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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

FEBRUARY 2021

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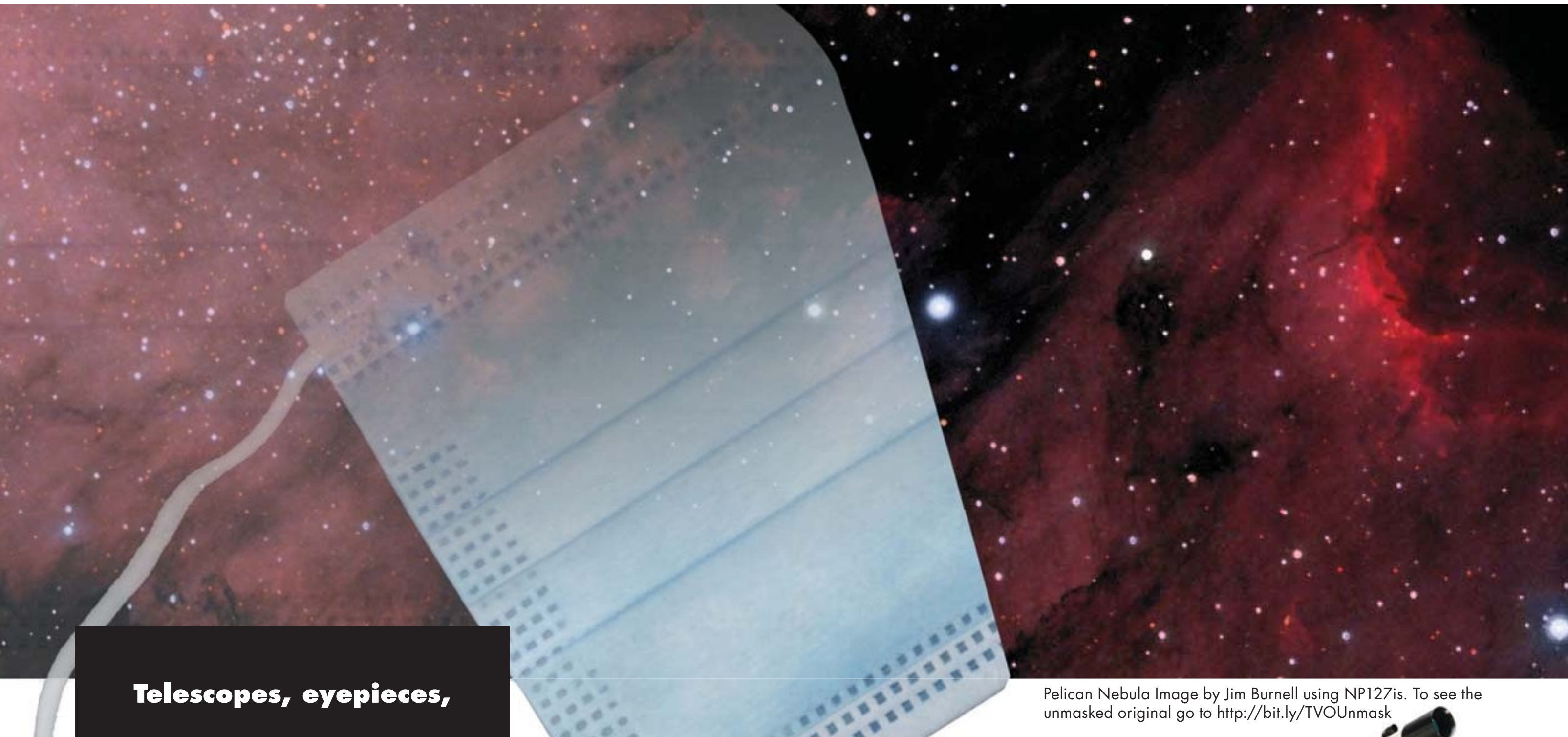

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ON THE COVER

The dome of the 2.1-meter Otto Struve Telescope

PHOTO: ETHAN TWEEDIE PHOTOGRAPHY

ONLINE

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New to astronomy? Find advice, free resources, and ways to grow your interest into a lifelong passion.
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Celestial Inkblot Tests

COMMON NAMES FOR planetary nebulae are some of the most imaginative in astronomy. Partly that's because the official designations of these vestiges of dying stars range from the blandly categorical (e.g., NGC 2346) to the truly ungainly (PN G75.5+1.7). "Butterfly Nebula" and "Soap Bubble Nebula," as the two objects just mentioned are informally known, tickle our fancies a bit more.

Maybe it's in part because the term "planetary nebula" is a misnomer — these gaseous blobs have nothing to do with planets — and when we shorten the term to "planetaries" it's even more absurd. Likening distant clouds of gas and dust to butterflies and soap bubbles jibes with that preposterousness.

But the main reason these entities offer such rich opportunities for whimsical christening is that they come in a dazzling array of evocative shapes, colors, and nebulous textures. As our brains try to make sense of what we're seeing, we naturally begin seeking resemblances to familiar things. Let the dubbing begin!

▲ The Dandelion Puffball Nebula (aka NGC 6751)

NASA / THE HUBBLE HERITAGE TEAM (STSCI / AURA)

In his article on imaging planetary nebulae on page 18, Ron Brecher covers some of the better-known ones: the Helix (NGC 7293), the Ring (M57), and the Cat's Eye (NGC 6543), to name a few. But among the 3,000 or so planetaries that astronomers have so far identified in the Milky Way, we also have, among others, the Lemon Slice Nebula (IC 3568), the Soccer Ball Nebula (Kronberger 61), and the Glowing Eye Nebula (NGC 6751), also known as the Dandelion Puffball Nebula.

While all those are visible from the Northern Hemisphere, the Southern Hemisphere has its own potpourri of planetaries with clever eponyms. The Spirograph (IC 418), the Robin's Egg (NGC 1360), and the Engraved Hourglass (MyCn 18) all visually call to mind their down-to-Earth counterparts. The southern planetary OH 231.8+04.2 goes — thank goodness — by both the Calabash Nebula for its shape and by the Rotten Egg Nebula for its known high sulfur content.

Some planetaries don't yet have established common names, which only take hold when many astronomers start using them. In the meantime, one can have fun coming up with one's own nicknames. I did just that after reading Brecher's piece. You'll have to look these up, but I'd call NGC 5307 the Tardigrade Nebula, NGC 2818 the Mantis-Eyed Nebula, and NGC 6326 the Kapow! Nebula.

To try your own hand at this celestial Rorschach test, open a web browser and do an image search for "planetary nebula." You'll hit upon both amateur and professional images, many taken by the Hubble Space Telescope. You can work your brain in a pleasurable way dreaming up apt appellations for what you see. Who knows? Maybe a common name of yours will stick.

Peter

Editor in Chief

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The Essential Guide to Astronomy

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

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Astronomy for All

From the Staff of *Sky & Telescope*: Thank you for all the responses we received to our editorial "Astronomy for All" (*S&T:* Oct. 2020, p. 4). Below are some helpful suggestions from readers for how to address the issues discussed in that editorial.

You are correct that there is a limited number of Black and Spanish-American participants in local astronomy outreach events. I emphasize children should attend. They love it. I had one 13-year-old boy shout, "This is the most exciting night of my life!" Little girls wear dresses with stars on them. What a joy to see their enthusiasm.

I highly promote smartphone apps for astronomy and stargazing. I recommend people not throw away their old phones but let children use them with night-sky apps to teach the family about the heavens. Children do very well pointing out everything they see on the app. That gets them involved in the family and education and gives them self-esteem.

Irene Baron
Member, Zanesville Astronomy Club
Zanesville, Ohio

Thank you for undertaking "Astronomy for All." Since 2004, I have been a volunteer Jet Propulsion Laboratory Solar System Ambassador and have experienced many opportunities and challenges. One particular event recalibrated my entire field of view. During check-in at a new school where I was to conduct a daylong series of programs, the principal and I had a nice chat.

While thanking me and discussing backgrounds, my military service came up. When he learned I was a retired military officer, he immediately said that many of the boys at his school lacked role models, and if I was interested, he would be grateful if I would serve as a mentor. Long story short, I have visited the school many, many times and been supportive.

Sometimes we may be called upon to operate beyond the astronomy/STEM domain to make a lasting impact, beyond an episodic star party that inspires a young person but leaves them unequipped to act on their own feelings. Please consider this deeper engagement aspect of outreach and be aware of needs where they may exist.

Max Corneau
Former President, Texas Astronomical Society of Dallas
Lieutenant Colonel (Ret.), U.S. Army
Rockwall County, Texas

I would suggest contacting community centers, churches, libraries, community parks, state parks. That's where people go. I would like to see articles on Black astronomers in *Sky & Telescope*, not just on your website. Our children need to learn history. Start with Benjamin Banneker [1731–1806]. The book *Hidden Figures: The Untold True Story of Four African-American Women Who Helped Launch Our Nation into Space* should be read by all students in school.

K. Lynn King
Member, Rittenhouse Astronomical Society
Philadelphia, Pennsylvania

The best time to arouse interest in astronomy is in early childhood. That worked with me more than half a century ago.

Could donating copies of your magazine to schools that are mostly attended by Black children be a possibility to help? Additionally, getting planetariums to donate admission tickets might help, too.

Federico Cardona
Bermatingen, Germany

I've been in the field for over 20 years teaching astronomy and how to buy and use telescopes as a volunteer at Virginia State Parks. The groups that come out for our presentations are evenly diverse, of all races and backgrounds. When someone looks through our telescopes for the first time and becomes emotionally engaged, we've planted that seed of learning.

You need a section in your magazine for beginners, especially kids. That's where most of us got started. Also, a section showing how to put on public demonstrations. Every year, we offer programs explaining how to put on an astronomy event to engage people using telescopes or to help children make a home planetarium that actually works!

Hands-on is everything in this hobby, and every race and background have joined us in enjoying the beauty of the night sky. Just as Carl Sagan embraced Neil deGrasse Tyson when Tyson was 17, we as amateur astronomers can all do the same. Keep up the great work!

Kim Kenny
Member, Crewe Astronomy Club
Crewe, Virginia

I live in Revere, Massachusetts, and the light pollution is terrible. Star hopping to a target is close to impossible when you can't even see many stars. I was thinking about inner-city youth today. What if one of them, like I did, took an interest in astronomy and wanted a telescope? What could *Sky & Telescope* do for them?

First, make sure your magazine gets into inner-city public libraries (to both encourage and feed the interest). Second, and this is really my suggestion, devote a page or more in each issue to urban astronomy. You always devote space to deep-sky objects (as you should), but if you want to encourage urban youth to take up the hobby, it might help to highlight objects available to them.

Dave Malaro
Revere, Massachusetts

Editor's Note: *You read our mind! Last month we launched the column you suggest. It's called Suburban Stargazer and will appear bimonthly.*

I support the magazine's goal to bring to the forefront the contributions and spirits of people of color working in the sciences, mainly astronomy in this case. I believe your most effective work must focus on helping young people of color to learn to love science and to envision fulfilling and successful careers for themselves as professional scientists or astronomers.

The area local to the magazine's offices has no shortage of scientists to inspire local youth, so the magazine could actively connect with them and local schools to find ways to engage youth with science. Partner with local or regional clubs like the Amateur Telescope Makers of Boston to enhance both the "in-school" science courses with discussions on practical observing, then help get kids involved in real observing with local amateurs.

Also, make connections with local academic/professional astronomers to create opportunities for kids to visit Harvard College Observatory, for example, and to be introduced to young astronomers and hear about the pathway to, and excitement of, a career in science.

Gary Shaw
Watertown, Massachusetts

Thank you for "Astronomy for All." I appreciate that you are concerned with bringing inclusion to astronomy; after all, we all live under the stars!

As I am white, I might not be the best person to give advice. But perhaps having a column dedicated to inclusion would be a good thing. Guest writers writing about diversity in astronomy or something like that? And, of course, there is Neil deGrasse Tyson — maybe a guest column from him talking about the issues.

We need to include Native American, Asian, and Hispanic, not just Black and white. I like all your ideas in your column.

Caroline Torkildson
Hovland, Minnesota

Several adopters of the OpenStax astronomy textbook for which I am the lead author asked me if I could recommend resources for teachers who want to showcase authentic voices from the Black community among astronomers at this important moment in the progress of the Black Lives Matter movement.

