnitude stars stretching southeastward from Omega and 4 Cancri (noted on the map on page 55). Two double stars, circled in this image, show in small scopes used at low magnification.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

7½° grazes **Zeta (ζ) Cancri**. Zeta comprises 4.9- and 5.9-magnitude suns 6.0″ apart. Nice. Moreover, the primary star is itself a tough binary. The 6.3-magnitude secondary, which plies a 59½-year orbit, was widest around 2018 and is now slowly closing. Currently, the gap has shrunk to 1.0″. The slender separation is no problem for the Mak-Cass, which resolves the duo cleanly at 300×. Yep, I love it.

A Starry Cascade

Backyard observing is extra fun when we "discover" something unexpected. My serendipitous moment occurred a few years ago as I lazily patrolled the Cancer-Gemini border, southeast of Pollux. The 4¼-inch had swept up a pretty pair: yellowish, 5.8-magnitude Omega (ω) Cancri and pure-white, 6.3-magnitude 4 Cancri, just 21′ apart. By chance, my peripheral vision caught a delicate, yet distinctive, 2°-long stream of stars flowing southeastward from the bright tandem. I dubbed it the **Cancer Cascade**, for its similarity to Kemble's Cascade in Camelopardalis.

Like Kemble's Cascade, the asterism I found consists of two essentially straight spans of stars that do a zigzag at the halfway point. While Kemble's Cascade is punctuated by a small cluster at its southeastern terminus, the Cancer version ends in a less splashy, V-shaped pattern resembling a fishhook. Most of the 30-plus Cancer Cascade stars range between 8th and 10th magnitude. Sometimes I see fainter ones — the total depending on sky conditions, size of scope, and magnification.

Operating at 22×, my 4¼-inch's 3°-diameter field perfectly frames the Cancer Cascade in a single field. At that power, two wide doubles — one 14′ north of Omega, the other 15′ southeast of 4 Cancri — appear pleasingly compact. The lower double decorates a triangle whose northwestern corner is established by yet another orangey variable, FO Cancri. Further southeastward in the Cascade, a blurry bit resolves at 93× into a 2.6′-long row of three stars (plus a fourth slightly out-of-line) sequenced dim-dimmer-dimmest. I picture this fuzzy row as the beginning of the faint fishhook. All in all, the Cancer Cascade is a pleasant little curiosity.

Time to pack up. I'm happy to report that the starscape between Gemini and Leo isn't barren after all!

Suburban Treasures in Cancer

Object	Type	Mag(v)	Size/Sep	RA	Dec.
M44	Open cluster	3.1	95′	$08^h\ 39.9^m$	+19° 40′
STF 1254 AB	Double star	6.4, 10.4	21″	$08^h\ 40.2^m$	+19° 40′
X Cnc	Variable star	5.7 – 6.9	—	$08^h\ 55.4^m$	+17° 14′
M67	Open cluster	6.9	30′	$08^h\ 50.8^m$	+11° 49′
ι Cnc	Double star	4.1, 6.0	31″	$08^h\ 46.7^m$	+28° 46′
57 Cnc	Double star	6.1, 6.4	1.5″	$08^h\ 54.2^m$	+30° 35′
φ^2 Cnc	Double star	6.2, 6.2	5.2″	$08^h\ 26.8^m$	+26° 56′
ζ Cnc	Double star	4.9, 5.9	6.0″	$08^h\ 12.2^m$	+17° 39′
Cancer Cascade	Asterism	—	2°	$08^h\ 03^m$	+24° 47′

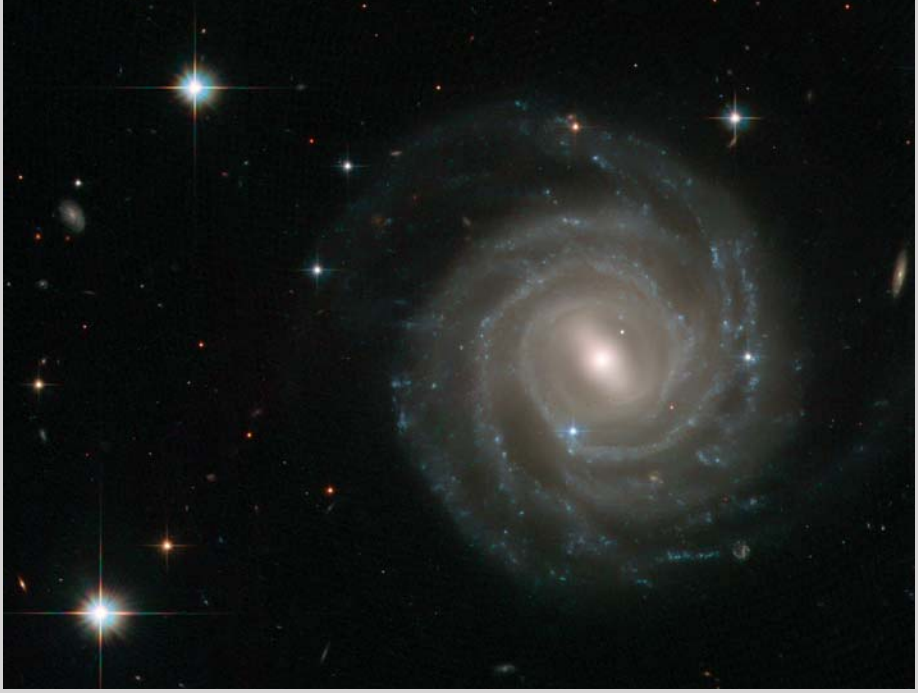
Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.

■ Contributor **KEN HEWITT-WHITE** has been trying to trace all of Cancer, the Crab, for half a century, without success.

Pro-Am Conjunction
by Diana Hannikainen

On Our Toes

Amateur astronomers have a superpower that professionals don't.



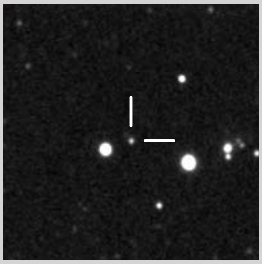
▲ British amateurs Mark Armstrong and Tom Boles independently discovered the supernova SN 2004ef (bright dot just lower left of the nucleus) in the face-on spiral galaxy UGC 12158. Alerting the Central Bureau of Astronomical Telegrams (**https://is.gd/cbat_iauc**) allowed for follow-up observations, such as with the Hubble Space Telescope, which took this image shortly after.

Amateurs are nimble. So long as the skies cooperate, they can pop out to their backyard or hop into a car at the drop of an astronomical telegram. (These are a real thing, by the way: **astronomerstelegram.org**.)

The pros are often a bit heavier on their feet. Sudden sky events have the cachet to scuttle long-scheduled observing runs. But for the most part, the nightly itinerary at major observatories leaves little room for chasing the unexpected. Amateurs' flexibility thus makes them perfect observers of celestial sights that require one to drop everything and dash for the dome.

Things that go bang. Amateurs have been discovering supernovae for a long time, historically through visual detections at the eyepiece. Things really took off in the 1990s when two advances coincided: Charge-coupled devices (CCDs) became more affordable, and cosmologists refined a technique for determining distances to the farthest galaxies that required detections of myriad Type Ia supernovae. Backyard observers armed with their CCDs came to the rescue, by easing the burden on professional facilities. Even with the advent of robotic endeavors, such as the All-Sky Automated Survey for Supernovae (yielding the delightfully whimsical "ASASSN" prefix for discoveries), amateurs continue to play an important role in finding supernovae.

Unlike with supernovae, the afterglows of gamma-ray bursts fade fast, often in the span of hours if not minutes. Speed is of the essence for identifying the optical counterpart of the gamma-ray burst, and in some cases amateurs get to their scopes before professionals do, as Finnish amateur Arto Oksanen did, for example. In 2007, he captured the afterglow of a gamma-ray burst (see image below) within 15 minutes or so of the alert and informed the professional community. Armed with Oksanen's precise coordinates, pros using 10-meter-class telescopes bristling with spectrographs obtained high-quality spectra, enabling them to determine the GRB's redshift and hence its distance. You, too, can do as Oksanen did and sign up to receive circulars distributed by The Gamma-Ray Coordinates Network at **https://is.gd/gcn_nasa**.



Closer to home. Possibly the most prolific amateur discoveries historically are comets in our own solar neighborhood. Here, amateurs have long received recognition: In addition to their official alphanumeric designations, comets bear the names of their discoverers. And so we have Comets Hyakutake and Lovejoy and Machholz, among others.

Comet names also directly pay tribute to the pro-am collaborative effort, since many were co-discovered by professional astronomers working alongside amateurs. Think of comets Hale-Bopp and Shoemaker-Levy 9, in which an amateur — Thomas Bopp or David Levy — joined forces with professionals — Alan Hale or Eugene and Carolyn Shoemaker — to first identify these objects.

Perhaps surprisingly, even the closest objects to Earth still offer pickings. In fact, in the late 1990s amateurs were the first to identify *lunar impact flashes*, brief twinkles from meteoroids hitting the Moon's surface. Pros were so interested in this phenomenon that NASA dedicated a whole program to monitoring the Moon for these events.

Both the Association of Lunar & Planetary Observers in the U.S. and the British Astronomical Association in the UK, for example, support amateur observations of both comets (**https://is.gd/alpo_comets**; **https://is.gd/baa_comets**) and lunar impact flashes (**https://is.gd/alpo_flashes**; **https://is.gd/baa_flashes**). Their informative webpages outline what you can do to get involved in these projects.

■ Observing Editor **DIANA HANNIKAINEN** wouldn't mind catching a supernova in her telescope.

SUPERNOVA: ESA / HUBBLE / NASA; GAMMA-RAY BURST: ARTO OKSANEN / NYRÖLÄ OBSERVATORY

Springtime Blossoms

THIS NEBULA'S A HOOT
In his eyepiece, Lord Rosse saw the two darker features as an owl's eyes, and hence M97 is fondly also known as the Owl Nebula. You'll find this planetary just outside the Big Dipper's bowl, some 2.3° southeast of Merak (Beta Ursae Majoris).

Vernal skies bloom with planetaries — some are more familiar while others are more challenging.

When the cores of low- to intermediate-mass stars run out of the hydrogen that has fueled their mostly stable life as main sequence stars, they begin an evolutionary voyage that takes them through a number of stages. In this transformative journey from main sequence star to white dwarf, the most intriguing span is the time spent as a planetary nebula. For a relatively brief but glorious period, the evolving star blossoms into a glowing nebula that can assume any number of varied shapes and colors.

The spring sky is populated with many interesting planetary nebulae. Some are well known, and some are rather obscure. We'll start with the better-known and more easily observed targets, but at the tail end of this tour, I'll include some really elusive objects to challenge you.

Starting with the Ghost

In her book *Celestial Sampler,* former *Sky & Telescope* contributing editor Sue French posits that British astronomer William Noble is responsible for the nickname "Ghost of Jupiter," which has become synonymous with **NGC 3242** in Hydra. In *Hours with a Three-Inch Telescope* (published in 1887), Noble describes the nebula as a "pale-blue disc, looking just like the ghost of Jupiter." William Herschel discovered NGC 3242 — located 1.8° south of Mu (μ) Hydrae — on February 7, 1785.

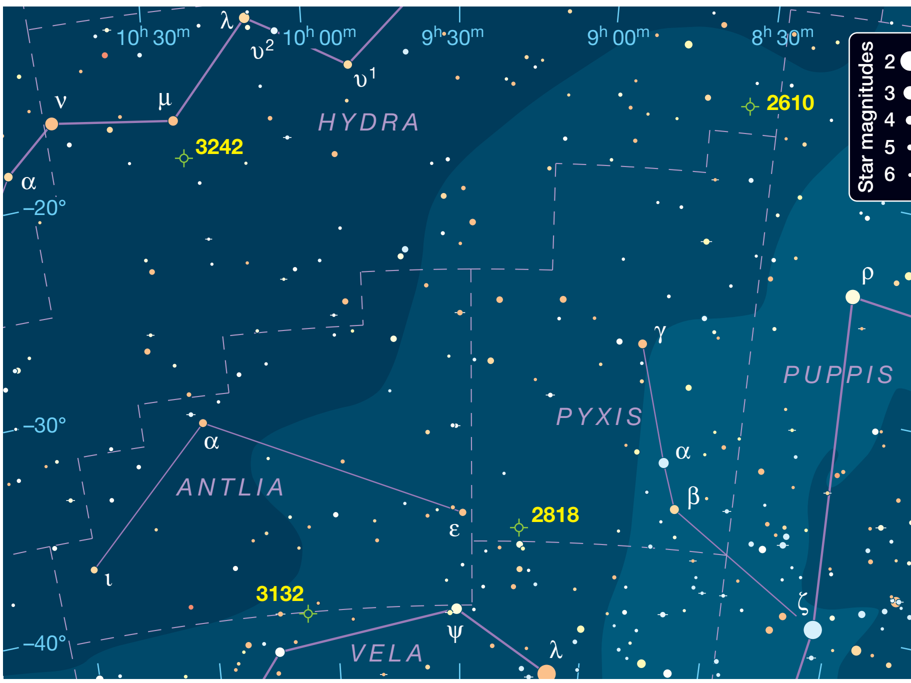
Today, it's a favorite target of backyard astronomers and one of the most prominent planetary nebulae in the spring sky. Bright and obvious, its elliptical disk lies within a much fainter extended halo. Careful observations reveal an interesting, looping inner structure. Observers disagree on its color: Some describe it as green and some as blue. See if you can detect the 13th-magnitude central star. Detecting the two extremely faint arcs — the visible manifestations of *FLIERs* (Fast Low-Ionization Emission Region) — that flank the object on its northwest-southeast axis is even more challenging.

NGC 3242 is an *elliptical planetary,* and its nonspherical morphology has been the subject of intense study. As with the majority of these objects, it exhibits asymmetrical structures that cannot easily be explained by the simplest interpretation of the prevailing model describing planetary nebula formation. The *interacting winds theory* describes how a fast stellar wind, ejected by the immediate precursors of planetary nebulae, *asymptotic giant branch* (AGB) stars, overtakes the slower material expelled earlier in the star's evolution. The fast wind compresses the slower wind, thereby generating the densities required to enable the photoionization of the circumstellar cloud by radiation from the hot central star (essentially, the exposed core of the progenitor). A number of possible factors have been invoked to explain why this process does not often convert a presumably spherical star into a uniformly spherical nebula.

Today, the most widely accepted explanation for the fact that a majority of planetary nebulae are nonspherical has led to the *binary hypothesis*. It's almost universally accepted

▼ **GHOST OF JUPITER** Located in Hydra a little less than 2° south of Mu Hydrae, NGC 3242 was discovered by William Herschel in 1785. Fellow British astronomer William Noble described this object as the "ghost of Jupiter" and the nickname stuck. The planetary nebulae described here are sprinkled across the night sky. Use the accompanying charts to guide you to their general locations. The images have north up unless otherwise indicated.

M97: MAKIS PALAIOLOGOU / STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY; NGC 3242: RAINER SPARENBERG / STEFAN BINNEWIES / VOLKER ROBERING / CAPELLA OBSERVATORY



◀ **EIGHT-BURST NEBULA** NGC 3132's curious nickname is derived from a series of arcs that likely trace previous ejection events in the planetary's history. It also goes by its nickname the Southern Ring Nebula due to the similarity with its northern counterpart, the Ring Nebula (M57). The NGC planetary might be a tougher catch for more northerly observers, but it's worth the effort if it rises above the horizon. Look for it on the border between Vela and Antlia, a smidgen less than 7° east of Psi Velorum.

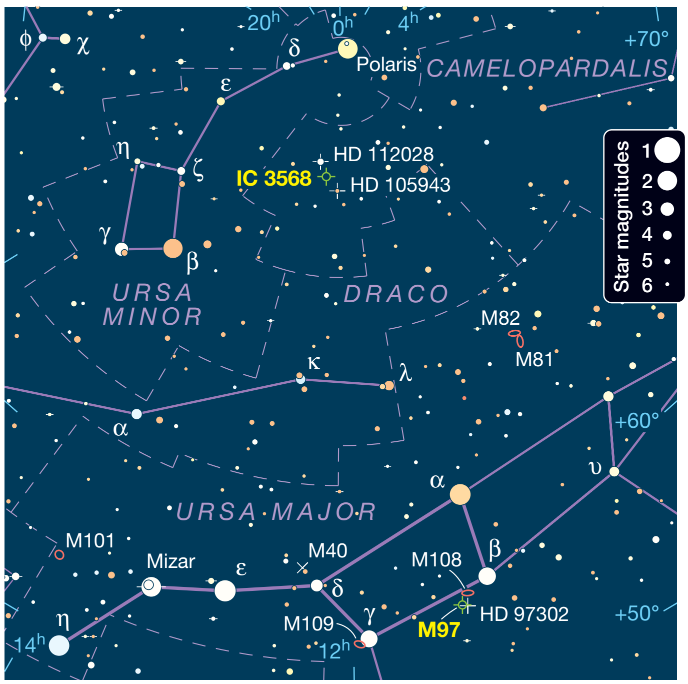
now that a binary companion, either stellar or substellar (for example, a brown dwarf or even a planet), is required for the shaping of bipolar or multi-polar nebulae. Oddly enough, while NGC 3242 was one of the first objects suspected of being sculpted by a binary interaction — in fact, a possible triple system may be responsible — it's still not definitively established that the Ghost's central star is (or was) a binary. Several targets on this tour are most likely shaped by binary stars, but none of that is evident in the eyepiece.

Many Shapes, Many Monikers

NGC 3132 in Vela may be a bit of a stretch for observers at more northerly latitudes but is well worth the effort if it rises above your horizon. Harlow Shapley and his collaborator John S. Paraskevopoulos dubbed it the Eight-Burst Nebula in a 1940 paper in which they suggested that a number of distinct arcs on the boundary of the object indicate at least eight ejection events or "bursts" in its history. Southern Hemisphere observers also know the object as the Southern Ring due to its similarity in size and shape to M57, the Ring Nebula. Unlike its Lyra alter ego, the central star in NGC 3132 is rather apparent. It's also a binary (the two stars are separated by 0.02 light-years), embedded in a disk that's brighter on its periphery, making it appear annular. First spied by John Herschel on March 2, 1835, it lies on the border between Vela and Antlia in a rather blank area of sky 6.9° east of Psi (ψ) Velorum and 1.3° west of a wide pair of 6th-magnitude stars.

Competing for the title of most famous spring planetary is **Messier 97**, the Owl Nebula. Pierre Méchain discovered it on February 16, 1781, and in 1848 Lord Rosse gave it its nickname due to the two dark round features that look a bit like the eyes on an owl's face. Sharing a low-power field with

▼ **FILTER OR NO FILTER** The use of a filter may enhance the enjoyment of viewing planetary nebulae (see sidebar at right). Some targets, however, don't require a filter at all, while for others filters are an absolute must. M97, for example, doesn't need one, but a filter will likely improve the view. The author recommends an O III filter for this exquisite nebula, if you have one.



NGC 3132: DIETMAR BÖCKER / CAPELLA OBSERVATORY; M97: FRANK SACKENHEIM / JOSEF PÖPSEL / STEFAN BINNEWIES / CAPELLA OBSERVATORY the barred spiral galaxy M108, the Owl lies 2.3° southeast of Merak, or Beta (β) Ursae Majoris, just outside the bottom of the Big Dipper's bowl. It appears as a large, diffuse disk that's relatively bright. In smaller scopes, the "eyes" may not be readily apparent, but they're very prominent in larger apertures. At an estimated distance of more than 2,000 light-years, it would have a diameter of 1.7 light-years.

Nebula filters enhance the visibility of most planetary nebulae, and this is true for M97: It's much easier to detect with a filter. Some planetaries require the use of a filter to detect them at all, while even the brightest and easiest usually show some additional structure when a filter is inserted in the light path (see sidebar below). The table on page 64 lists the filters I used for the observations discussed here — the entries in brackets indicate that the listed filters aren't necessary for enjoying the view but might improve it.

Located just 8° from Polaris, **IC 3568** in Camelopardalis is available to northern observers all year but is ideally placed during spring. This is a relatively young planetary at a distance of around 9,000 light-years, and its apparent size of 10″ yields a diameter of about 0.4 light-years. Several American astronomers have contributed to our understanding and enjoyment of this planetary nebula. The first, Robert Aitken, discovered this planetary on August 31, 1900, while observing Comet Borrelly-Brooks (1900 b) from Lick Observatory. The planetary has the appearance of a uniform, gray or blue-green disk, with a visible central star. Employing a nebula filter will enhance its visibility. Lawrence Aller described it as the "theoretician's planetary nebula," acknowledging its presumably simple spherical morphology. The Hubble Space Telescope image of IC 3568, however, shows an intricate structure, which inspired James Kaler to coin its nickname: The Lemon Slice Nebula.

▲ **ONE NAME, TWO OBJECTS** Earlier observers associated the planetary nebula with the open cluster — in fact, both objects bore the same designation, NGC 2818, until the cluster gained a new listing, Collinder 206. In fact, the notion that the planetary nebula's progenitor star was a cluster member prevailed until recent studies showed the two objects to be at different distances, with the planetary in the foreground. Mid-northern observers should be able to access this nebula in southern Pyxis.

The catalog designation **NGC 2818** refers both to a planetary nebula in Pyxis and the open cluster (also listed as Collinder 206) that lies adjacent to it. Scottish astronomer James Dunlop, observing in New South Wales, Australia, discovered them both on May 28, 1826. Apparently, Dunlop assumed that the nebula was a condensation of nebulous material associated with the cluster. John Herschel identified it as a planetary nebula when he observed it on April 7, 1837. NGC 2818 was widely assumed to be associated with the cluster — in fact, the progenitor star was assumed to be a cluster

Which Filter?

Two types of filters are generally useful for observing planetary nebulae. They can be grouped into *deep-sky filters*, like the O III and hydrogen-beta filters, and *light-pollution filters* such as the Ultra-High Contrast (UHC) filters. They differ in how much of the visible spectrum that they pass. O III filters usually have a bandpass about 10–15 nm wide and transmit the blue-green light emitted by doubly ionized oxygen at 496 nm and 501 nm. This O III emission is the principal radiation emitted by planetary nebulae and an important criterion for classifying an object as such. A hydrogen-beta filter blocks most light except a thin band centered on 486 nm, the wavelength emitted by hydrogen atoms in a nebula. The wider bandpass of the popular UHC filters is usually about 20–30 nm wide, which includes both the O III and hydrogen-beta lines. The effectiveness of these filters varies; some objects "respond" to one filter more than another. Very few planetary nebulae benefit from use of the hydrogen-beta filter, whereas an O III or UHC filter will improve the contrast significantly in a majority of targets. For some objects, the improvement will be subtle, but in others, a filter will mean the difference between detection or invisibility.

Filters are usually employed by screwing the filter into the eyepiece barrel. Happily, commercially available filters and eyepieces from most manufacturers have compatible thread sizes. A second strategy is to manually insert the filter into the light path by holding it between the eyepiece and the observer's eye. This technique has the advantage of allowing a rapid comparison of the filtered and unfiltered view, which in effect causes emission nebulae to "blink" (appear to brighten due to the contrast gain of the filter). The disadvantage is that "blinking" a filter like this effectively is a bit of an acquired skill.