I have put together such a resource and wanted to let you and your readers know about it, since it may be of interest to amateurs as well. You can find it free of charge at **https://bit.ly/blackastro.**

Andrew Fraknoi
Professor of Astronomy
Fromm Institute, University of San Francisco
San Francisco, California

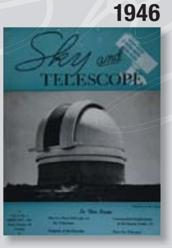
FOR THE RECORD

● The Moon's closest perigee this year (*S&T:* Oct. 2020, p. 47) was on April 7th at 17:59 UT.

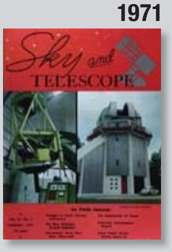
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1946



1971



1996

◖ February 1946

200-inch Views "'The telescope,' explains Dr. John A. Anderson . . . 'will not be used for work that can be done equally well by existing instruments. Always the object will be to reserve it for those observations which require its greater light-gathering power . . .'

"But wait, there will be at least one exception. Russell W. Porter, architect of Palomar Observatory, has been promised his hour [at] an eyepiece of the 200-inch while it is pointed at the moon. He will make pencil sketches of lunar marvels and try to record details so delicate that ordinarily they escape the grasp of photographic plates.

"In revealing this arrangement, Mr. Porter, sometime shepherd of amateur astronomers and co-promoter of the present-day amateur mirror making hobby, lifted his pipe from his mouth and smiled."

Porter, it seems, never got his hour of telescope time. He did perform star tests during final adjustments of the 200-inch telescope in 1948 but died early the next year.

◖ February 1971

Bird Navigation "Indigo buntings fly primarily by night during their long-distance migrations between the eastern United States and Central America. . . . Stephen T. Emlen [of Cornell University] hand-raised 26 buntings in a laboratory with a diffusely illuminated ceiling, where they never saw the sky. Two months before the autumn migration season, he divided them into three groups. Birds in group A remained in the same laboratory and never experienced point sources of light. Group B birds were placed three nights a week under a planetarium sky oriented just like the actual sky outside and rotating with it. The third group, C, also had planetarium sessions, but with the rotation about a false axis that made [Orion] a brilliant circumpolar star pattern around which the other constellations wheeled. . . .

"These experiments provide strong evidence these young birds initially acquire their orientation from the *rotation* of the night sky. Afterward, Dr. Emlen suggests, the birds learn to recognize stars or star groups . . . to locate the north-south direction."

◖ February 1996

Jovian Plunge "Thursday, December 7th, was a day of anxiety, then elation, for engineers and scientists gathered at the Jet Propulsion Laboratory. Six years after being dispatched from Earth, the Galileo probe slammed into Jupiter's atmosphere at 38 kilometers per second and endured an estimated 215-*g* deceleration force. The instrument-packed capsule then transmitted data to the Galileo orbiter for 57 minutes, eventually succumbing about 160 kilometers below the tops of Jupiter's clouds . . .

"Minutes later the orbiter's braking rocket came to life . . . slowing the craft enough for it to become Jupiter's first artificial satellite."

ASTEROIDS

Spacecraft Takes a Bite of Asteroid Bennu

CHEERS ERUPTED in the control room on October 20th as NASA's OSIRIS-REX mission successfully "tagged" the diamond-shape asteroid 101955 Bennu.

The spacecraft's touch-and-go sample acquisition mechanism (TAGSAM) dug its head up to 48 cm (19 inches) into the regolith, puffed nitrogen gas to stir up and capture surface material, and reared away.

Just approaching the boulder-strewn surface was a feat for the OSIRIS-REX team: The surface was much rougher than expected, and the team took extra time to select a landing site. As it flew in, the spacecraft first had to slip past a two-story-high boulder nicknamed "Mount Doom" before targeting a clear slot about the width of two parking spots. The mission was 18.5 light-minutes from Earth, so the spacecraft navigated the approach on its own. Though the final landing target was much smaller than the mission's initial 25-meter-radius requirement, OSIRIS-REX touched the surface within a meter of where it was supposed to land.

▼ OSIRIS-REX's sampling arm contacts Bennu.

NASA / GODDARD / UNIVERSITY OF ARIZONA

The day after collection, the mission team imaged the TAGSAM to confirm success. In fact, the maneuver was almost *too* successful: The sample overflowed the head as multiple large rocks wedged open a Mylar flap and allowed some smaller grains to escape. The team acted quickly, using the TAGSAM arm to place the precious cargo in the return capsule on October 27th.

Immediately stowing the sample meant forgoing a spin test, which would have "weighed" the collection by measuring the spacecraft's moment of inertia and comparing it to a baseline obtained before the touch-and-go maneuver. Nevertheless, calculations showed the collected mass exceeded expectations: The team estimates the asteroid encounter filled the TAGSAM head with 258 to 575 grams (0.56 to 1.26 lb) of material — well above the minimum target of 60 grams set for the mission. It appears only a small fraction of this was lost due to the open Mylar flap.

Although the sampling phase is complete, OSIRIS-REX won't begin its return to Earth until March 2021, and the return trip will take some time: The flyby and sample drop-off is expected on September 24, 2023. Once collected from the landing site in the Utah Test and Training Range, the sample will be divided: a quarter will go to the mission's science team and 4% to partners at the Canadian Space Agency. Another 0.5% will go to the Japanese Aerospace Exploration Agency in exchange for pieces of the asteroid 162173 Ryugu, which JAXA's Hayabusa 2 mission will drop off during an Earth flyby in December 2020 (*S&T:* June 2019, p. 10). The remainder of the sample will be preserved, available to future researchers worldwide as investigative technologies advance.

■ DAVID DICKINSON

IN BRIEF

Bennu's Surface Surprises

In preparation for OSIRIS-REX's sampling maneuver on Bennu, the mission team mapped the surface at a resolution down to 5 cm (2 inches) per pixel. Besides enabling a safe landing, the images revealed unexpected properties of Bennu's surface. Daniella DellaGiustina (University of Arizona) and colleagues report September 21st in *Nature Astronomy* six anomalously bright, large boulders that stand out from the rest of the much darker surface. The rocks' compositions indicate their likely origin on another asteroid: 4 Vesta. Perhaps Bennu picked them up as it wandered through the asteroid belt to its present trajectory inside Mars's orbit. The images also showed reflective patches on some otherwise-dark boulders, which caught the eye of Hannah Kaplan (NASA Goddard) and colleagues. They found that the bright spots are rich in carbonates, particularly calcite, a highly reflective form of calcium carbonate. In the October 8th *Science*, Kaplan and colleagues make the case that these veins of minerals precipitated out of hot water flowing through cracks deep inside a young planetesimal. Bennu is likely a chip off that planetesimal block, formed from the debris of a catastrophic collision about 1 billion years ago.

■ JEFF HECHT

Read more about findings on Bennu's surface at https://is.gd/BennuVesta.

COSMOLOGY

Astronomers Chart History of Star Formation

A HISTORICAL RECORD of molecular hydrogen gas — the stuff that makes stars — provides astronomers with a sweeping survey of star formation, as well as a prediction for when the universe's stars will go dark.

Astronomers have already charted the rise and fall of galaxies' star formation over time, revealing a stellar baby boom that peaked about 10 billion years ago; rates have been decreasing ever since. To explore these trends, astronomers went a step earlier in the process, tracking not just the stars born but the material used to make them.

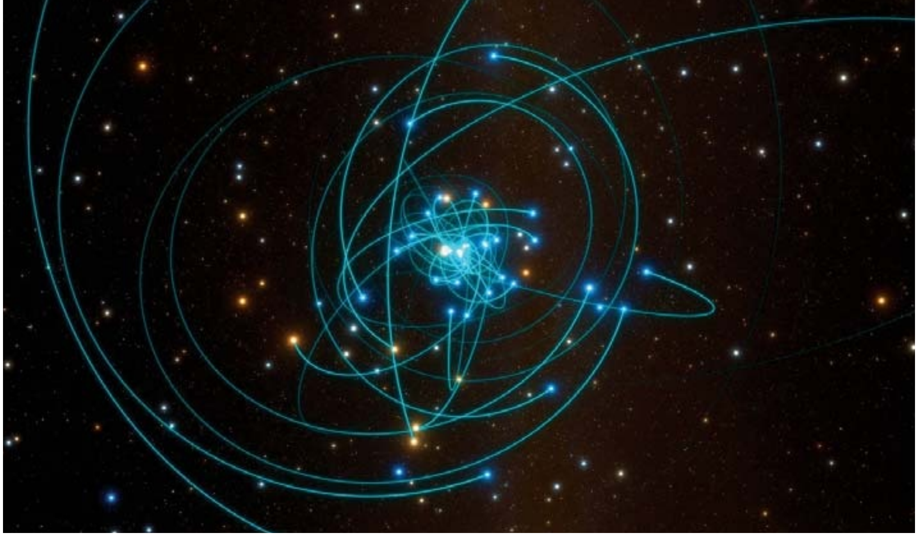
ASTRONOMY & SOCIETY

Black Hole Scientists Win Nobel Prize in Physics

A PHYSICIST AND TWO ASTRONOMERS have bagged 2020 Nobels for helping clinch the case for black holes' existence: physicist Roger Penrose and astronomers Reinhard Genzel and Andrea Ghez. Penrose will receive half of the 10 million Swedish kronor ($1.1 million) prize; Genzel and Ghez will share the other half equally.

We know today that black holes are an unavoidable consequence of Einstein's general theory of relativity, published in 1915. In this framework, gravity is geometry: Mass tells spacetime how to curve, and spacetime's curves tell mass how to move. Black holes are where mass curves spacetime so much that nothing, not even light, can escape.

But black holes were not scientifically palatable for several decades. Many researchers helped change that, but it was Penrose (University of Oxford, UK) who, in the mid-1960s, showed that collapse to a singularity always happens when there's enough mass/energy packed together. He introduced a new mathematical concept to make this leap, called *trapped surfaces*, from which the path inward is inexorable — one-way traffic only.



▲ Simulation of known stars orbiting the Milky Way center

Penrose also discovered that it's possible to extract energy from a spinning black hole, which helps explain how distant supermassive black holes, known as quasars, can power jets that extend thousands, even millions of light-years long. Still, astronomers needed more evidence to show that supermassive black holes sit at the center of nearly every major galaxy.

Work by Genzel (Max Planck Institute for Extraterrestrial Physics, Germany) and Ghez (University of California, Los Angeles) was pivotal in this effort. Thanks to a series of technical feats, the two competing astronomers and their teams have spent nearly three decades using ground-based near-infrared telescopes to watch dozens of stars looping pell-mell around an invisible object at the heart of the Milky Way. By tracing stellar motions, the astronomers revealed that the stars revolve around an unseen, unmoving, and compact something-or-other with the mass of 4 million Suns. Astronomers call this black hole Sagittarius A*.

The teams' observations have also enabled them to confirm two predictions of general relativity (*S&T:* Sept. 2018, p. 22): the *gravitational redshift* of light as one of the stars dipped into the spacetime valley the black hole makes around itself, and the slight shift in that star's path as it traveled through the warped spacetime, a process known as *orbital precession*.

■ CAMILLE M. CARLISLE

Fabian Walter (Max Planck Institute for Astronomy, Germany) and colleagues used the Atacama Large Millimeter/submillimeter Array (ALMA) to survey the Hubble Ultra Deep Field, publishing the results in the October 20th *Astrophysical Journal*.

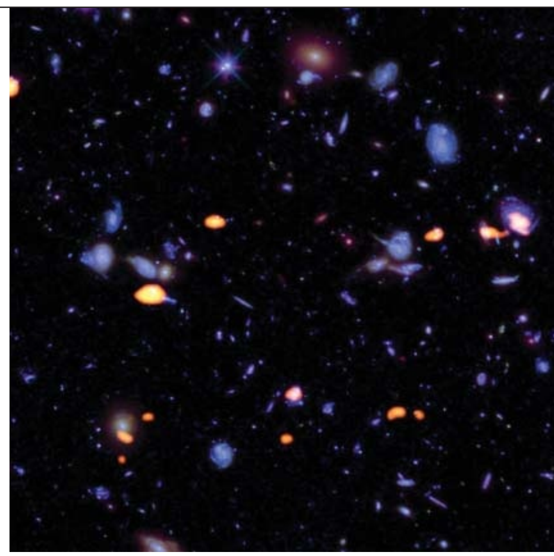
ALMA's radio dishes spy cool gas and dust in galaxies whose light has been traveling for up to 12 billion years, enabling Walter and colleagues to understand the flow of gas throughout cosmic history.

The gas that falls into galaxies is ionized and has to cool before it can form stars; first ions become neutral atoms, then they pair up into molecules. Walter and colleagues traced both atomic (H) and molecular (H_2) gas to follow the flow from galaxies' outer reaches to their star-forming hearts.

The new radio and millimeter-wavelength observations show that galaxies never, at any one point in time, hold all the gas they need to make all their stars. The gas has to come from outside, flowing inward in a continual process.

Gas inflow will keep declining, the researchers write, "and the cosmic star formation rate density will continue its steady descent to the infinitesimal." But even as the influx of star-making material decreases by half over the next 5 billion years, galaxies will nevertheless continue to make new stars with what they still receive. We're hardly at the end of times just yet.

■ MONICA YOUNG



▲ Within the Hubble Ultra Deep Field, galaxies rich in molecular hydrogen, as seen by ALMA, are highlighted in gold.

SIMULATION: ESO / L. CALÇADA / SPACEENGINE.ORG; HUBBLE ULTRA DEEP FIELD: B. SAXTON (NRAO / AUI / NSF) / ALMA (ESO / NAOJ / NRAO) / NASA / ESA HUBBLE

ASTRONOMY & SOCIETY

Pandemic Inspires Surge in Telescope Sales

THERE'S A SILVER LINING to the COVID-19 pandemic: a rediscovered interest in the night sky. With that interest come equipment needs, and telescope vendors and manufacturers are reporting a surprising surge in sales.

"I've never seen this kind of growth in the industry," Jeff Simon, director of Sky-Watcher North America, tells *Sky & Telescope*. "We often see a bump in interest around a big event such as a total solar eclipse or a bright comet, but this has been unprecedented."

The companies we talked to are seeing an increase in business from 60% to 400% over the previous year. Moreover, sales of entry-level telescopes aren't the sole driver of the increase in sales. Astro-imaging cameras, robotic telescope mounts, premium eyepieces, and other specialized equipment are flying off the virtual shelves as amateurs find more time to engage in their hobby.

"Who would have thought that it would take a global pandemic to save amateur astronomy?" says David Nagler, president of Tele Vue Optics. "People now have the time to discover (or rediscover) the night sky, and pull the trigger on that Go To telescope or premium refractor they were on the fence about purchasing."

But the boom comes with its own challenges. The global reaction to the rapid spread of COVID-19 caused international shipping to practically grind to a halt, leading to long waits on orders. This is especially true for vendors sourcing from China, who have encountered extended delivery delays.

But not all vendors face this predicament. Roger Rivers, Sales and Marketing Manager for iOptron, tells us their production team is keeping up with the unexpected surge in demand. Dustin Gibson of Oceanside Photo & Telescope even says he has found himself in the pleasant position of hiring new staff in a difficult time.

■ SEAN WALKER

SOLAR SYSTEM

Missions Head for the Moon in 2021

TWO COMMERCIAL LANDERS will travel to the lunar surface next year as precursors to the crewed missions of NASA's Artemis initiative.

The agency has awarded contracts to two companies, Astrobotic Technology and Intuitive Machines, to carry out the landings under its Commercial Lunar Payload Services program. The proof-of-concept landers will carry experiments and technology demos.

Astrobotic, based out of Pittsburgh, Pennsylvania, originally agreed to launch its Peregrine Mission One in July 2021. It will be part of the United Launch Alliance's inaugural flight of its Vulcan Centaur rocket. The lunar lander will carry 26 payloads, including 10 from NASA, to Lacus Mortis, a lava plain on the northeastern part of the Moon. The NASA payloads will collect scientific data on the Moon's regolith, magnetic fields, and volatiles, and test technology for future missions.

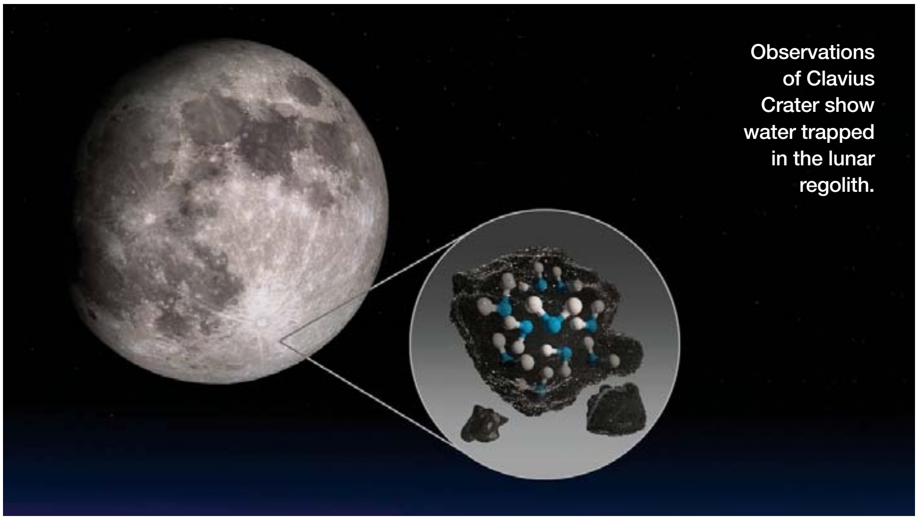
Next up is the Nova-C mission from Intuitive Machines, headquartered in Houston, Texas. Due to launch in October 2021 on SpaceX's Falcon 9 rocket, it will aim for Oceanus Procellarum, near where Apollo 18 would have landed had the U.S. continued the Apollo Moon program. The lander will carry five NASA payloads to the surface, including a low-frequency radio receiver.

These NASA-funded commercial missions are part of the agency's larger Artemis initiative. Artemis 1, the first uncrewed launch of NASA's Space Launch System, is expected in November 2021 and will deliver 13 CubeSats to and around the Moon.

■ DAVID DICKINSON

▲ Artist's concept of Astrobotic's Peregrine lander on the Moon

OBSERVER AND TELESCOPE: SEAN WALKER / *S&T*; PEREGRINE LANDER ON MOON: ASTROBOTIC



Observations of Clavius Crater show water trapped in the lunar regolith.

THE MOON

Water on the Moon Not Just in Polar Craters

PERMANENTLY DARK CRATER FLOORS at the Moon's poles appear to hold plentiful water ice — but they're not the only places to look. The Stratospheric Observatory for Infrared Astronomy (SOFIA) has found evidence of water molecules sheltering in the Moon's sunlit Southern Highlands. And an analysis of lunar topography has revealed enough *micro cold traps* — small areas where ice collects — to affect the Moon's potential water content. However, more work is needed to understand what the discoveries' effects will be on lunar exploration.

The first result, reported by Casey Honniball (now at NASA Goddard) and colleagues on October 26th in *Nature Astronomy*, follows on previous studies that had found spectral fingerprints of hydrogen on the sunlit part of the Moon. However, while those features could come from water, they could also indicate hydroxyl-containing minerals. While the Sun's harsh ultraviolet radiation ought to break up water molecules, it would not split hydroxyl groups.

Honniball's team used the airborne SOFIA telescope to investigate two regions for a particular spectral feature at 6 microns that's unique to water: one around 60°S near Clavius Crater, where high hydrogen levels had previously been measured, and a reference site at lower northern latitudes in Mare Serenitatis, where hydrogen levels were low. The researchers not only found water molecules, they also report that the Clavius site hosts concentrations 100 to 400 parts per million higher than the reference site.

But how have the water molecules survived? Comparing spectra of the Clavius site with those of meteorites and Earth-based basalts showing signs of water interaction, Honniball's team suggested that water could be trapped in impact glasses formed after micrometeorites smash onto the lunar surface.

Separately, but in the same issue of *Nature Astronomy*, Paul Hayne (University of Colorado, Boulder) and colleagues analyzed the topography in 5,250 images taken by NASA's Lunar Reconnaissance Orbiter. Using photos taken when sunlight struck the surface at steep angles, they identified the distribution of shadows and modeled the surrounding landscape. They report large numbers of permanently shadowed cold traps as small as one centimeter across, increasing the total cold-trap area by 20%, to about 40,000 square kilometers (15,000 square miles), or 0.15% of the lunar surface.

Both discoveries open several additional questions, and more observations are coming soon on both fronts: from SOFIA and from in situ investigations aboard NASA's polar lander, due to launch in 2022.

■ JEFF HECHT

NASA / DANIEL RUTTER

FROM THE DPS

(Very) Small Chance of Apophis Impact in 2068

Sunlight's subtle effect may turn near-Earth asteroid 99942 Apophis toward Earth by April 2068, but chances for impact remain small. At the virtual meeting of the Division for Planetary Sciences (DPS), David Tholen (University of Hawai'i) announced that the asteroid's orbit is slowly tightening. Discovered in 2004, the roughly 350-meter-wide rock was originally thought to be on a collision course with Earth in 2029 or 2036, but more precise observations reduced the chance of impact in those cases to zero. However, the *Yarkovsky effect*, the subtle net force of sunlight on a small rotating body, tweaks Apophis's orbit over longer periods of time. Tholen and colleagues gauged this effect by precisely measuring the asteroid's position using the 8.3-meter Subaru telescope on Mauna Kea, Hawai'i. Their results indicate that the semi-major axis of the asteroid's orbit is decreasing by 170 meters per year, so its Earth encounter in 2068 may be closer than thought. The chance of impact remains small, though, currently about 1 in 150,000. Much depends on how close Apophis comes to Earth when it passes by in 2029.

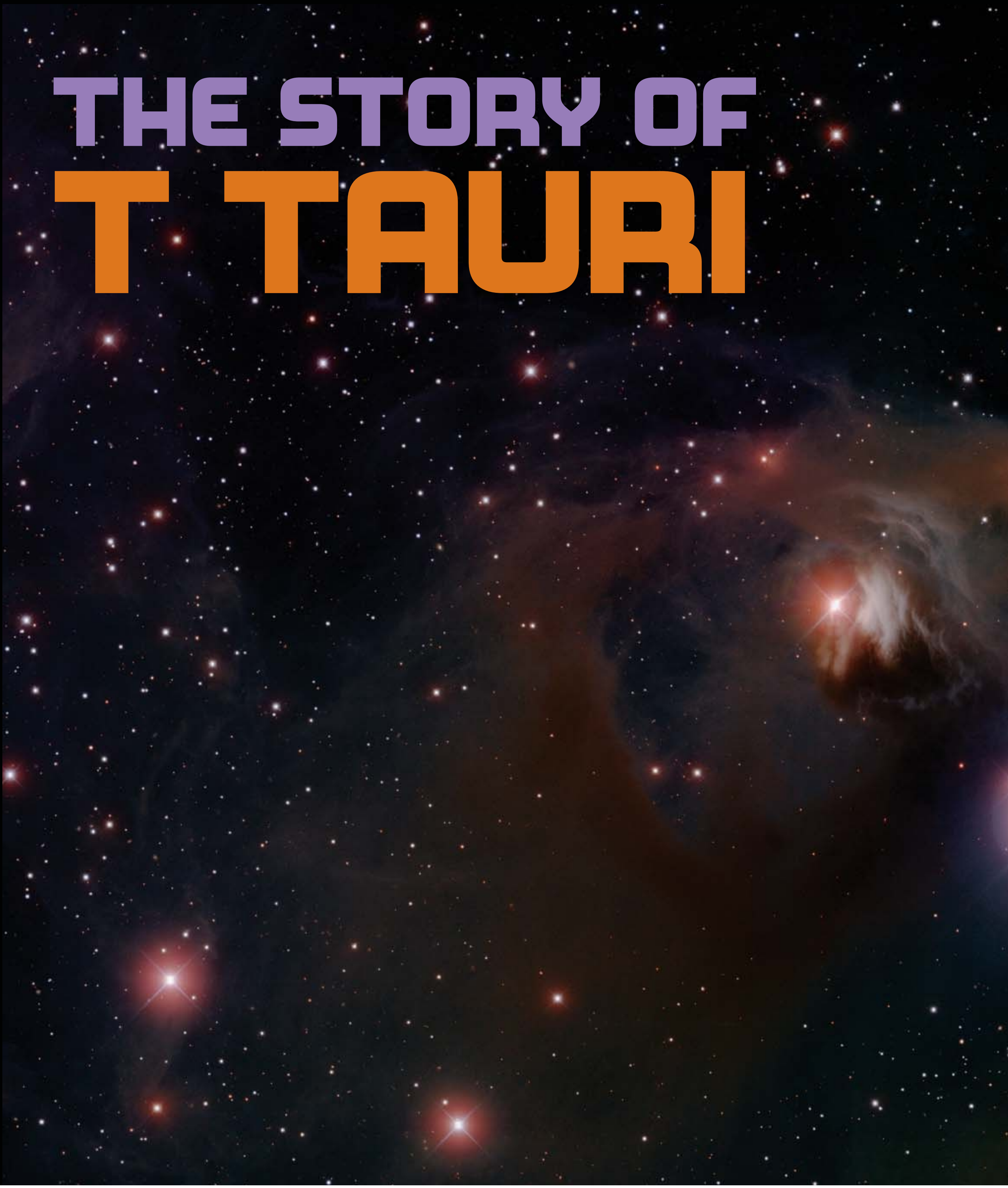
■ GOVERT SCHILLING

The Nature of Psyche

Researchers say 16 Psyche, target of NASA's eponymous Psyche mission, shows iron on its surface. High radar reflectivity had already suggested metals on the main-belt asteroid, and at the virtual meeting of the Division of Planetary Sciences, Tracy Becker (Southwest Research Institute) presented ultraviolet Hubble Space Telescope observations that confirm surface iron. At least 10% of Psyche's surface would need to be iron to explain the UV signal, Becker and colleagues report in the December *Planetary Science Journal*. But at the same meeting, Lauri Siltala (University of Helsinki) presented a new mass measurement for the asteroid, resulting in a density of just 3.4 grams per cubic centimeter – much lower than expected for a supposedly iron-nickel body. Siltala measured Psyche's mass by its effect on a number of small main-belt asteroids. However, even if Psyche's composition is more of a mix, it's still more iron-rich than most asteroids and could have experienced *ferrovolcanism* — Becker might even have detected its metallic lava flows.