DIETMAR BÖCKER / ERNST VON VOIGT / CAPELLA OBSERVATORY

Nestled in the trapezoid asterism of Corvus, the Crow, NGC 4361 comprises an obvious central star surrounded by a gossamer disk of nebulosity.

member. This pairing is often presented as the best case for a planetary nebula physically linked to an open cluster. The association has been called into question, however — radial velocity measurements place the planetary in the foreground, evidence that it may be just a chance alignment. In any case, the two objects make for an intriguing observation.

NGC 2818's low declination makes it less accessible to northern observers, but even from mid-northern latitudes, it's easily within reach. A somewhat irregular-looking oval disk, it's significantly improved with a nebula filter. Find it in the southern part of Pyxis, some 7.4° east of Beta Pyxidis and 47′ north of a 4.6-magnitude star.

A planetary nebula in Gemini has the unusual designation **J 900** as it was discovered in 1912 by French astronomer and double star enthusiast Robert Jonckhèere. In fact, it was initially cataloged as a double star. The nebula sits about 3° northwest of Gamma (γ) Geminorum (Alhena), and a 12.5-magnitude star lies about 12″ south-southwest of the nebula. The planetary appears as a small, bright disk. It's more apparent through a nebula filter but can be detected without.

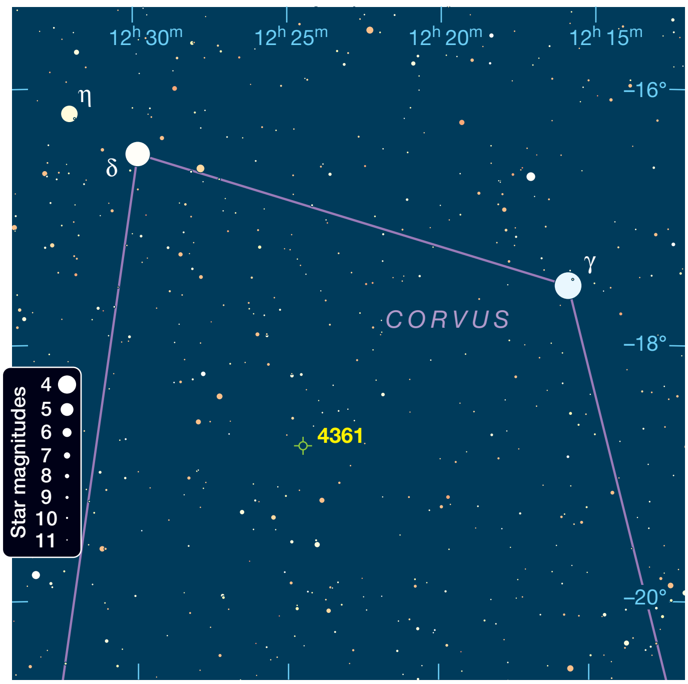
Nestled in the trapezoid asterism of Corvus, the Crow, **NGC 4361** comprises an obvious central star surrounded by a gossamer disk of nebulosity. A nebula filter will bring out the uneven brightness of the inner part of the disk. Images show two opposing, jetlike features in the inner disk often described as "lawn sprinkler arms." William Herschel discovered NGC 4361 on February 7, 1785, the same night he discovered NGC 3242 (and several other objects), and Heber Curtis identified it as a planetary nebula in 1918. At a distance of a little more than 2,900 light-years, it would be about 1.8 light-years wide.

Planetary nebulae with a high degree of ionization are classified as *high-excitation* planetaries. Many exhibit the presence of both photoionized (ionized by interaction with a photon) and collisionally ionized (ionized by collision with other particles) plasmas. These objects are excellent laboratories for studying the processes that shape planetary nebulae. **NGC 2610** in Hydra is a high-excitation planetary with the added benefit of appearing smooth and homogenous; there are no complicating structures such as low-ionization knots or filaments, making it particularly useful to scientists.

NGC 2610's faint disk is visible without a filter in my 8-inch SCT, while in my 18-inch Dob it appears vaguely annular. The central star remains hidden, and there is little to no color. Filters improve its contrast only slightly. It sits a bit less than 3.5′ southwest of a 6.6-magnitude star and about 4° southwest of 12 Hydrae. This planetary was discovered by William Herschel on December 31, 1785, and is about 7,200 light-years from Earth.

When it was first discovered in 1939, the planetary **JnEr 1** was initially confused with a nearby galaxy pair (NGC 2474/5), a misconception that lasted until 1977. It's

▼ **LAWN SPRINKLER ARMS** NGC 4361 is neatly nestled within the trapezoid asterism of Corvus, the Crow. Two opposing, jetlike features give rise to features reminiscent of the sprays of water shooting out from the sprinklers you might use to water your grass. At a distance of a little more than 2,900 light-years, the nebula is about 1.8 light-years across.



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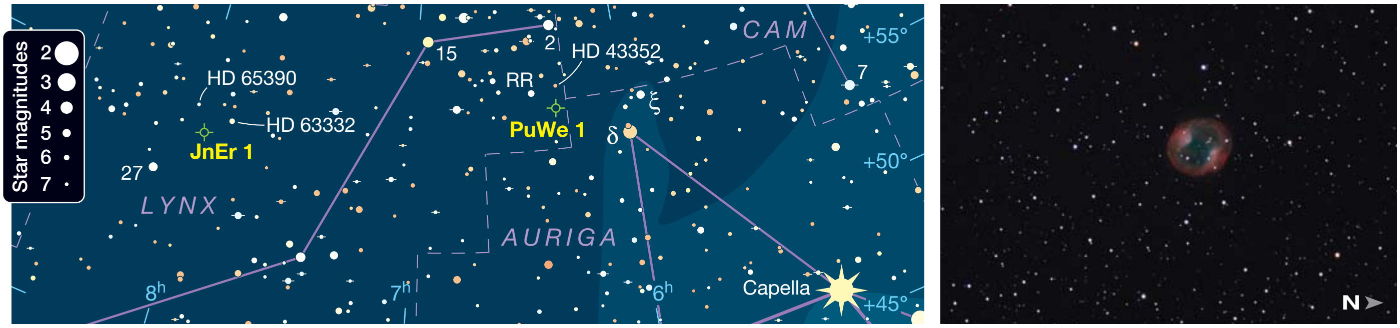


▲ **MANY MONIKERS** The complex processes that sculpt planetary nebulae often give rise to intricate shapes. Everyday objects inspire observers, professionals and amateurs alike, to bestow creative nicknames upon these ethereal targets. And thus JnEr 1 is also known as the Headphone Nebula. Look some 2.5° northwest of 27 Lyncis to locate this planetary. You'll need a nebula filter and low power to see its faint disk.

STEFAN BINNEWIES / CAPELLA OBSERVATORY

located in Lynx about 2.5° northwest of the 4.8-magnitude star 27 Lyncis. The planetary only becomes apparent when viewed at low power through a nebula filter and appears as a large faint disk. According to planetary nebula aficionado Kent Wallace, *S&T* Contributing Editor Steve Gottlieb and fellow observer Jack Marling made the first known visual sightings of this object in 1985. But it was Prairie Astronomy Club members David Knisely and Rick Johnson who bestowed its nickname the Headphone Nebula.

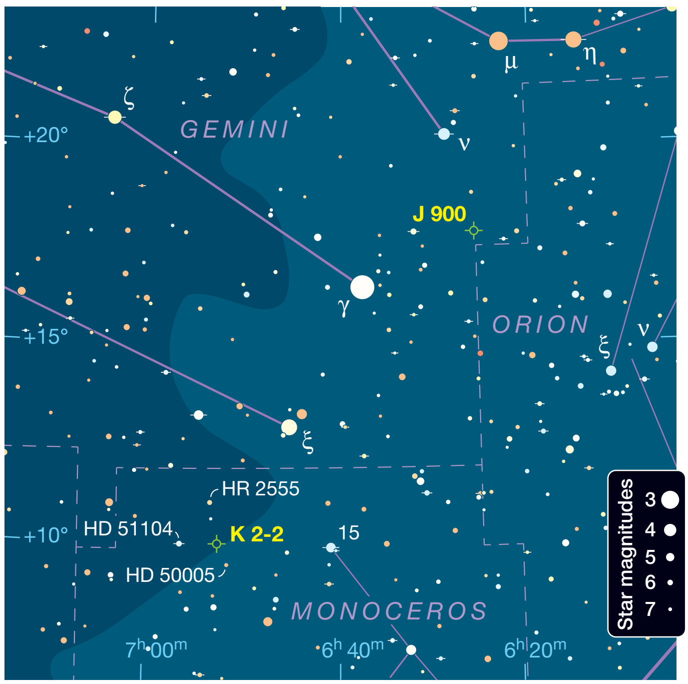
The Elusive Three

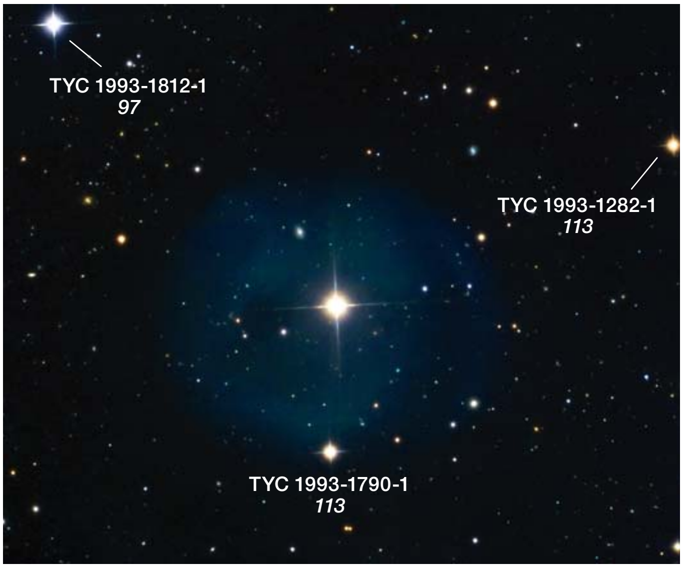
The spring sky contains a number of planetary nebulae that are very challenging. Three of them are presented here to round out our tour and provide the most adventurous readers a chance to test their observing skills — only a limited number of successful sightings have ever been reported.

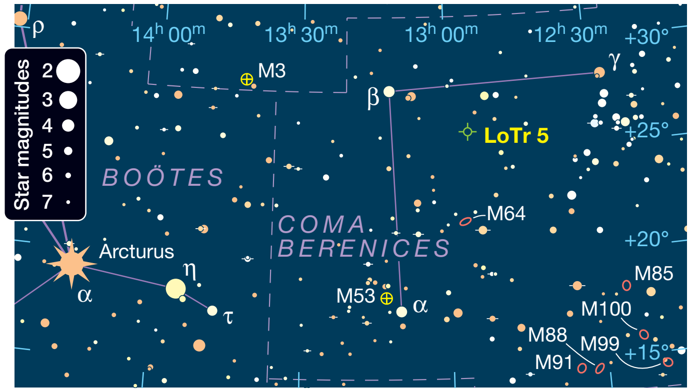
K 2-2 in Monoceros presents a large, extremely faint disk. Czech astronomer Luboš Kohoutek discovered it on a *National Geographic Society — Palomar Observatory Sky Survey* (*POSS*) plate in 1963. You'll find it 2.8° east of 15 Monocerotis, the brightest star in NGC 2264, the Christmas Tree Cluster. Look for a triangle of bright stars: HD 51104 (magnitude 5.9), HR 2555 (6.3), and HD 50005 (6.8), with sides a little more than a degree in length that show well in the finder. The western side of the triangle is bordered by HR 2555 to the north and HD 50005 to the south. K 2-2 is located along the line between them about a third of the way from HD 50005. You'll need low power and a nebula filter to spy this elusive disk. Try sweeping across the field to detect the subtle change in brightness as you cross the rim of the planetary.