■ GOVERT SCHILLING

THE STORY OF T TAURI



An infant star in Taurus helped reveal a truth once thought radical: The universe still makes new stars.

◀ **STELLAR INFANT**
T Tauri (center) is the prototype of newborn stars comparable in mass to the Sun. Hind's Variable Nebula immediately to the west (right) changes in brightness and position as clouds pass between it and the star. North is up.

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

A century ago, the universe seemed a static place. No one knew it was expanding. Indeed, Albert Einstein even temporarily added a fudge factor to his equations in order to keep his model of the cosmos stationary.

But surprisingly, even after recognizing the universe's expansion, astronomers failed to appreciate another fundamental feature of the cosmos. It's something so commonsensical that both professional and amateur astronomers take it for granted today: The universe still creates new stars.

"At that time it was assumed that all stars were formed in some massive catastrophe in the early universe," says Bo Reipurth (University of Hawai'i). Thus, no stars form now.

Today we know our galaxy is actually a prolific star creator, spawning new stars in clouds of gas and dust such as the Orion Nebula. Each year the Milky Way converts about two solar masses of its gas and dust into new stars. Most are much less massive than the Sun, so this figure equates to the birth of about five new stars a year throughout our galaxy.

But the harbinger of the revolutionary revelation that the universe still makes new stars was hardly a spectacle. Instead, it was a dim star in Taurus named T Tauri, about 470 light-years from Earth.

A century elapsed between this star's discovery and the recognition of its youthful nature. Nor have its surprises stopped: In just the past year, astronomers have reported new features about the star that suggest it may be even younger than they had thought.

Introducing T Tauri

On October 11, 1852, English astronomer John Russell Hind spotted a "very small" and "very faint" nebula north of the Hyades star cluster. Near the nebula he also discovered a 10th-magnitude star. The star did not appear on star charts: "Possibly it may be variable," he wrote, inferring that the star had earlier been too dim to see.

Incredibly, the nebula is also variable (*S&T:* Feb. 2018, p. 22). It faded and in 1868 vanished. It later returned, but its position had changed. When Hind made his find, the nebula lay south-southwest of the star; now, it's west of the star. The nebula came to be called Hind's Variable Nebula and the star T Tauri, the third variable star found in Taurus.

Over the following century, astronomers discovered other stars like T Tauri. In 1945, Mount Wilson astronomer Alfred Joy grouped 11 stars together and named the class after the alliterative member in Taurus, in part because T Tauri was the best known and also one of the brightest. Seven of the 11 stars lay in Taurus or neighboring Auriga. All the stars, Joy said, flickered irregularly by about three magnitudes; ranged in spectral type from *F5* to *G5*; had luminosities like the Sun's; and lay near nebulae, as T Tauri itself does — because, as we now know, they are shining on the same clouds that gave them birth. But Joy's lengthy paper makes no mention of star formation. Ongoing star formation was then considered anathema.

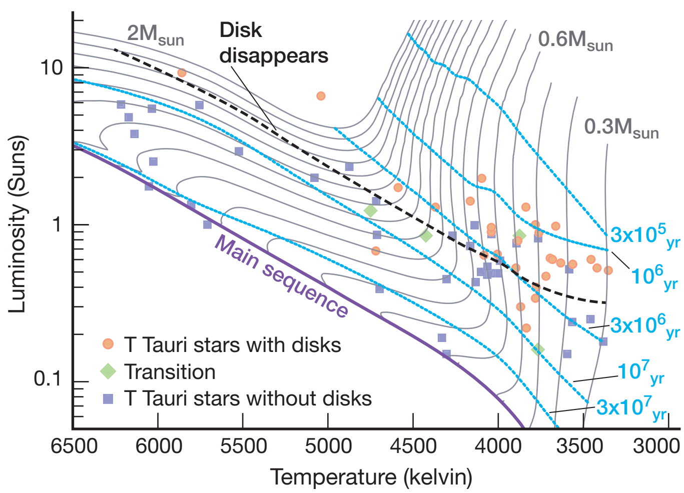
Instead, other astronomers soon interpreted T Tauri stars as normal suns that by chance were passing through interstellar clouds. When material either fell onto the stars or obscured them, they brightened or faded, explaining their variability.

A Newborn Star

In 1947, however, Soviet astronomer Viktor Ambartsumian saw the truth — and soon after took a jab at astronomers elsewhere. "Our experience shows that Western astronomers often display an inconsistency when trying to give cosmogonic interpretation of results of astrophysical observations," he wrote. "Doubtless, the progressive Soviet science, inspired by the genius of great Stalin, will overcome all difficulties on the way of cosmogonic investigations and clarify the main laws of origin and evolution of stars."

Ambartsumian's praise of a brutal tyrant notwithstanding, his astronomical reasoning was sound. He noted that T Tauri stars occur in groups, which he called T-associations; he cited the one in Taurus and Auriga as an example. The Milky Way's tidal forces should have torn these groups apart, he said — unless they formed just a few million years ago. He made a similar argument about *O* and *B* stars, which also reside in associations. Thus, he reasoned, the Milky Way still mints new stars today.

Unfortunately, because Ambartsumian's works appeared in Russian or his native Armenian, most astronomers in America and Europe didn't hear the news until the mid-1950s. By that time, other evidence was also suggesting that T Tauri stars could hardly be normal stars passing through nebulae.



▲ **T TAURI EVOLUTION** Infant stars contract and heat up as they form from collapsing clouds and eventually start hydrogen fusion. Because they are larger than the main-sequence stars they will later become, T Tauri stars appear more luminous, lying above the main sequence on the Hertzsprung-Russell diagram. With time, the stars travel down and left, following the solid gray lines according to their masses. The blue lines that cut through the gray lines show stellar ages, and the black dotted line marks when the young stars lose their disks. The underlying data points are T Tauri stars in the Taurus-Auriga T association and are sorted by their evolutionary stage.

"I WAS KIND OF SURPRISED THAT I HAPPENED TO BE THE ONE WHO STUMBLED ACROSS THE THIRD STAR IN THE SYSTEM." —CHRIS KORESKO

For starters, the stars were too luminous. Take T Tauri itself. Although Joy had classified it as spectral type *G*5 — similar to the Sun's *G*2 spectral type — modern spectra put it at type *K*0. A *K* main-sequence star emits less light than the Sun, whereas T Tauri's actual luminosity, according to modern measures, is about six times greater than the Sun's. The reason: Stars start out big and bloated, then shrink as gravity compresses them. Because T Tauri is larger than the Sun, it radiates more light. Its large size and luminosity are thus signs of its youth.

What turned out to be another youthful trait also emerged during the 1950s, when astronomers made a major discovery about T Tauri. The star harbors far more of the rare element lithium (atomic number 3) than the Sun does. So do meteorites, which reflect the high lithium level of the newborn Sun. Young stars have more lithium, we now know, because stars normally destroy the element over time. As a result, T Tauri stars have lithium-to-hydrogen ratios more than 100 times that of the Sun.

An Infrared Companion

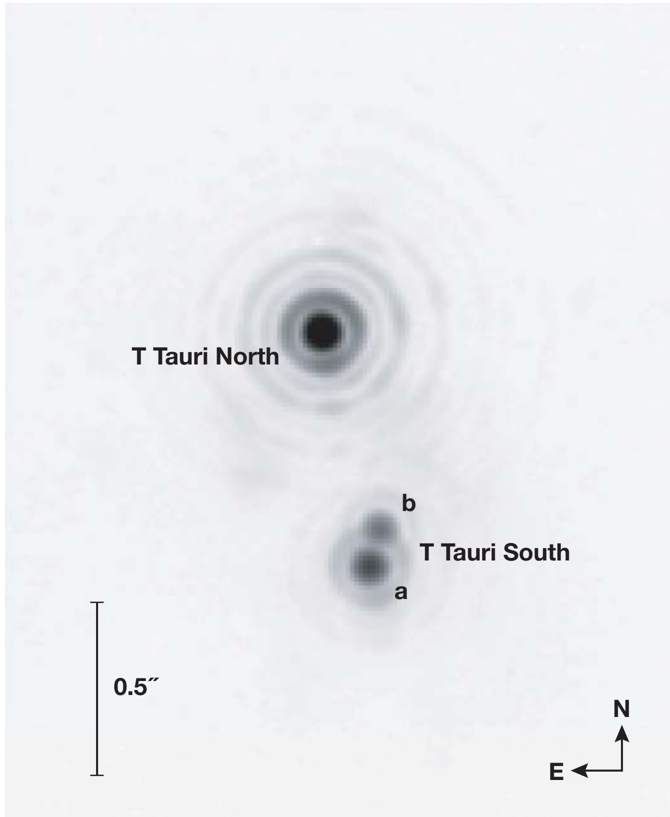
Unexpected discoveries about T Tauri continued long after astronomers accepted it as the prototype for young stars. In October and November 1981, H. Melvin Dyck, Theodore Simon (both then at University of Hawai'i), and Benjamin Zuckerman (now UCLA) observed T Tauri by using infrared *speckle interferometry*, a technique that yields high-resolution views (*S&T:* Oct. 1982, p. 334). The astronomers hoped to study the structure of a dusty disk around the star. If such a disk existed, starlight would heat the dust and explain earlier work that had found an excess of infrared radiation.

Instead, the astronomers saw that T Tauri was a double. "Total surprise," Zuckerman says. "We were looking for dust, not for an infrared companion." The find was the first infrared star ever seen orbiting a T Tauri star.

The infrared star is 0.7 arcsecond south of the visible star and so enshrouded in dust that even today no one has ever seen its visible light. If the northern and southern stars, named T Tauri North and T Tauri South, are equally distant from us, they are 100 astronomical units apart, slightly greater than three times Neptune's distance from the Sun. The two stars probably take hundreds or thousands of years to orbit each other, which unfortunately is so long that we can't use their orbital motion to measure their masses.

And Then There Were Three

Then, in 2000, Chris Koresko (then JPL) reported that T Tauri's infrared companion is itself a double. Given all the astronomers who had studied T Tauri, "I was kind of surprised that I happened to be the one who stumbled across the third star in the system," Koresko says.



▲ **TRIPLE TAKE** This infrared image shows that the prototype of stellar infants actually consists of three separate youngsters: one visible star, T Tauri North, and two infrared stars, T Tauri South a and T Tauri South b.

This discovery was especially helpful because the two infrared stars — T Tauri South a and T Tauri South b — are sufficiently close together that they orbit each other every 27 years. Since astronomers have now observed the pair for nearly that long, the orbit reveals the stars' masses. According to work published in the July 2020 *Astronomical Journal* by Gail Schaefer (CHARA Array) and her colleagues, T Tauri South a has about 2.05 solar masses. If it acquires no more material, it will end up an *A*-type main-sequence star resembling brilliant Sirius A.

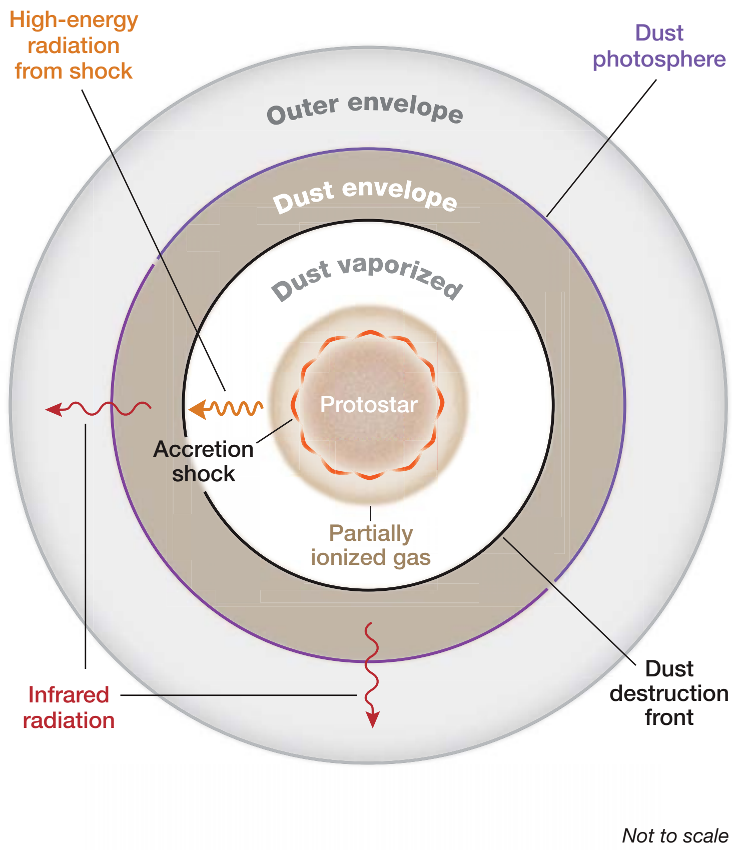
In contrast, T Tauri South b is a smaller star, on track to become the most common stellar type in the galaxy: a humble red dwarf. It's only about 43% as massive as the Sun, so it will someday look much like the nearby red star Lalande 21185 (*S&T:* June 1995, p. 68).

On average, the two infrared stars are about 12 a.u. apart, a bit farther than Saturn is from the Sun, but the small star

EVEN THOUGH IT IS THE PROTOTYPE FOR THE ENTIRE CLASS, IN MANY WAYS IT IS NOT A TYPICAL T TAURI STAR.

follows a rather elliptical orbit around its mate. In the May 2020 *Research Notes of the AAS*, Rainer Köhler (University of Vienna, Austria) and Karolina Kubiak (University of Lisbon, Portugal) noted an intriguing pattern. The little star brightens and fades depending on where it is in its orbit. The astronomers attribute this behavior to a nearly edge-on dust disk that is known to surround the two infrared stars. The disk is more tenuous toward its edge, so when the little star skirts farthest from its partner, less dust obscures it, and so it brightens. The two stars will be closest together around 2023.

Unfortunately, no one has weighed T Tauri North, the one star in the system whose visible light we see, and its exact nature is uncertain. Even though it is the prototype for the entire class, in many ways it is not a typical T Tauri star. For one thing, the star outshines most of its peers. The high luminosity suggests the star is more massive than most other T Tauri stars, and in the past astronomers have estimated a mass about twice that of the Sun. T Tauri North has a disk, but it's nearly face-on, which may be why we can see



PROTOSTAR VS. PRE-MAIN-SEQUENCE STAR

Most T Tauri stars are young *pre-main-sequence stars* that were born within the last several million years and are less than 2.5 times as massive as the Sun. T Tauri itself, however, may be an even younger variety of star, called a *protostar*.

Despite their similar names, the two stellar types — protostars and pre-main-sequence stars — are different stages of stellar evolution. A protostar forms after a clump in an interstellar cloud rapidly collapses under the force of gravity. Gravity causes material to crash down toward the object's surface, heating it so much that it begins to emit light. Thus gravity — and not nuclear fusion — powers the newborn star.

New material from the birth cloud keeps raining down onto the protostar, increasing its mass. In fact, the protostar is so shrouded in its dusty birthplace that no visible light escapes into space (see diagram above).

The protostar phase is brief. How brief depends on the star's aspirations: Just as someone who wants to earn a PhD has to spend more time in school acquiring knowledge than someone who has a high-school diploma, so a more massive star has to spend more time as a protostar accreting material than a less massive star. The Sun's protostar stage lasted only a few hundred thousand years. Less massive stars — the vast majority — spend even less time as protostars.

A powerful wind from the protostar soon blows away most of its dusty cocoon, letting the star's visible light emerge. This metamorphosis marks the transition from protostar to pre-main-sequence star.

Unlike a protostar, a pre-main-sequence star no longer acquires much new material. Still, the star keeps on shining, because gravity gently squeezes and heats the star. Over time, thanks to gravity, a pre-main-sequence star shrinks, getting smaller and smaller.

Most stars spend far more time as pre-main-sequence stars than protostars. The Sun, for example, was a pre-main-sequence star for 36 million years. Less massive stars linger longer, and the least massive red dwarfs remain pre-main-sequence stars for billions of years. Some of the *M* stars

GREGG DINDERMAN / *S&T*, SOURCE: S. W. STAHLER / *PASP* 1994

◀ **PROTOSTAR** A dense core of dusty gas collapses to form a protostar, which draws material onto itself gravitationally. The material strikes the protostar and creates an accretion shock, and the heated gas that's produced radiates — the source of the protostar's luminosity. Eventually, the cloud (here simplified as a sphere) will collapse into a protoplanetary disk; the protostar will accrete most of its mass during the disk stage.

the star's visible light but not the light of its two southern siblings, whose disk is more edge-on.

In the August 1, 2020, *Astrophysical Journal*, however, Christian Flores, Bo Reipurth, and Michael Connelley (all University of Hawai'i) offer a new interpretation of T Tauri North. They used high-resolution infrared spectra to uncover another peculiarity: The star's surface gravity is low, a sign the star has a large diameter. In fact, the star is so large and luminous, they say, that it's not a pre-main-sequence star at all. Instead, it's an even younger type of star: a *protostar*.

Protostars are stars so young they are still in the process of being born (see sidebar below). Such stars are normally invisible at optical wavelengths because they are encased in the dust clouds that gave them birth, and from which material still rains down upon them.

Why, then, can we see T Tauri North's visible light? "T Tauri North is an orphaned protostar," Reipurth says. In his view, all three stars in the system were born close together a few hundred thousand years ago. But the other two stars kicked T Tauri North out of the dust cloud just a few thousand years ago, allowing us to see its light, even though it's still a protostar. This idea also explains why the star is larger and more luminous than most other T Tauri stars: because it hasn't yet contracted much toward the main sequence.

T Tauri North continues to orbit T Tauri South, Reipurth says, and he thinks that within a few thousand years T Tauri North will dive back into its birthplace for a family reunion with its two siblings. He expects chaos, because three stars close together normally fling one another around and often eject the least massive one. That's probably what happened with the Alpha Centauri system, which has two Sun-like stars and a distant red dwarf they likely kicked away (*S&T:* Apr. 2019, p. 34). If T Tauri's three stars do something similar, then T Tauri North and South a will link up to form a closer binary and cast the red dwarf far away — perhaps out of the system altogether.

Thus, T Tauri has a storied past whose class played a pivotal role in revealing that the universe is still an active star maker. But the star's future story promises to be rich as well — both for itself, as its three members dance with one another, and for astronomers, as they discern new clues about this famous infant in the sky.

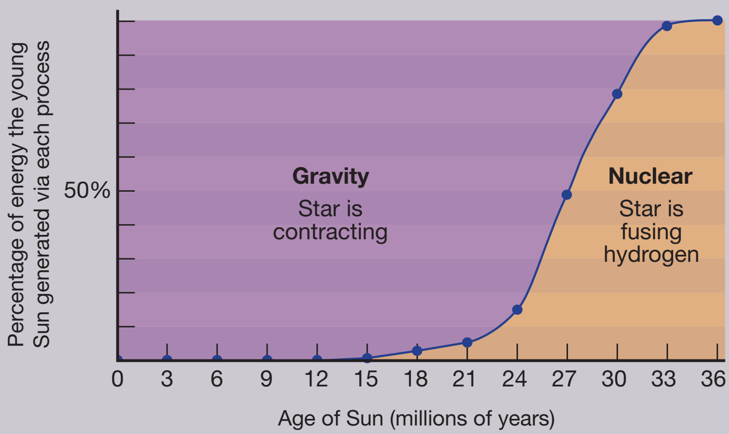
■ While earning his PhD, **KEN CROSWELL** observed three T Tauri stars that had flared up in brightness. He is the author of eight books, including *The Alchemy of the Heavens* and *The Lives of Stars*, and has also written for *Knowable Magazine*, *National Geographic*, and *PNAS*.

in the Pleiades star cluster, which is 120 million years old, still shine via gravity power, not nuclear power.

Early in its career, however, an infant star does get hot enough to stoke one simple nuclear reaction, which turns deuterium, or hydrogen-2, into helium. Unlike ordinary hydrogen, deuterium burns at a temperature of only 1 million kelvin, which even protostars attain. Deuterium-burning gives the star additional energy. But deuterium is rare, so deuterium-burning doesn't last much beyond the protostar phase.

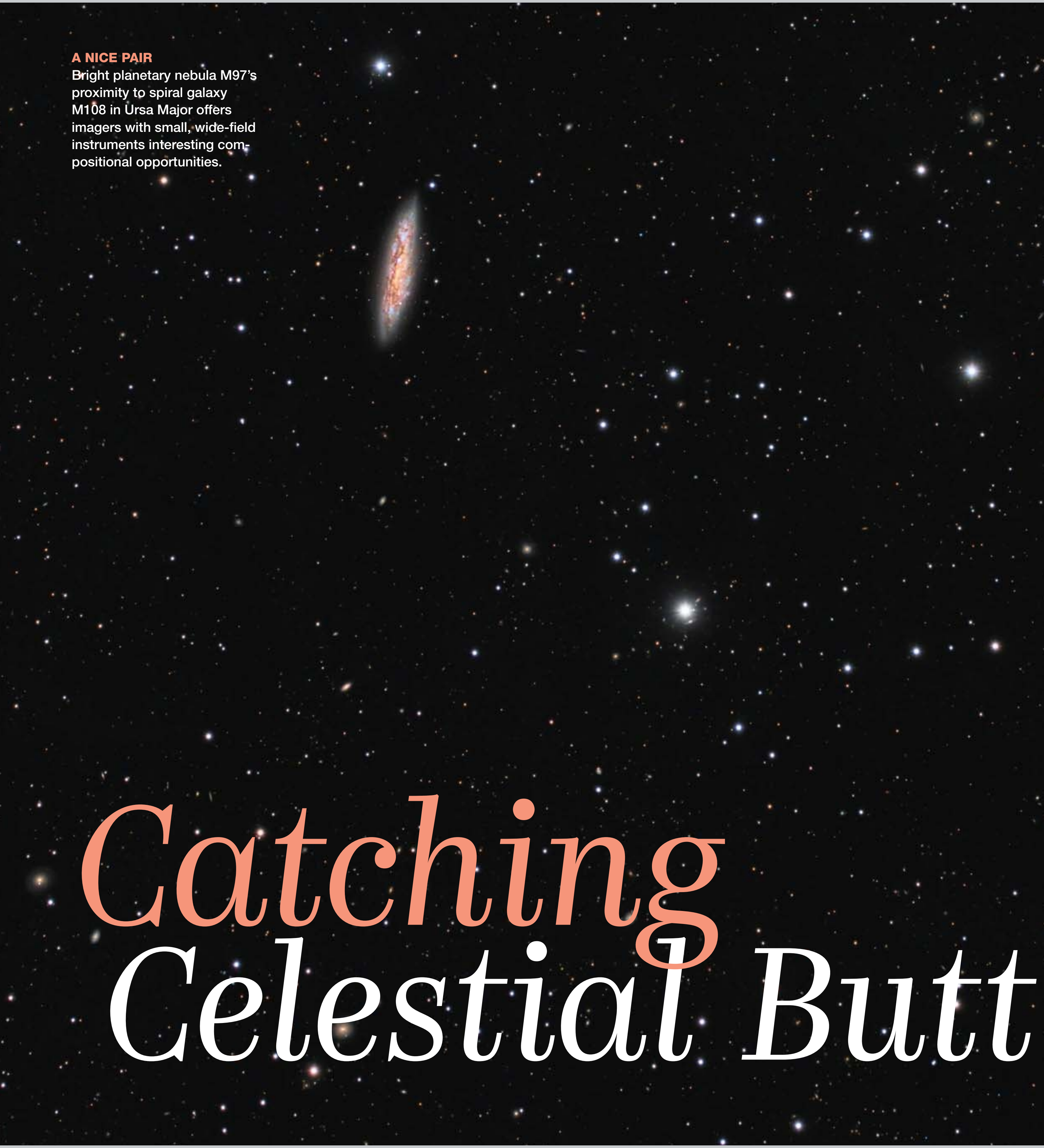
As gravity further squeezes and heats the pre-main-sequence star, its center gets so hot that enough hydrogen-1 ignites to provide significant additional energy. Eventually this new energy source halts the star's contraction, at which point the star starts its tenure on the *main sequence*.