Even more difficult, perhaps, is **PuWe 1** in Lynx. Austrian astronomers Alois Purgathofer and Ronald Weinberger discovered this planetary in 1980 also on a *POSS* plate. In apparent angular size it's the largest planetary known and has extremely low surface brightness. It's about 1,400 light-years away and located 3.2° northeast of Delta (δ) Aurigae and 1.2° southwest of the 5.5-magnitude RR Lyncis. The 15.3-magnitude central star of PuWe 1 is extremely hot and hydrogen-rich. PuWe 1 was once considered one of the rare examples of a triple-star system producing a planetary nebula. However, two of the stars are now understood to be at a different distance to the nebula and unrelated to its formation. The closest I've come to detecting this huge target was with a 30-inch f/4.5 Dob. I recorded only a "suspected glow" at 111× with an Ultra-High Contrast filter. I've heard from other observers, however, who have reported a more confident detection. Give it a try and if you succeed, I hope you'll let me know.

Another catch logged by only a few observers is **LoTr 5**. It, too, was discovered in 1980, by British astronomers Andrew J. Longmore and Susan B. Tritton. Using an 18-inch Dob, Jay McNeil (of McNeil Nebula fame) made one of the earliest documented visual observations — perhaps the very first with an amateur-size instrument — at the 1999 Texas Star Party. LoTr 5 is located in Coma Berenices 6.8° east of Collinder 256, the naked-eye open cluster that represents Berenice's "hair." The central star of LoTr 5 is the variable star







◀▲ **FINAL CHALLENGE** Located in Coma Berenices, LoTr 5 is some 6.8° east of the cluster that represents Queen Berenice's locks, Collinder 256. It's neatly placed within a triangle formed by three 10th- and 11th-magnitude stars. The nebula's central white dwarf is an easy catch and shows up well in images such as this one. But only a handful of observers have bagged the planetary itself. Have you?

IN Comae (BD +26 2405), a known binary with a period a little more than 7 years, making it one of the longest-period binaries associated with planetary nebulae. It likely consists of a G-type subgiant with a very hot subdwarf companion. The central star is rather easily seen. The nebula, on the other hand, is quite another story. I wonder how many observers have confidently sighted it?

When we view planetary nebulae, we are witnessing a process whereby low- to intermediate-mass stars enrich the interstellar medium with many of the elements essential to life on Earth. Carbon, nitrogen, oxygen, neon, and sulfur are all present in significant quantities. It seems serendipitous that these remarkable objects glow their brightest at the very wavelengths that we humans are best disposed to detect. We might also consider ourselves fortunate that so many of these nebulae are visible to us at all — they bloom for so relatively short a time. In my first article for *Sky & Telescope* (June 2010), I likened them to celestial flowers. They also foretell the eventual fate of our Sun and remind us of our place in the cycle of creation.

■ Contributing Editor **TED FORTE**'s favorite targets are planetary nebulae. He's the coordinator of the Astronomical League's Planetary Nebula Observing Program and would enjoy hearing from observers who wish to share their observations. He can be reached at **tedforte511@gmail.com**.

Springtime Planetaries

Object	Name / Nickname	Const.	Filter	Mag(v)	Mag(*)	Size	RA	Dec.
NGC 3242	Ghost of Jupiter	Hya	[O III / UHC]	7.7	13.3	64″	10^h 24.8^m	–18° 39′
NGC 3132	Eight-Burst Nebula	Vel	[O III]	9.2	10.0	88″	10^h 07.0^m	–40° 26′
M97	Owl Nebula	UMa	[O III]	9.9	16.0	170″	11^h 14.8^m	+55° 01′
IC 3568	Lemon Slice	Cam	[O III / UHC]	10.6	13.4	10″	12^h 33.1^m	+82° 34′
NGC 2818	—	Pyx	O III / UHC	11.6	19.5	93″	09^h 16.0^m	–36° 38′
J 900	PN G194.2+02.5	Gem	[O III / UHC]	11.7	17.8	14″	06^h 26.0^m	+17° 47′
NGC 4361	—	Crv	—	10.9	13.2	126″	12^h 24.5^m	–18° 47′
NGC 2610	—	Hya	UHC	12.7	15.9	42″	08^h 33.4^m	–16° 09′
JnEr 1	PN G164.8+31.1	Lyn	O III / UHC	12.1	16.8	380″	07^h 57.9^m	+52° 25′
K 2-2	PN G204.1+04.7	Mon	O III	—	15.0	415″	06^h 52.5^m	+09° 58′
PuWe 1	PN G158.9+17.8	Lyn	UHC	—	15.3	1200″	06^h 19.6^m	+55° 37′
LoTr 5	PN G339.9+88.4	Com	O III	—	14.9	525″	12^h 55.6^m	+25° 53′

Brackets around filters indicate they aren't necessary but improve the view. 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.

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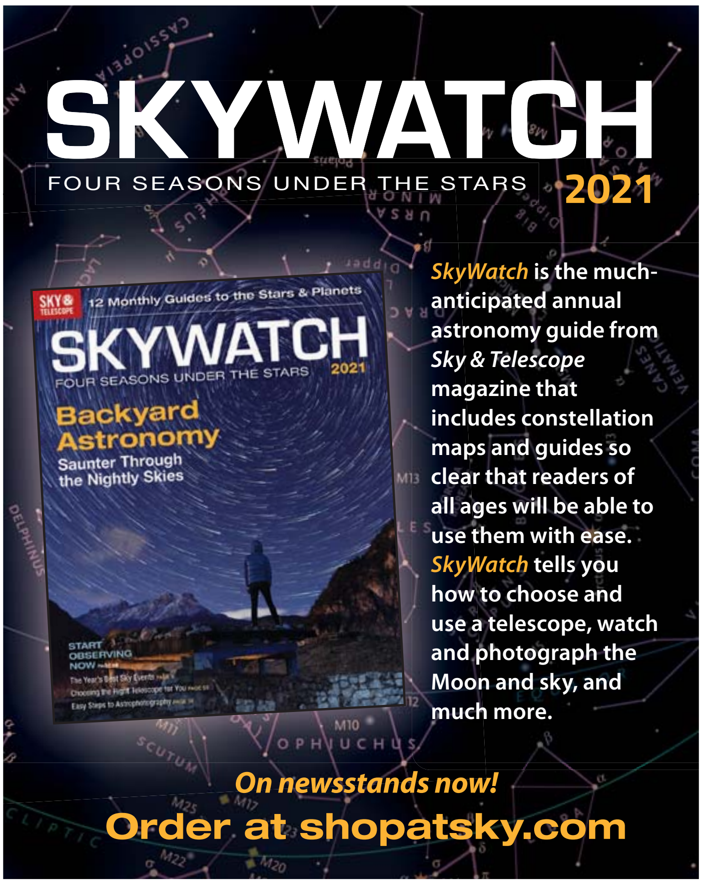
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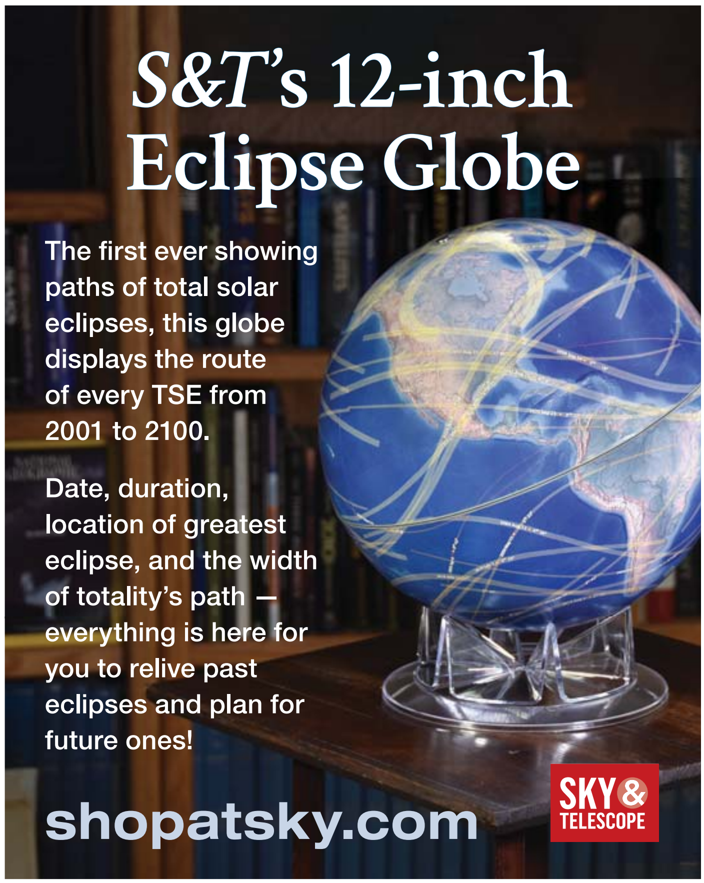
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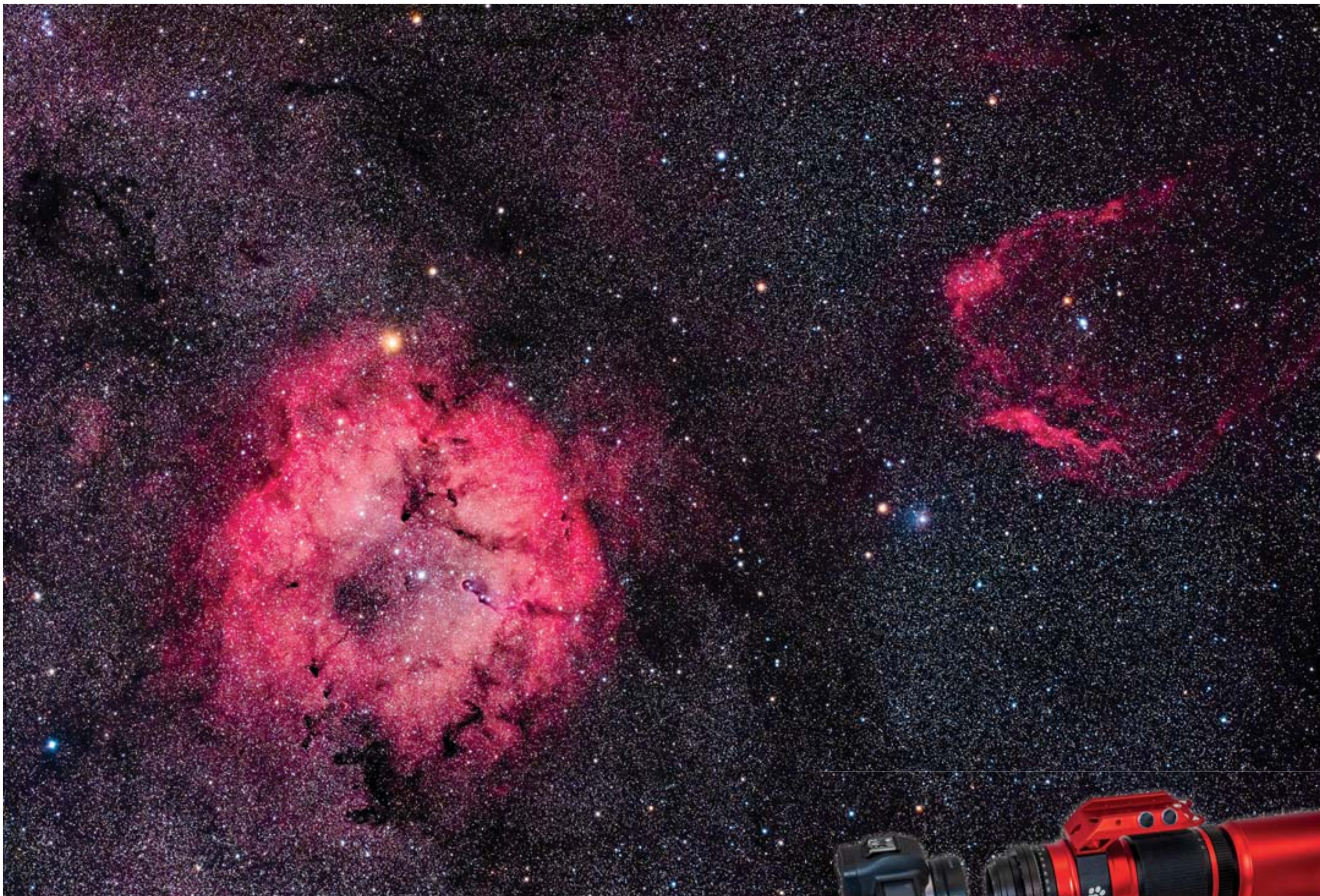


▲▲ The author used the William Optics RedCat to capture IC 1396 (left) and fainter Sharpless 2-129 in Cepheus using a Canon EOS Ra camera. This is a stack of four 12-minute exposures at ISO 5000 through an Optolong L-Enhance filter blended with six 8-minute exposures taken without a filter at ISO 1600.