Notably, the rarest and most massive stars, which exceed about six solar masses, skip the pre-main-sequence stage altogether. While still protostars, they begin burning hydrogen-1 and graduate directly from the protostar phase to the main sequence.



▲ **THE SUN'S POWER SOURCE** Early on, a pre-main-sequence star generates nearly all its energy from gravity, which gently squeezes and heats the star. Eventually, however, this gravitational contraction heats the star's center so much that another power source starts to contribute: the nuclear burning of hydrogen-1. For a star with the Sun's mass, the star then continues to contract for millions of years, until the switchover to nuclear is complete.

LEAH TISCIONE / S&T, SOURCE: EMANUELE TOGNELLI (UNIVERSITY OF PISA, ITALY)



A NICE PAIR
Bright planetary nebula M97's proximity to spiral galaxy M108 in Ursa Major offers imagers with small, wide-field instruments interesting compositional opportunities.

Catching Celestial Butt

Hone your imaging techniques on these fascinating beauties.

Planetary nebulae are among the most rewarding celestial targets for observers and astrophotographers alike. They're expanding gaseous shells ejected in the final stages of an intermediate-mass star's life and present intriguing, small-scale details not found in other emission or dark nebulae. And while the majority are on the small side, they typically have high surface brightness, which allows them to punch through light pollution — something that makes planetaries particularly appealing for urban astro-imagers shooting under bright skies.

Stellar Origin

I think of planetary nebulae as the butterflies of the celestial ecosystem, produced in a metamorphosing process that transforms a Sun-like star into a brightly hued treasure. Most appear spherical, though some display non-symmetrical shapes. As these stars run out of fuel, they expel their outer layers of hydrogen, oxygen, sulfur, and other, more exotic gases into space to eventually become the raw material for other stars. The remaining hot stellar core of the dying star, known as a white dwarf, emits strong ultraviolet radiation that excites the atoms in the expanding shell, causing it to glow. Due to their typically small sizes and shapes, they appeared similar to planets to early observers. Today, we know that these attractive celestial nebulae have little or nothing in common with orbiting bodies.

These little butterflies are relatively short-lived. Over the course of several thousand years, they continue to expand and thin out, while the central white dwarf star cools, producing less ultraviolet energy, and the nebula fades from view.

Planetary nebulae are distributed fairly evenly across the sky, with a higher concentration towards the galactic center. That means a few good ones are visible most any clear night. They come in a range of brightness and sizes that suit a variety of imaging setups. They're one of the few types of objects beyond the solar system that display color in the eyepiece. But their true extent and vivid hues are revealed only in deep photographs.

As emission nebulae, planetaries display a wonderful range of colors when shot in either broadband "natural" color or when imaged through narrowband filters. In natural color, the pinkish areas correspond to ionized hydrogen (Hα) and sulfur emissions (S II). Teal hues are mainly produced by excited oxygen (O III) atoms, which emit both blue and green light. Because planetary nebulae are made up primarily of ionized gasses, they respond particularly well to imaging with narrowband filters. This makes them especially good targets for imagers shooting through strong light pollution.

While many planetary nebulae require moderately large apertures and long focal lengths to be adequately resolved,
(Continued on page 22)

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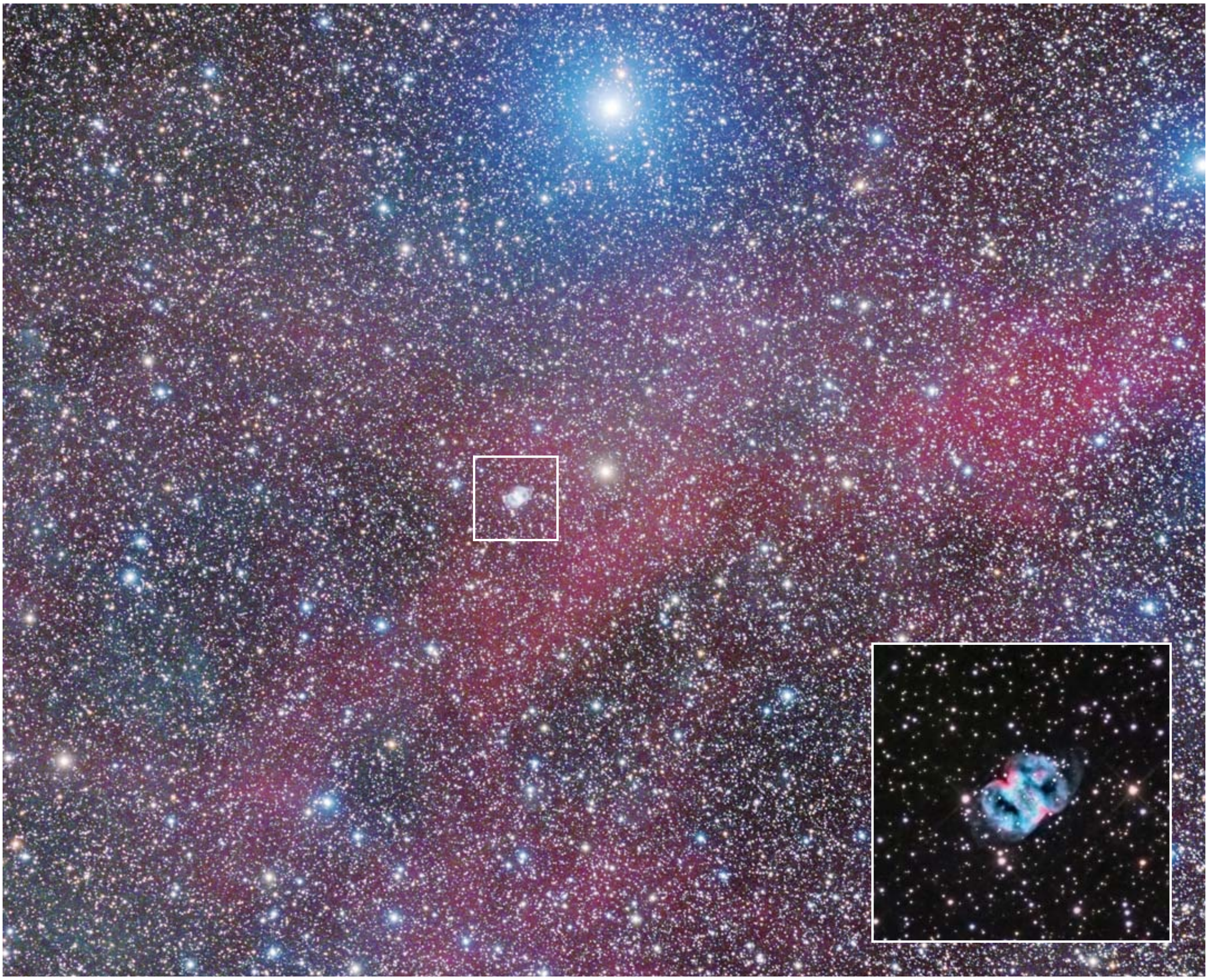
▶ **MORE THAN MEETS THE EYE**
M27 usually resembles its dumbbell nickname or an apple core in short exposures. However, deep images like the example at right, consisting of more than 12 hours of exposure data recorded through RGB and narrowband filters, reveal the nebula's outer "wings."

▼ **DIFFERING PERSPECTIVES**
M76 offers an interesting view in both wide-field and high-resolution imaging rigs. Large fields imaged with long exposures reveal tenuous hydrogen nebulosity throughout the area, while in close-up compositions (inset), the planetary offers intricate, looping details.



WIDE FIELD: MDW SKY SURVEY

BIG AND FAINT While Abell 31 in Cancer is one of the largest planetary nebulae visible in the Northern Hemisphere, it's exceedingly faint and requires long exposures to properly capture.

(Continued from page 19)
some make great targets for imagers with smaller instruments. Here are some of my favorites.

Skulls, Owls, and Squids

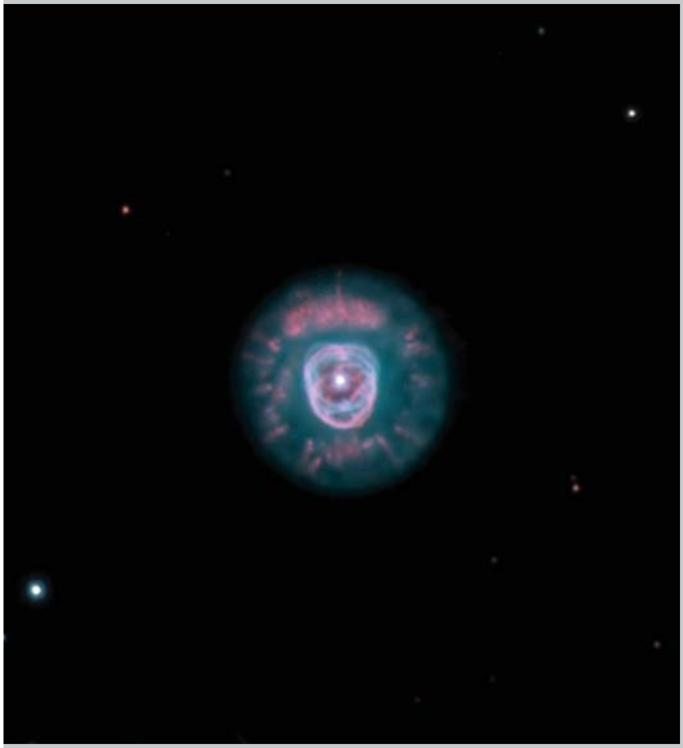
Let's start our planetary nebula hunt in central Ursa Major. **Messier 97** (the Owl Nebula) is a top-tier imaging target for amateurs. Its 2.8′ diameter may be on the small side, but its proximity to spiral galaxy M108 (about 48′ northwest) makes for a great composition if you include both targets by using a small, wide-field instrument with at least a 1°-wide field of view. The Owl displays a reddish shell with a bluish or greenish inner region and two dark voids making up the eyes that give the Owl its distinctive nickname. Extremely deep narrowband exposures show a very faint outer halo that expands the nebula's size beyond the stated diameter — a common refrain for many of these targets.

Hopping over to Perseus, **Messier 76**, commonly referred to as the Little Dumbbell, has the distinction of being one of the faintest targets in the Messier catalog. Nevertheless, like many PNs, its light is concentrated in a relatively small area and is a great target for imagers with long-focal-length optics. But imagers with wide-field instruments shouldn't pass over this tiny target, because it resides in a field filled with faint hydrogen-alpha (Hα) emission nebulosity. While visual measurements put the nebula at slightly more than 1 arcminute across, deep photographs show it to be more than twice that size. M76 sports a mix of red and teal hues. High-resolution images give this complex nebula the appearance of a baby's teething ring.

Heading south to Cetus, you'll find **NGC 246** — a challenging, faint target. Spanning 4.1′, NGC 246 is a larger PN, requiring lots of exposure to display the intricate, mottled details in the nebula's center and around its edges.

A small, bright PN that's well-placed for late winter/early spring imaging is **NGC 2392** in Gemini. Northern Hemisphere amateurs can relate to its appearance — NGC 2392 reminds me of a cold observer wearing a fur-lined parka staring back at me. As one of the smallest planetaries on my list, you'll need a long-focal-length scope to resolve this PN's complex inner arcs surrounded by a striated circular halo. Fortunately, NGC 2392 has a relatively high surface brightness and shows up in short exposures.