▲ The RedCat 51LX includes a 21-cm-long (8¼-inch) mounting bar with a Vixen-style dovetail on one side and an Arca-Swiss dovetail on the other. The top bracket is a recommended option. The rear cell includes a 48-mm male thread that accepts a wide T-ring (one is attached here). The lens cap incorporates a Bahtinov mask for precise focusing.

ALL PHOTOS BY THE AUTHOR

RedCat 51LX APO 250mm f/4.9

U.S. Price: $748
williamoptics.com

What We Like

Superb edge-to-edge sharpness and even illumination

Precise focusing and camera rotation

Integrated Bahtinov focusing mask

What We Don't Like

Filter swaps require camera removal, or purchasing a $180 filter-drawer accessory

I WAS FIRST DRAWN TO William Optics' popular refractor, the little 51-mm RedCat, via YouTube videos that owners presented promoting its qualities. It's through YouTube that many newcomers to the hobby now learn about equipment and how to use it.

While I question some of the YouTubers' methods and equipment choices, in this case the popularity of the RedCat proved warranted. For deep-sky photography, small refractors provide wide fields of view, ease of mounting and guiding, and portability. The RedCat ticks all those boxes and more.

With a unit on loan from a local dealer, **ferventastronomy.com**, I tested a sample of the upgraded RedCat 51LX introduced in early 2020.

Optical Performance

The William Optics RedCat is a 51-mm f/4.9 refractor using a Petzval design with a doublet front element incorporating FPL-53 glass, plus a single central element and a single rear lens, which together serve as a field flattener. While an instrument with only 51-mm aperture is limited for visual observation, the RedCat is designed primarily for imaging, making it an astrograph. Think of it as a specialized telephoto lens with a 250-mm focal length.

As such, my first thought upon seeing the RedCat was: Why would I need it? I already have a 200-mm telephoto lens that, at f/2.8, is one and two-thirds photographic stops faster. One night I shot the same field with both the RedCat and my 200-mm, a premium Canon L-series lens.

Sure enough, the RedCat did prove sharper and with less chromatic aberration (in fact, none) than the telephoto — but only when the Canon lens was used wide open at f/2.8. Stopping the 200-mm lens down to f/5 to match the RedCat's f/ratio leveled the playing field. The lens now closely matched the RedCat for both on- and off-axis sharpness and lack of color aberration. Indeed, I gained a new respect for the Canon lens, which I had long considered to be a little soft. But extracting its best performance required stopping it down more than I usually do and also precisely focusing the lens using the RedCat's included Bahtinov mask.

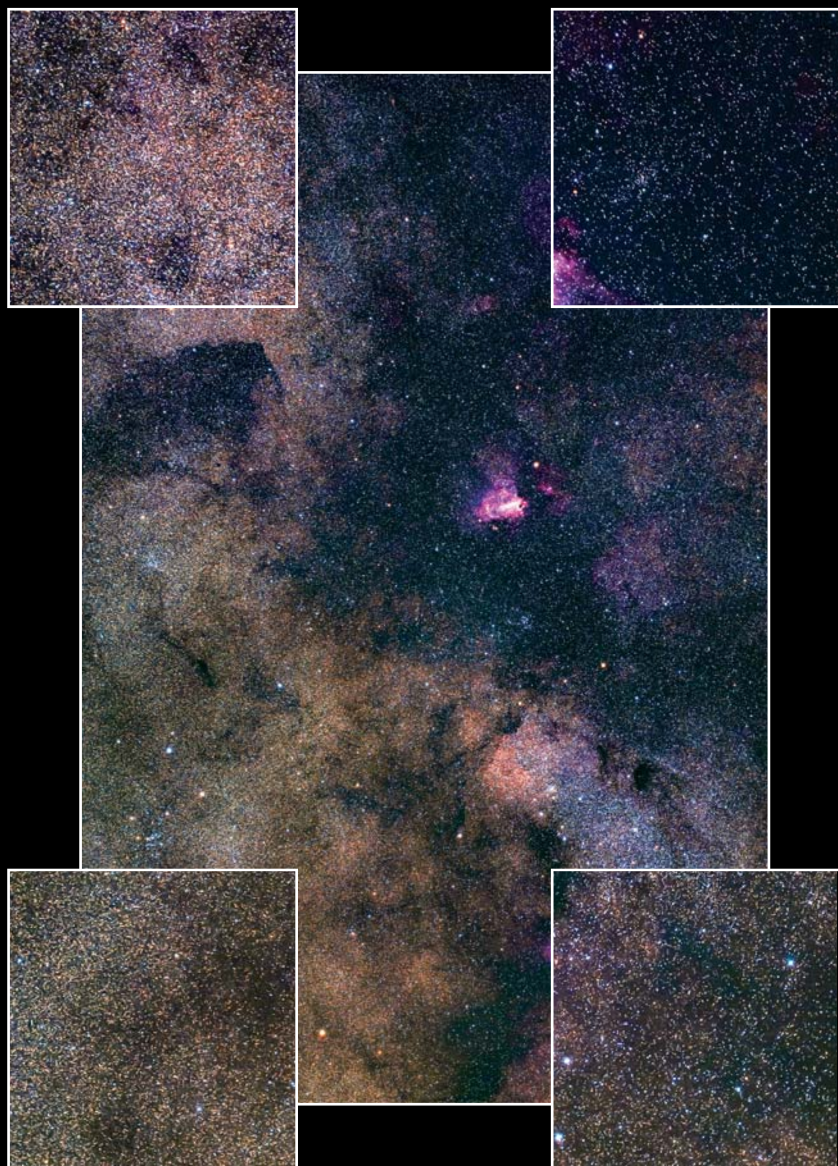
Nevertheless, the RedCat's pinpoint stars corner-to-corner on a full-frame detector are impressive. And bright stars don't exhibit the diffraction spikes introduced by diaphragm blades when shooting with a telephoto lens stopped down. Only slight vignetting was visible in the extreme corners of the field.

The RedCat's $748 price is similar to the Canon 200mm f/2.8 L-series lens I compared it to, with the lens offering more speed when needed, but comparable sharpness when stopped down. So, the question remains: Why buy a RedCat? While its optics are certainly superb, I found its mechanics are what set it apart.

Mechanical Features

The RedCat is heavier and longer than most 200-mm telephotos, but it has significant advantages over a conventional camera lens. Most importantly, the RedCat's design includes two means of easily rotating the camera for framing, with no worries about the setup slipping, as it can when mounting a camera and telephoto lens tipped over on a ball head or other form of tripod head.

First, the entire tube and camera can be rotated within the mounting cradle. Alternatively, the camera can be rotated with respect to the tube using an integral camera-angle adjuster that is marked in one-degree increments. This can facilitate shooting multi-frame mosaics in which the camera has to be rotated by a specific amount to keep



With a full-frame sensor, the RedCat provides a field 8.3° by 5.5°, ideal for Milky Way starfields. Stars are very sharp across the field, exhibiting just a trace of astigmatism and lateral color when viewed at a pixel-peeping level in the extreme corners.

adjacent frames parallel. Even with single shots, I found the scale useful for rotating the camera by the angle I had determined ahead of time using planetarium software to plan the framing.

Rotating the camera did not introduce any focus shifts. Once the RedCat cooled down, its focus also stayed consistent through several hours of shooting, though my tests were on mild summer and autumn nights.

In addition, the RedCat's helical focuser is much more precise than those on typical camera lenses, and it is lockable, making it easy to nail and maintain focus. I did find that the lock ring occasionally seized tight when it warmed up after being brought indoors. Getting the RedCat as cold again as it was at night, in one instance by placing it in the freezer, freed it up.

The top surface of the mounting cradle has four small tapped holes of unspecified thread. An optional, but almost essential, carrying handle ($45) can be bolted here that accepts the standard dovetail shoe now used by most finderscopes. It's where a small guidescope can attach, making for a quick yet secure connection.

▲ With the dewcap reversed and stored on the tube (top), the RedCat is 24.1 cm long. The dewcap extends 10.1 cm beyond the objective, for good protection. With mounting bar and top bracket, the RedCat weighs 2.1 kilograms (4.6 pounds).

Unlike a lens, the RedCat's rear cell incorporates push/pull screws for adjusting the tilt of the camera to ensure uniform sharpness across the field. I had to make some initial adjustments as, out-of-the-box, images were a little softer on one side of the frame.

▼ An extreme blow-up of the field around Epsilon Lyrae shows the stars soft and aberrated with the author's 200-mm Canon lens at f/2.8, but comparable to the RedCat when stopped down to f/5 to match the RedCat's f/4.9 focal ratio.

When using a telephoto lens, shooting through a light-pollution or narrowband filter requires using a clip-in filter made specifically for that DSLR or mirrorless camera, often limiting the choice of filters. By comparison, the RedCat's rear cell accepts any standard 2-inch (48-mm) screw-in filter. However, despite the William Optics web page describing the RedCat as having a filter "slot," inserting a filter requires removing the camera and screwing the filter into the rear adapter ring. There is no drop-in slot per se.

Those shooting with cooled CMOS cameras likely wouldn't need to use this filter placement, as the RedCat's 55 mm of back focus should accommodate an external filter wheel. But that's not an option for DSLR cameras that require all the available back focus.

Inserting a filter required removing the camera, then replacing it after screwing in the filter, which inevitably introduced field rotation. I like to blend filtered and unfiltered images to achieve a more natural color balance. If the two sets are rotated with respect to each other, aligning them requires cropping, perhaps spoiling the composition and some loss of the wide field the RedCat can deliver.

A better option for DSLR users would be a drawer for inserting a filter without having to touch the camera. Fortunately, Starizona (**starizona.com**) offers an after-market filter drawer, for $180. But installing it requires removing the RedCat's tip-tilt plate, one of the features added to the RedCat in its 2020 upgrade. Removing the plate maintains the 55 mm of back focus needed for optimal field flattening with DSLRs. Images taken with the Starizona filter drawer in place showed uniformly sharp focus across the full-frame Canon Ra, so the loss of the tip-tilt plate wasn't detrimental.

On the plus side, the metal lens cap cleverly incorporates a plastic Bahtinov mask to aid in achieving precise focusing, a convenient design touch. In all, the mechanical features of the RedCat do make it easier to mount, focus, frame, filter, and guide than with telephoto lenses.

▲ *Top:* Two-inch filters screw into the rear adapter ring that goes between the rear adjustable cell and the 48-mm T-ring. Note the indexed camera rotator. *Bottom:* The after-market filter drawer from Starizona adds the convenience of quick filter changes but requires the removal of the RedCat's tip-tilt rear cell.

Mounting Options

With its included Vixen-style dovetail bar, the RedCat 51 can go on most any small equatorial mount. However, the RedCat's small size invites mating it to a small camera tracker for utmost portability. The combination that William Optics illustrates in the RedCat's Quick Start Guide, and that has proven popular with YouTubers who promote it, is pairing the RedCat with iOptron's SkyGuider Pro tracker ($498 plus tripod).

While I typically refrain from using any tracker with lenses longer than 135 mm, I tried the RedCat with the SkyGuider Pro and found the combination does work, albeit with some caveats. The SkyGuider Pro tracks well enough that out of dozens of one-minute unguided exposures, about half were untrailed enough to be suitable for stacking.

A better portable package, say for airline travel, would be mating the RedCat to a Sky-Watcher Star Adven-

▲ The RedCat can be mated to a tracker such as iOptron's SkyGuider Pro, a popular combination but one that lacks fine adjustment in declination.

turer 2i Pro Pack ($419 plus tripod). The Star Adventurer's declination bar has a manual slow motion, a feature missing

The RedCat works well with light-pollution and narrowband filters for enhancing emission nebulae. But at its f/4.9 speed, sub-frames need to be 8 to 16 minutes long through a filter, as they were for this image.

on the SkyGuider Pro, which significantly improves your ability to precisely frame your subject. In tests with the new Wi-Fi-enabled Star Adventurer 2i, autoguiding proved almost essential, as it did with the scope mounted on the SkyGuider Pro, with two-minute exposures at ISO 3200 working well to ensure no declination drift.

So, yes, in a pinch the RedCat can be used with a camera tracker. However, for use at home or any site you can drive to, a far more solid choice is a full German equatorial mount. I tested the RedCat on Sky-Watcher's new lightweight EQM-35 mount ($725). The improved tracking and dual-axis guiding allow longer exposures at lower ISOs, producing images with less noise and wider dynamic range. When shooting with focal lengths of 250 mm or more, having Go To and electric slow-motion controls make finding and framing targets so much easier than with a tracker.

▲ *Left:* An ideal combination for portability and affordability in a deep-sky imaging system is pairing the RedCat with Sky-Watcher's EQM-35 Go To mount. *Right:* The RedCat comes in a zipped, padded case with cutouts for accessories. With its accessory handle attached, the tube doesn't quite fit.

Recommendations

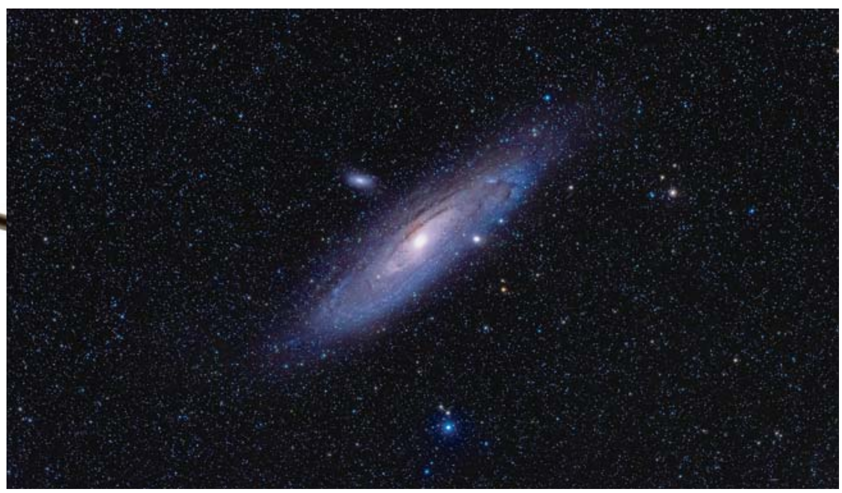
Unless airline portability is paramount, I recommend using the RedCat on a full German equatorial mount. Even a lightweight mount will yield better images more consistently than using the RedCat on a small camera tracker pressed to or beyond its limits. Many influential but novice YouTubers have yet to learn just how important a solid mount is for deep-sky imaging.

By contrast, bigger isn't always better with optics. The little RedCat is a fine example of a small astrograph that is easy to use yet can produce publication-quality results. For an advanced astrophotographer, the RedCat can serve as a wide-field complement to a larger telescope. For the beginner, the RedCat can provide top-class images without breaking the bank. But do match it to a solid mount.

■ See more of Contributing Editor **ALAN DYER**'s images, tips, and product reviews on his website at **amazingsky.com**.

◀ Ignoring the clash of colors, the Sky-Watcher Star Adventurer 2i serves as a good mount for situations in which portability is important.

▼ As a test of this compact combination, the author mounted the RedCat with the EOS Ra camera on a Sky-Watcher Star Adventurer 2i tracker to shoot a set of 18 two-minute autoguided exposures at ISO 3200. It worked!



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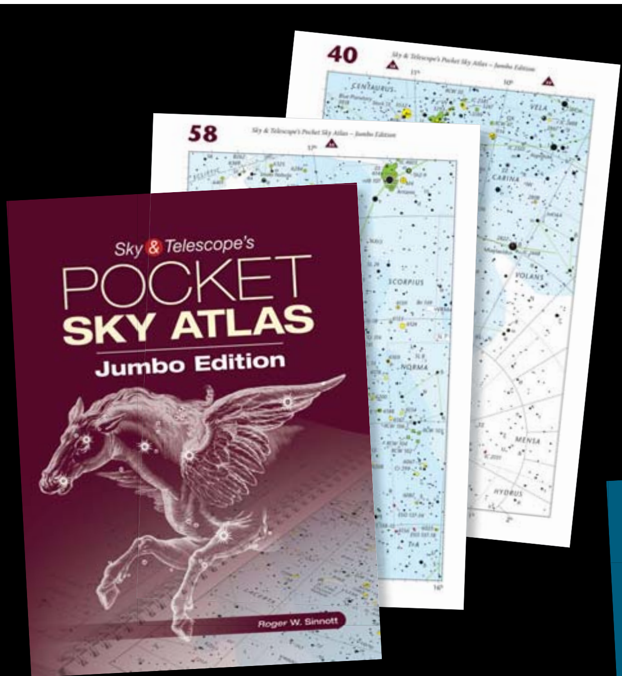

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SKY & TELESCOPE

Arrowhead Hill Observatory

Natural materials make for a rustic but beautiful structure.

WHEN SOUTH CAROLINA AMATEUR astronomer James Welsh retired, his thoughts naturally turned to building a home observatory. Unfortunately, his house is surrounded by trees that he wasn't allowed to cut. However, he did have a one-acre hilltop lot across the street from his lake cabin, and although trees surrounded that, too, he could remove those trees.

It seemed a shame to fell the trees and haul them away only to import milled lumber for an observatory, so Jim decided he would cut out the middleman and build the observatory out of the logs that grew right there on the site.

Jim reports that "Cutting and hauling logs, stripping the bark, digging footings, and raising the logs was a good workout. I burned up quite a few calories and one chainsaw in the process." He got better at peeling the logs over time. The major difficulty was in raising the logs as the cabin got higher. He managed it himself by lifting one end and sliding the logs up, but he recommends a helper for anyone interested in trying this themselves.

As he worked, he thought about the early American pioneers making their first shelters and how much labor that took. "They did it while at the same time hunting, planting, and feeding their families. That thought made me really respect our ancestors."

He used as many recycled materials as possible, except for the concrete for the pier, the leveling plate, the metal roof, and some lumber that he had to purchase. The hilltop was — and still is — off the electrical grid, so Jim used hand tools ("Other than the poor, deceased chainsaw") and a battery-powered drill/driver to construct the building. He labored on it through a South Carolina summer, taking his time and only working in the cool hours, which meant it took him about six months to complete (if one can ever say their observatory is complete).

The resulting 8-by-10-foot building is one of the most beautiful home observatories I've ever seen. The logs are tightly chinked with mortar and painted with an exterior stain that gives them a rich glow. The green door and roof complete a natural, tree-like look that makes it blend in perfectly with its surroundings.

Despite the rustic building materials, Jim's observatory has a traditional roll-off roof that glides easily with a push onto its support structure. Inside, a tall concrete pier provides vibration-free support for a 10-inch Meade Schmidt-Cassegrain telescope. Shelves in one corner provide storage for various pieces of observing equipment, and a stand made of salvaged mahogany holds eyepieces and the telescope's Go To hand controller. The flooring is leftover vinyl from his son's house.

Jim reports that it's a joy to observe from. "I get a pleasant walk up the hill and through the woods each time, and I love the fact that I am set up and ready to observe in just a few minutes." The thick wooden walls protect from fast temperature changes, and in fact they offer such good protection from the wind that Jim

◀ James Welsh's Arrowhead Hill Observatory is as functional as it is attractive. The hilltop's trees are still there, just in a different form. Jim named the observatory Arrowhead Hill after discovering this arrowhead while digging the foundation.

JAMES WELSH (4)

▲ Jim constructed the observatory entirely with hand tools.

often has to remove layers of clothing even in the wintertime.

The idea of an observatory also got friends and neighbors interested in coming up and having a look through a telescope for the first time. So far from being an isolating experience, the observatory has proven to be an excellent outreach tool instead.

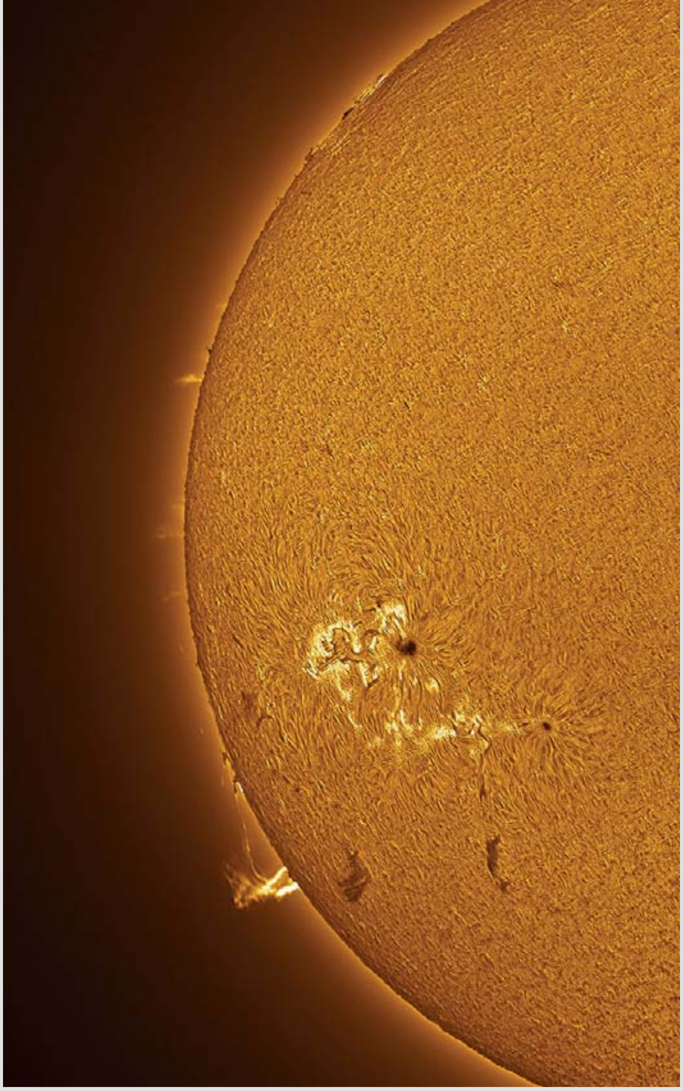
While transparency in South Carolina can be an issue in the hot summer months, darkness and seeing are generally good year-round. The Milky Way is usually visible from this site.