If you want a break from imaging galaxies early in the year, try photographing one of my personal favorite planetaries: **Abell 31**, or Sharpless 2-290. Located in Cancer, it has one of the largest apparent sizes of any planetary, spanning about half the Moon's diameter. That means that images taken with even modest instruments can reveal a wealth of detail. Abell 31 is quite faint, so you'll need a lot of exposure time on this object to get a high-quality result. Frames shot with a Hα filter display a distinct, sharp, shock front, where the nebula is crashing into the interstellar medium on the southern edge, while the northern part appears diffuse. O III emissions dominate the inner, bluish area, and large instru-

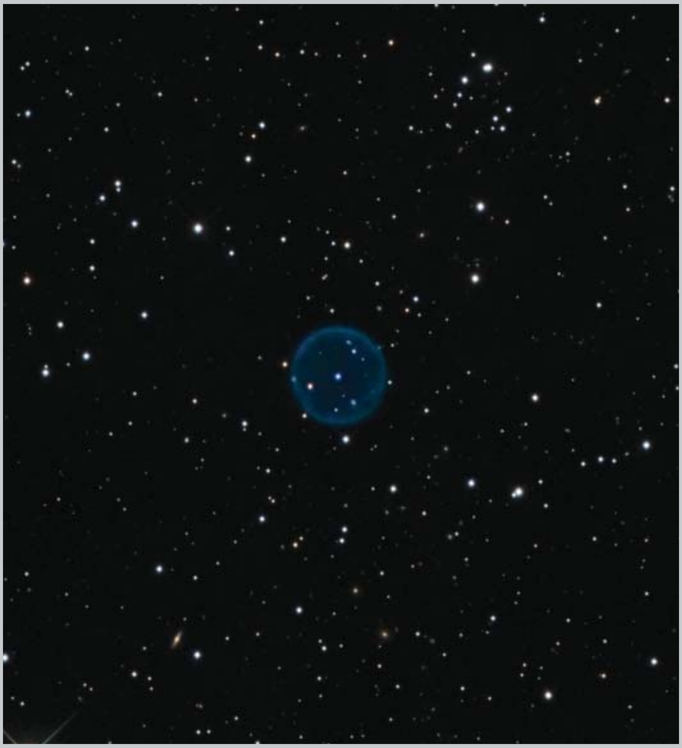


▲ **COLD TARGET** The small but bright planetary NGC 2392 is a great short-exposure target for long-focal-length telescopes equipped with small detectors. South is up in this image.

▲ **SPIRALING NEBULA** The Helix Nebula is a large, eye-shaped planetary that displays a wide color palette and fine detail in most any imaging setup.

NGC 2392: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

▲ **COLORFUL RING** The Ring Nebula (M57) is one of the best-known planetaries in the northern sky and looks good in most any well-tracked image. But as with many planetaries, lots of cumulative exposure brings out its faint outer shell. To its northwest is spiral galaxy IC 1296.



▲ **CRYSTAL BALL** With a diameter of 2.5 light-years, Abell 39 is the largest near-perfect spherical object known. Distant galaxies are visible through the nebula when imaged with larger instruments.

▲ **GHOSTLY SKULL** NGC 246 in Cetus begins to resemble its skeletal nickname when imaged with large telescopes.

▲ **INTERSTELLAR FELINE** Short exposures of the bright planetary NGC 6543 show why it's called the Cat's Eye Nebula. Spending more time on it will reveal its exceedingly faint, complex outer extent.

NGC 246 AND NGC 6543: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA ments show complex dark lanes throughout this ancient planetary.

All of the nebulae discussed above appear more or less circular, but there are exceptions, such as the aptly named Squid Nebula (**Ou4**). Its length is 2.5 times the Moon's diameter, equivalent to a true dimension of more than 50 light-years. Ou4 appears to lie within, and at the same distance as, Sh2-129 (the Flying Bat Nebula), a huge hydrogen-rich region in Cepheus. If you want to capture the Squid, plan to rack up the exposure time: I needed more than 60 hours of O III-filtered light before I was satisfied with the resulting image.

▲ **EAGLE'S BALL** NGC 6781 in Aquila displays a subtle dark star-shape in its inner regions.

Summer Gems

A rich and famous imaging target, **M27**, the Dumbbell Nebula, resides in Vulpecula. At about 8′ × 4′ in size, it's both large and bright for a planetary. Even relatively short exposures show the apple-core-shaped interior of the nebula, and long exposures give it the shape of a richly textured, teal-and-red football. Patient imagers who go deep with narrowband filters can pick up its faint, extended shells of glowing Hα and O III, nearly doubling M27's apparent size.

Perhaps the best known planetary of all is **M57**, the Ring Nebula, in Lyra. It appears in the eyepiece as a 76″-long oval of greyish smoke in most any sized instrument, but even short exposures show its rich red, yellow, and teal hues. This well-known PN sports a mottled texture in its outer edge and a couple of stars in the central region. As with other planetaries, long exposures with a Hα filter resolve its faint outer shells that nearly double the apparent extent of this object. Larger instruments will also capture the nearby 14th-magnitude spiral galaxy IC 1296, located less than 4′ northwest of M57.

Moving about 17° east into Cygnus brings us to **PN G75.5+1.7**, better known as the Soap Bubble Nebula. This spherical shell resembles Abell 39, but because it resides in a field awash in H II nebulosity, it went unnoticed until 2008. You'll need to accumulate lots of exposure time to capture this one. It's most evident in frames shot through a Hα filter. Fortunately, it's easy to find roughly ⅔° east-southeast of the Crescent Nebula, NGC 6888. Both fit comfortably in the same 1.5° field southwest of Sadr, Gamma (γ) Cygni.

Heading south to Aquila we find **NGC 6781**, a moderately large, circular PN 1.8′ in diameter. This nebula has one sharp and one soft edge. Even though it has a true diameter of more than one light-year, it appears small because of its great distance, of around 2,500 light-years.

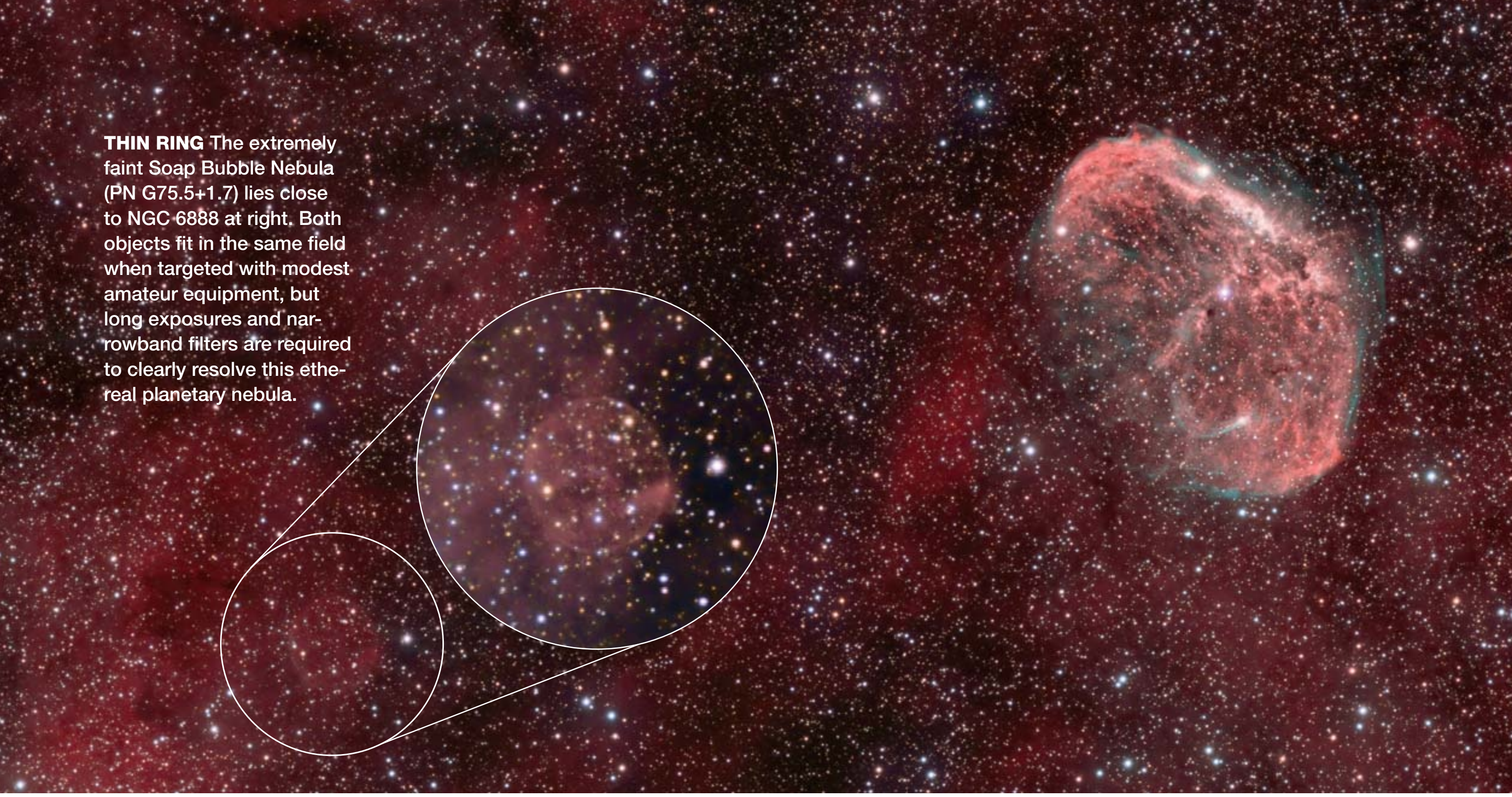
I find **Abell 39** in Hercules to be one of the most enigmatic planetaries in the sky. This tenuous, teal-colored sphere resembles a ghostly green crystal ball. With a diameter of around 2.5 light-years, it's the largest known near-perfect spherical object. Deep images with large scopes show a few distant galaxies behind the nebula's translucent veil.

Farther to the north, **NGC 6543**, the Cat's Eye Nebula, is a small, bright object of about 20″ diameter, making it the

Planetary Nebulae

Object	Constellation	Mag(v)	Size	RA	Dec.
M97	Ursa Major	9.9	2.8′	$11^h 15^m$	+55° 01′
M76	Perseus	10.1	67″	$01^h 42^m$	–51° 34′
NGC 246	Cetus	10.9	4.1′	$00^h 47^m$	–11° 52′
NGC 2392	Gemini	9.2	19.5″	$07^h 29^m$	+20° 55′
Abell 31	Cancer	—	17′	$08^h 54^m$	+08° 55′
Ou4	Cepheus	—	150′ × 30′	$21^h 12^m$	+59° 59′
M27	Vulpecula	7.3	8′ × 4′	$20^h 00^m$	+22° 43′
M57	Lyra	8.8	76″	$18^h 54^m$	+33° 02′
PN G75.5+1.7	Cygnus	—	4.3′	$20^h 15^m$	+38° 03′
NGC 6781	Aquila	11.4	1.8′	$19^h 18^m$	+06° 33′
Abell 39	Hercules	—	2.6′	$16^h 28^m$	+27° 55′
NGC 6543	Draco	8.1	20″	$17^h 59^m$	+66° 38′
NGC 7293	Aquarius	7.3	16′ × 12′	$22^h 30^m$	+20° 48′
NGC 7662	Andromeda	8.3	17′	$23^h 26^m$	+42° 33′

Angular sizes are from recent catalogs. Photographically, an object's size is often larger than the cataloged value. Right ascension and declination are for equinox 2000.0.



THIN RING The extremely faint Soap Bubble Nebula (PN G75.5+1.7) lies close to NGC 6888 at right. Both objects fit in the same field when targeted with modest amateur equipment, but long exposures and narrowband filters are required to clearly resolve this ethereal planetary nebula.

smallest nebula included in my list. However, long exposures show a larger, tenuous, complex outer shell that increases its apparent size to nearly 6′. Imagers targeting NGC 6543 with a pixel scale of less than 1 arcsecond can reveal its fascinating symmetrical inner details. The Cat's Eye is circumpolar for observers at mid-northern latitudes, though it's best seen in summer when it transits high in the north.

Another frequently imaged planetary is **NGC 7293**, the Helix Nebula. Residing in Aquarius, the Helix is the closest planetary to Earth as well as the largest at 16′ × 12′, though deep exposures show it covering an area almost the size of the full Moon. Due to its proximity, the Helix presents a wealth of detail in long exposures, including dense concentrations appearing to radiate from the nebula's central star, and the partial outer shell "eyebrow" along its northern edge. The Helix appears primarily bluish, yellow, and red in natural-color photographs.