The observatory has an interesting historical connection, too. Jim explains: "I named this the Arrowhead Hill Observatory because the first shovelful of dirt that I turned over as I broke ground contained an arrowhead. That was not the first arrowhead that I had found in the area, but it was a surprise, and I felt compelled to dedicate the observatory to those who hunted the land hundreds or thousands of years ago as I will hunt objects in the sky today and in the future."

For more information, contact Jim at **jimwelsh_2000@yahoo.com**.

■ Contributing Editor **JERRY OLTION** grew up in a log house. It was one of the most comfortable — and comforting — houses he's ever lived in.

◀ The interior is roomy enough to work comfortably in.



▷ SOL AWAKENS

Jim Militello

After a long period of solar inactivity, Sunspot AR 2786 swung into view during the final week of November 2020, crackling with energy and unleashing several powerful flares.

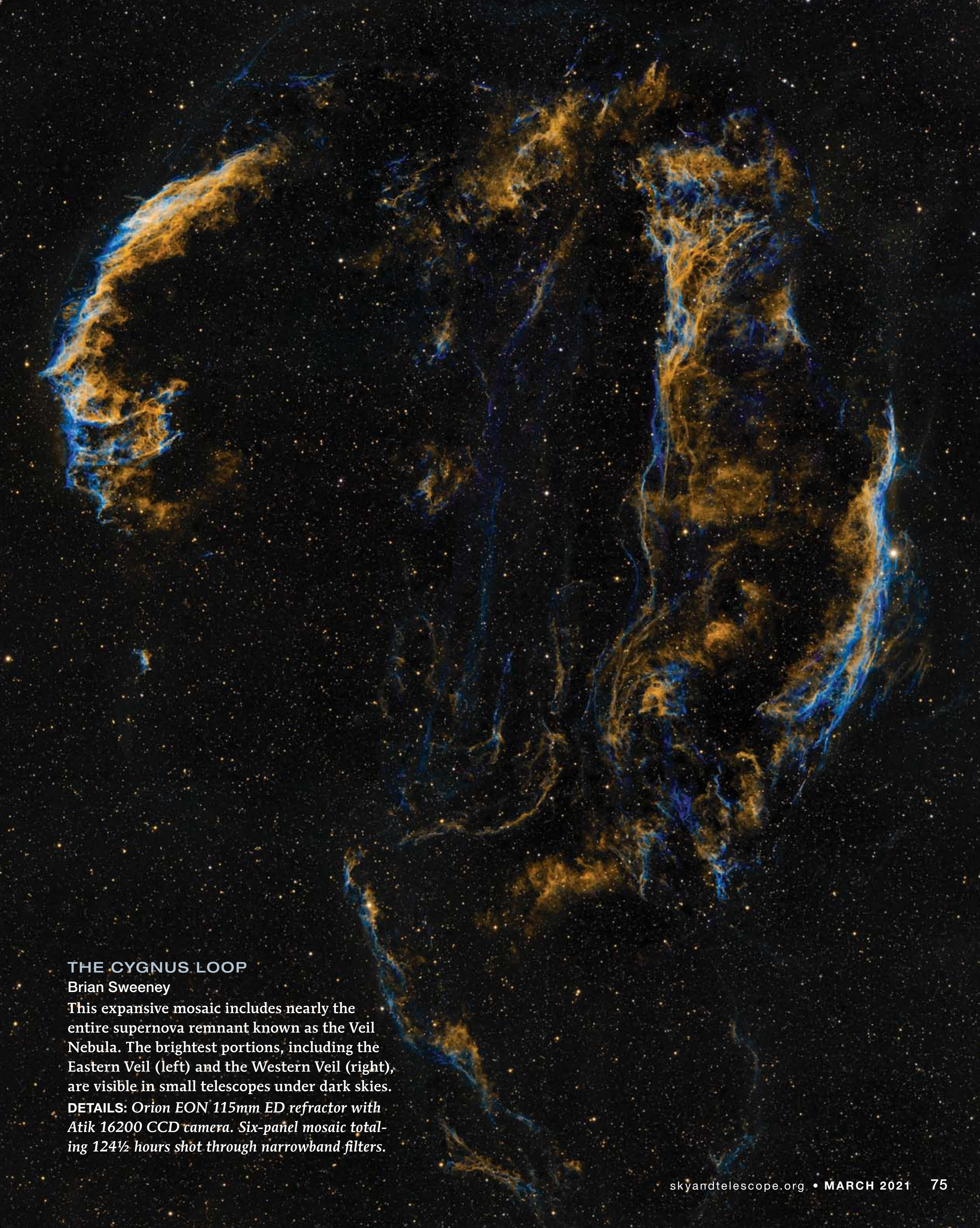
DETAILS: *Coronado Solarmax 90 hydrogen-alpha telescope with ZWO ASI178MM video camera. Stack of 450 video frames recorded on November 26, 2020.*

▽ MIDSUMMER MEMORIES

Sérgio Conceição

The Milky Way from Cassiopeia to Sagittarius arches above the fortress of Juromenha, Portugal. Saturn and brighter Jupiter are visible to the right of the parish ruins.

DETAILS: *Canon EOS R mirrorless camera with 14-mm lens at f/2. Panorama assembled from 26 individual 15-second exposures recorded at ISO 6400.*



THE CYGNUS LOOP

Brian Sweeney

This expansive mosaic includes nearly the entire supernova remnant known as the Veil Nebula. The brightest portions, including the Eastern Veil (left) and the Western Veil (right), are visible in small telescopes under dark skies.

DETAILS: *Orion EON 115mm ED refractor with Atik 16200 CCD camera. Six-panel mosaic totaling 124½ hours shot through narrowband filters.*

▷ BIG BLUE PLANETARY

Chris Schur

Jones 1 is a large planetary nebula glowing faintly in Pegasus that was discovered by Rebecca Jones at Harvard College Observatory.

DETAILS: *Orion 10-inch f/3.9 Newtonian Astrograph with ZWO ASI071MC Pro color CMOS camera. Total exposure: 2 hours both unfiltered and through Hα and O III narrowband filters.*

▷▷ MARTIAN CRATER

Leo Aerts

Many small-scale details are visible in this image of Mars, including the distinct outline of Crater Huygens seen left of center.

DETAILS: *Celestron C14 Schmidt-Cassegrain with ZWO ASI174MM video camera. Stack of multiple video frames recorded through color filters at approximately 23:09 UT, October 1, 2020.*

▷▷▷ FLOWERING NEBULA

Fabian Rodriguez Frustaglia

Sharpless 2-170 in Cassiopeia is a faint emission nebula surrounding the sprinkling of stars that make up open cluster Stock 18.

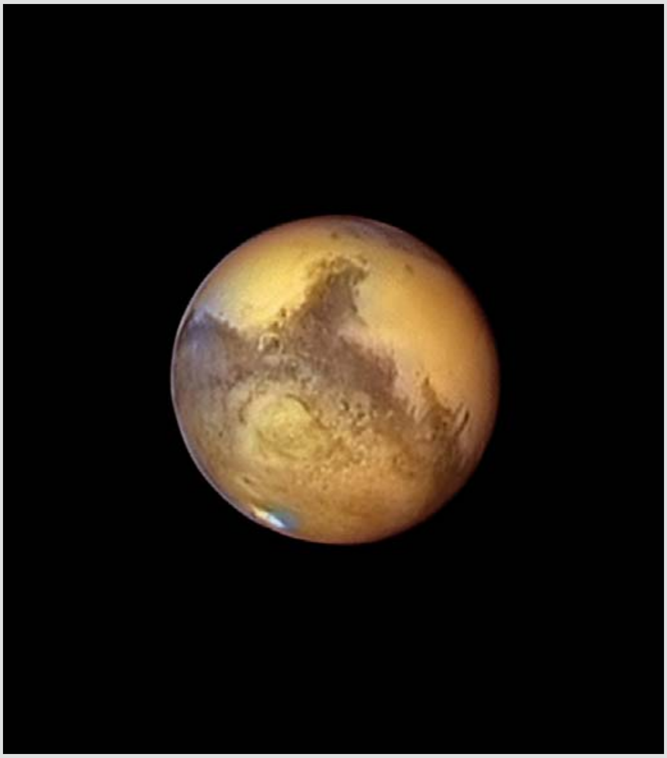
DETAILS: *Meade 115mm Series 6000 ED refractor with ZWO ASI1600MM CMOS camera. Total exposure: 9½ hours through narrowband filters.*

GOSSAMER REFLECTIONS

Chuck Manges

Bluish reflection nebulae vdB 15 (left) and vdB 14 (top right) are the brightest areas of a much larger dust cloud in Camelopardalis.

DETAILS: *Celestron EdgeHD 11 with HyperStar V4 equipped with a QHY163M CMOS camera and AT65EDQ refractor with QHY128C CMOS camera. Total exposure: 228 minutes.*

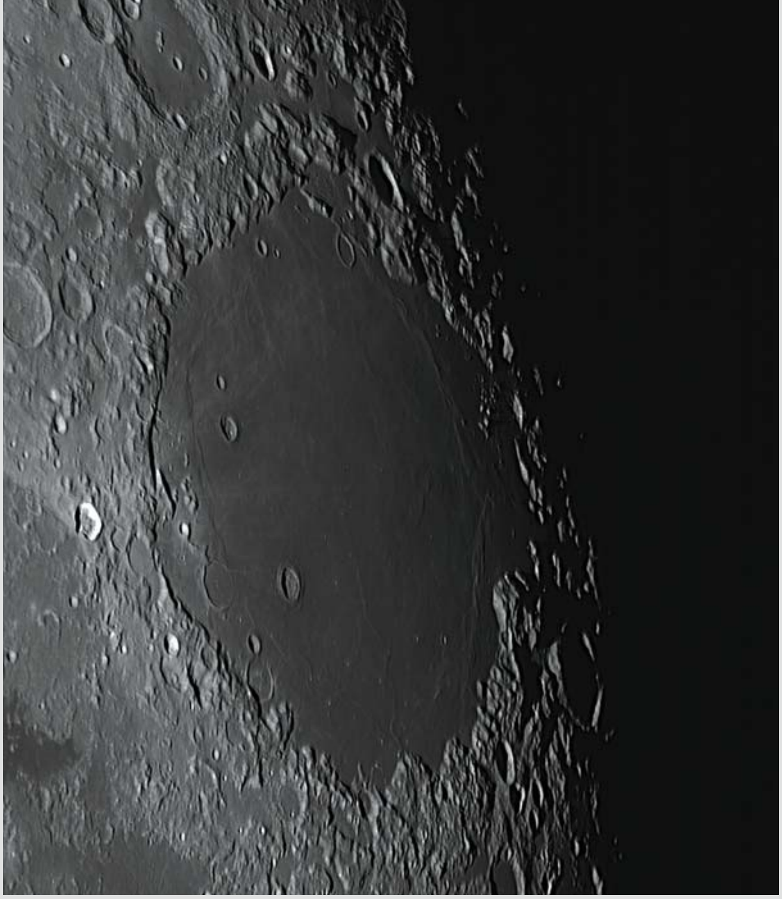


SUMMER SPLENDORS

Alistair Symon

Many emission nebulae stand out in this swath of the Milky Way, which includes the constellations Cassiopeia, Cepheus, and Cygnus.

DETAILS: *Takahashi FSQ-106 refractor and 85-mm Sigma lens with SBIG STXL 11002 CCD camera. Forty-nine-image mosaic utilizing 430 hours of exposure through narrowband filters.*



▷ SUNSET ON THE SEA OF CRISES

Steve Thornton

Mare Crisium is seen here in excellent relief just one day following full Moon. To the west (left), the bright walls of the rayed Crater Proclus are visible.

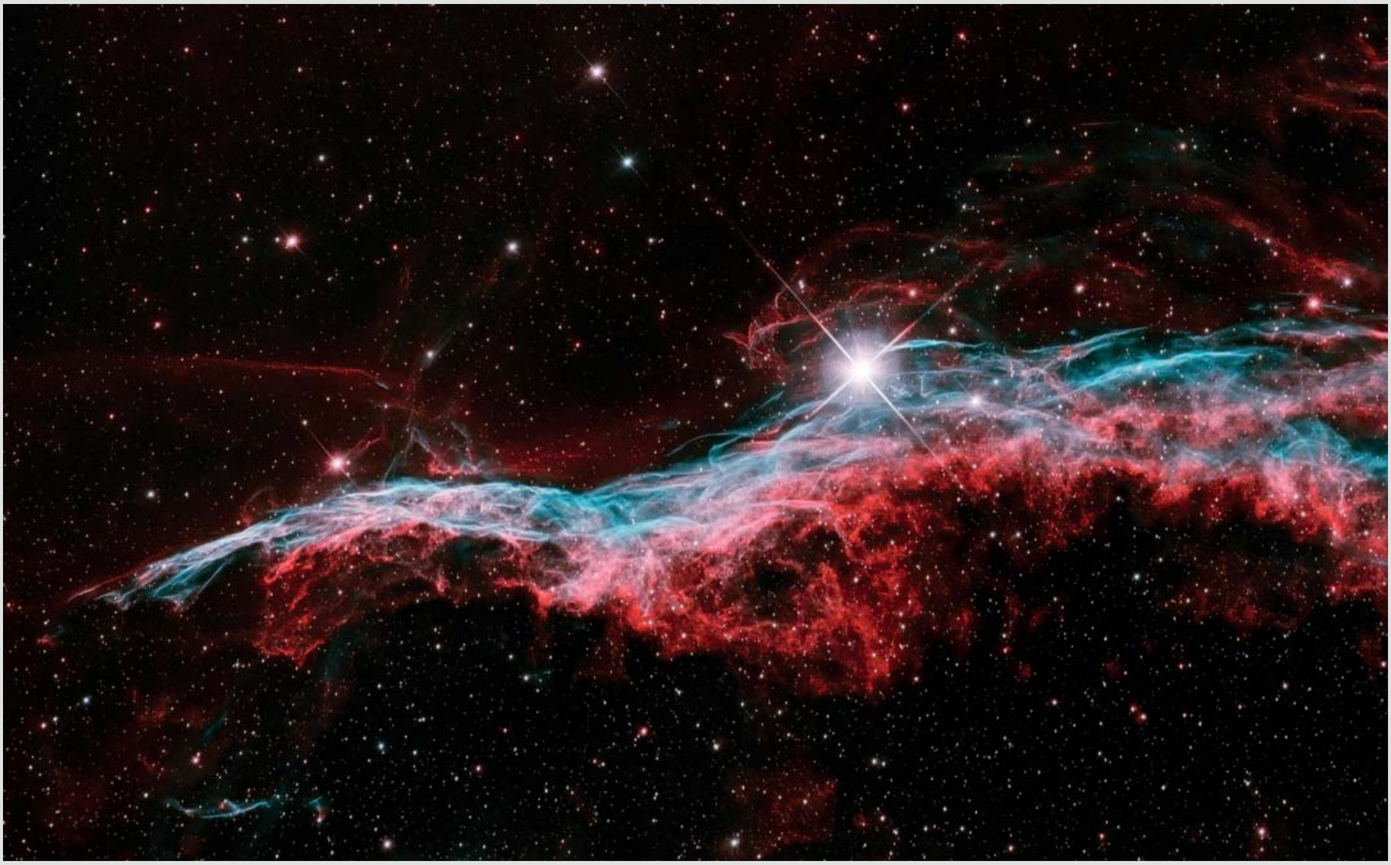
DETAILS: *Celestron C9.25 Schmidt-Cassegrain telescope with ZWO ASI120MM video camera. Stack of 1,600 frames.*

▽ THE WITCH'S BROOM

Greg Polanski

This bright region of the Veil Nebula, designated NGC 6960, displays lace-like filaments near the star 52 Cygni. You can identify this section of the supernova remnant in the image found on page 75. North is towards the left.

DETAILS: *Sky-Watcher 150-mm Newtonian reflector with QHY163M CMOS camera. Total exposure: 11½ hours through Hα and O III narrowband filters.*



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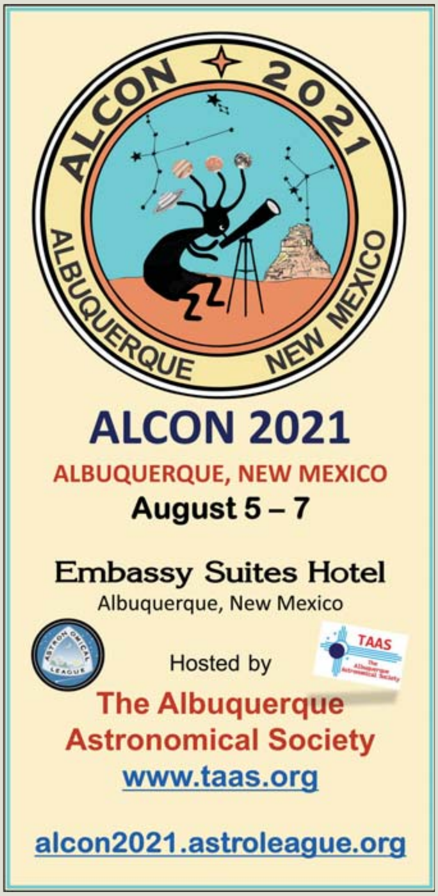

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AD INDEX

Event Calendar

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

February 8–14
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Scout Key, FL
scas.org/winter-star-party

March 6
TRIAD STARFEST
Jamestown, NC
https://is.gd/tristar

April
GLOBAL ASTRONOMY MONTH
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April 4-11
INTERNATIONAL DARK SKY WEEK
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April 7–10
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

April 10–11
NORTHEAST ASTRONOMY FORUM
Suffern, NY
rocklandastronomy.com/neaf1.html

May 2–9
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

May 15
ASTRONOMY DAY
Events across North America
https://is.gd/AstronomyDay

June 5–12
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/gcsp2021

June 9–13
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 10–13
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 10–13
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
https://is.gd/WIObserversWeekend

July 7-11
GOLDEN STATE STAR PARTY
Bieber, CA
goldenstatestarparty.org

August 1–6
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

August 3–8
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

August 4–6
ALCON 2021
Albuquerque, NM
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• For a more complete listing, visit https://is.gd/star_parties.

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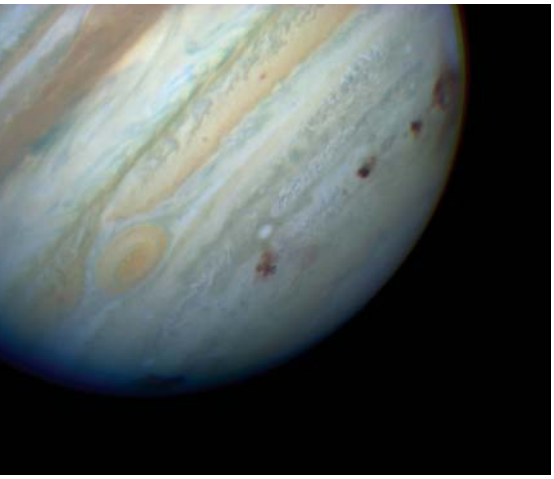
The Next Big One

The coronavirus pandemic reminds us that preparedness is critical when catastrophes come out of the blue, including from space.



◀ Planet-size “bruises” that Comet Shoemaker-Levy 9’s fragments left in Jupiter’s atmosphere in 1994 are a sobering reminder of what could happen on Earth if our luck ran out.

WHEN WE IN THE UNITED STATES first began to hear about a new virus in China, it dawned on me that the city of Wuhan where the outbreak had occurred was where a former colleague of mine lived. Having become enamored of Chinese culture, he’d moved there several years before to teach.

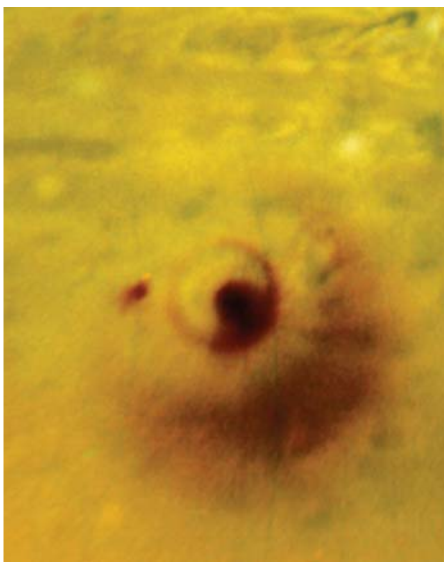
I immediately dashed off an email asking him how he was doing. I was semi-relieved to hear back that he was okay but self-isolating in his flat, and that things were starting to look pretty hairy in the city. Never did it occur to me that “it can happen here.”

Of course, it can, and did, and more swiftly than anyone would have believed (save epidemiologists and sci-fi and disaster-film enthusiasts). But the coronavirus pandemic is not the only sort of catastrophe that might pounce on us anytime, and it has something to tell us about how to think about certain other kinds.

One summer night in 1994 my wife and I took a small telescope into the country to observe one of the most spectacular astronomical events in our solar system ever witnessed by human eyes. The broken-up Comet Shoemaker-Levy 9 was pummeling Jupiter — hit after hit after hit. The points of impact were just beyond Jupiter’s horizon, but as the planet rotated, its big “black eyes” came into view one after the other. Some of these strike zones approached Earth in size (see below).

Some laypeople had worried that this event could endanger our planet, and I’d written to the local newspaper saying it certainly posed no risk to us. But could a similar comet haymaker happen here?

In the years since, I’ve learned a great deal about the threat posed to our own planet by comets (and asteroids) whose orbits cross Earth’s. In particular, I’ve come to appreciate that a comet can not only delight us with a spectacle, but can also put us at mortal peril, as the average size of a comet nucleus is large enough to possibly destroy human civilization were one to hit us.



▲ The comet’s “G” fragment gave Jupiter this “black eye” when it struck on July 18, 1994. The big crescent is about 12,000 km (7,460 mi) across, or about 94% of our planet’s diameter.

Some people try to reassure us that a collision is highly unlikely. Yet after Comet Shoemaker-Levy 9 came Comet Siding Spring, which narrowly missed hitting Mars in 2014. And last July 1 was the 250th anniversary of humanity’s closest known brush with potential extinction by a comet, when giant Lexell’s Comet shot past our planet less than six times the distance between Earth and the Moon.

> A comet can not only delight us with a spectacle, but can also put us at mortal peril.

What we’ve learned from the COVID-19 pandemic is that a lack of adequate preparedness and a failure to respond rapidly can make all the difference. If tomorrow we discovered a comet with our name on it at the orbit of Jupiter, we might have only nine months before impact. As the late comet expert Michael A’Hearn testified to Congress in 2013, “you would have to have something ready to launch” to have any chance of preventing the impact. Currently we do not have that preparedness, nor do we have a plan in place to attain it.

My colleague in Wuhan was eventually evacuated and spent two weeks under quarantine at Travis Air Force Base in California before returning to his home in Connecticut. But as he soon discovered, because there had not been quick enough action in this country to deal with the virus, there was nowhere to hide.

■ **JOEL MARKS** is professor emeritus of philosophy at the University of New Haven in West Haven, Connecticut, and a self-described philosophical astronomer. He recently served on a NASA Small Bodies Assessment Group team charged with updating planetary defense considerations.

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