Our final planetary is in Andromeda. Smaller than even the Cat's Eye, **NGC 7662** is often referred to as the Blue Snowball Nebula. *Burnham's Celestial Handbook* describes it as "*vB, pS, R*" — very bright, pretty small, and round — which accurately sums up its photographic appearance. Targeting this planetary with modest equipment shows a bright, round object with some structure and a relatively uniform teal-colored disk.

Imaging Strategies

Most of these planetary nebulae are only a few arcminutes or less in diameter. This can be both a blessing and a curse. Being small, they may cover only a few pixels on your camera's sensor, limiting resolution. However, the flip side is that you don't require a large sensor. The best option is to use a long-focal-length telescope and a high-sensitivity detector. To get the most out of these targets, try to match your imaging scale to about 1″ per pixel.

Because planetaries are emission nebulae, they are excellent targets for monochrome cameras equipped with narrowband filters. You can also achieve good results with one-shot-color (OSC) cameras and multi-band filters designed specifically for using OSCs from light-polluted locales or under moderate moonlight.

Some find the natural colors of broadband images to be more pleasing than narrowband palettes. Others, like myself, prefer a mix of the two to retain natural star colors while also recording faint nebulosity.

Roughly 3,000 planetary nebulae are known, and like snowflakes, no two are quite the same. In fact, quite a few (including the Soap Bubble) were recently discovered by amateurs while imaging other targets, so be sure to carefully check your images for tiny greenish or blue spots that don't quite look like stars.

Next time you're looking for a new challenge, consider targeting some of these glittering butterflies among the forest of stars.

▶ **BLUE SNOWBALL** Another small planetary with a large, faint outer shell, NGC 7662 emits light almost exclusively in the blue-green region of the spectrum.

NGC 7662: PETER GOODHEW

■ **RON BRECHER** targets all types of deep-sky objects from his backyard observatory in Guelph, Ontario. See more of his deep-sky astrophotography at **astrodoc.ca**.

Orion's Club Di

Going off the beaten track in Orion brings pleasant surprises.

Orion, the giant hunter of Greek mythology, rules our winter nights. Astride the celestial equator for all to see, the showcase constellation with the brilliant star pattern is a delight to the eye and a feast for the telescope.

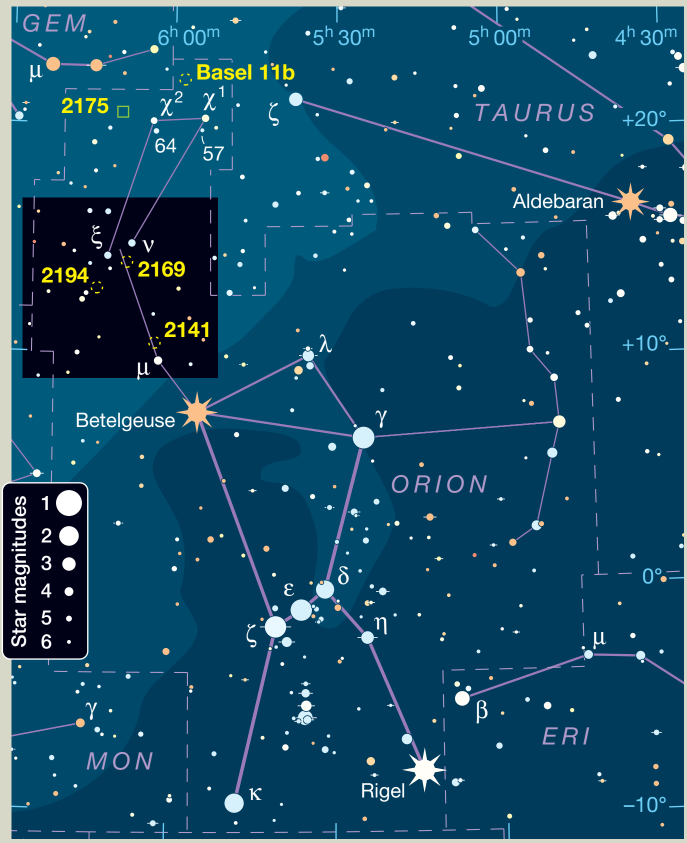
Of course, Orion isn't all gleam and glitter. The stars depicting the Hunter's shield and club are much less conspicuous. Likewise, the telescopic objects above his hourglass figure aren't exactly award winners. In 50 years of dedicated deep-sky sleuthing, I hadn't observed any of them. Time to fix that! Last winter, I decided to explore Orion's eastern arm, all the way to the top of his big, brandished club.

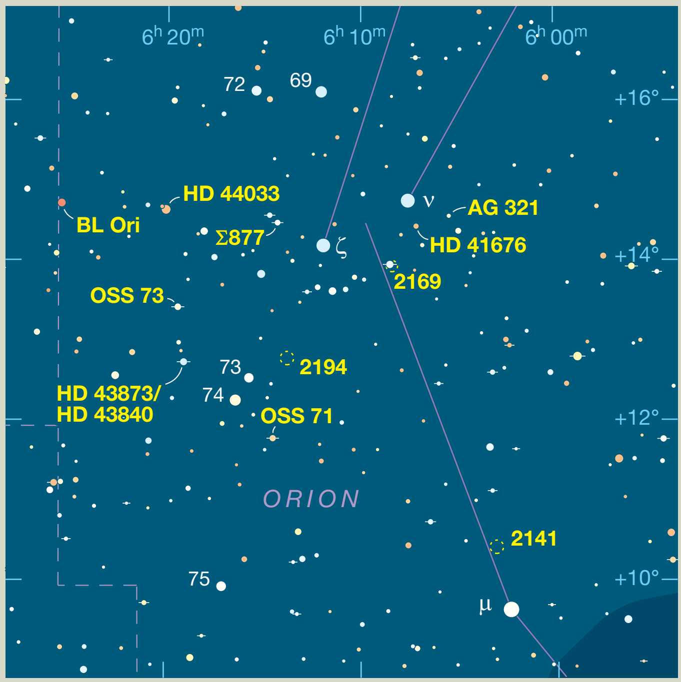
As I'd be observing under a light-polluted suburban sky, I didn't expect much joy. At minimum, I'd try for the open clusters plotted on charts 76 and 96 of the *Uranometria 2000.0 Deep Sky Atlas* (2nd edition, 2001). I employed my 10-inch f/6 Dobsonian reflector for the bulk of the work but occasionally used smaller scopes — even binoculars.

In the end, my backyard instruments delivered *more* than I anticipated. Grab your scope, whatever it may be, and join me for a stroll through Orion's little-known Club District.

Pale Powders

Starting at zero-magnitude Betelgeuse, Alpha (α) Orionis, I planned to sweep 3° northeastward to 4.1-magnitude Mu (μ) Orionis, then veer north-northeastward to 9.4-magnitude **NGC 2141**. Simple, right? Well, no, it wasn't. The cluster is just 10′ in diameter and symbolized on *Uranometria* chart 96 as a starless circle. I reminded myself that the *Uranometria* plots stars down to magnitude 9.7. The *Millennium Star Atlas* goes to magnitude 11, yet no dots appear





◀▲ **ORION'S CLUB DISTRICT** Northeastern Orion is the great celestial Hunter's highest-reaching area, but it's rarely top-of-mind for backyard astronomers. Most of the deep-sky objects here are relatively distant open clusters that look small and dim in backyard telescopes. But exploring the Club District can be rewarding for those who enjoy observational challenges.

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inside its symbol for NGC 2141 (chart 204), either. Would I be able to detect this weak wonder in my 10-inch Dobsonian?

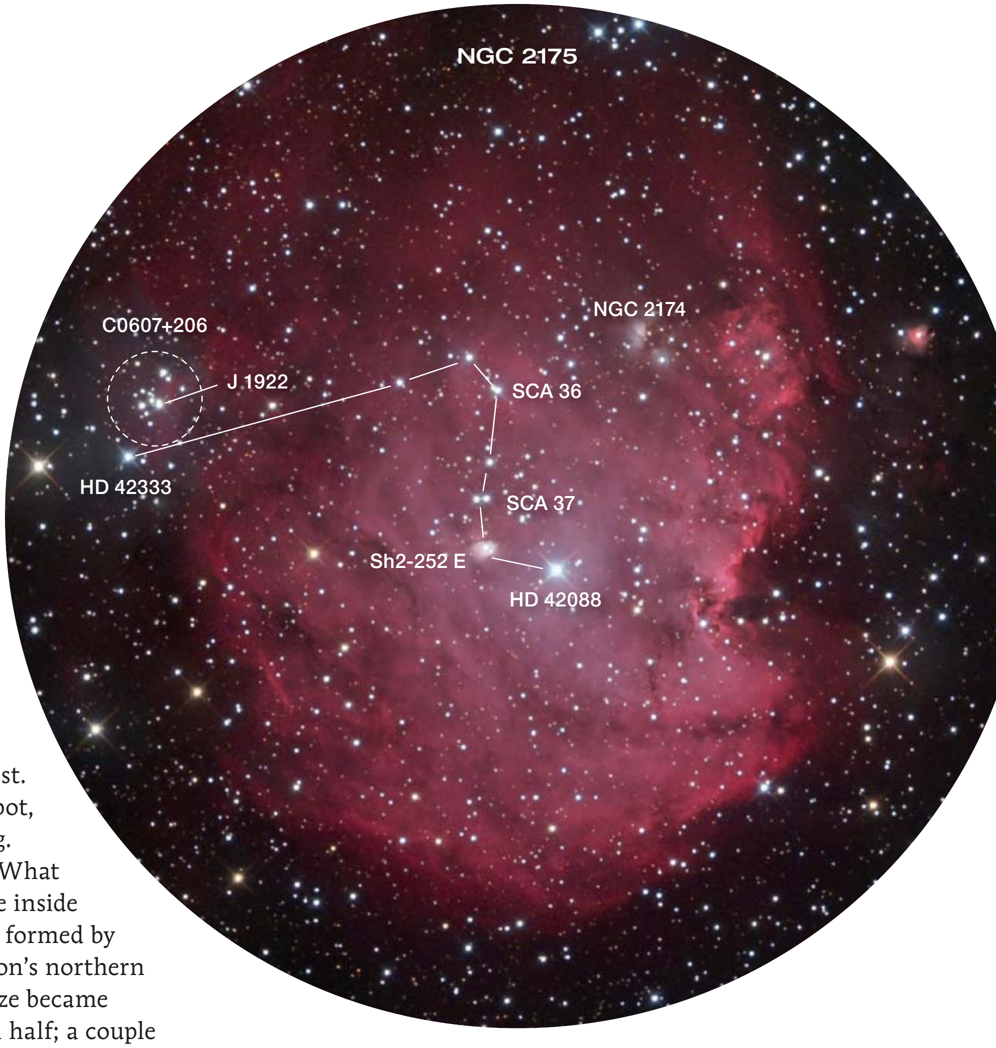
After centering Mu Orionis in a wide-angle eyepiece generating 51×, I shifted northward 1½° to a 9′-long isosceles triangle, oriented east-west, shaped by three 8th- and 9th-magnitude stars (a fourth star sits inside). An imaginary line from the triangle back down to Mu grazes the cluster less than halfway along. I saw nothing there. What to do? I dropped ½° south of the triangle to an 8.6-magnitude star (HD 250956) plus two 9.6-magnitude flankers. According to the chart, the barely bent line-of-three points to the cluster ¼° southwest. I followed my wonky signpost to the precise spot, then increased cautiously to 64×. Still nothing.

Boldly, I upped the magnification to 169×. What emerged with patient staring was a pallid haze inside a five-star pentagon, roughly 7′ × 5′ in extent, formed by 10th- and 11th-magnitude stars. (The pentagon's northern tip aims back to HD 250956.) At 218×, the haze became mottled. Two dim stars inhabited its northern half; a couple of even fainter ones flickered in the southern half. Although photos show NGC 2141 filling the pentagon, my hazy find occupied less than a third of the five-sided area. I admit it was thin gruel. Was I disappointed? No, because capturing the "gruel" was a challenge successfully met.

Lowering the magnification, I headed northeast 3¾° to 5.0-magnitude 74 Orionis, plus slightly dimmer 73 Orionis ⅓° to the northwest. From 73 Orionis it was a half-degree hop to **NGC 2194**. Officially 10′ across, 8.5-magnitude NGC 2194 is another inconspicuous cluster represented by a starless symbol on the chart. Happily, the 10-inch Dob delivered again. Working at 64×, it revealed a 5′-wide mist punctuated by a quadrilateral of 11th-magnitude stars on its southern edge. Doubling the magnification produced a somewhat grainy powder suggestive of more detail. Increasing to 169× teased out several more specks of starlight. More thin gruel.

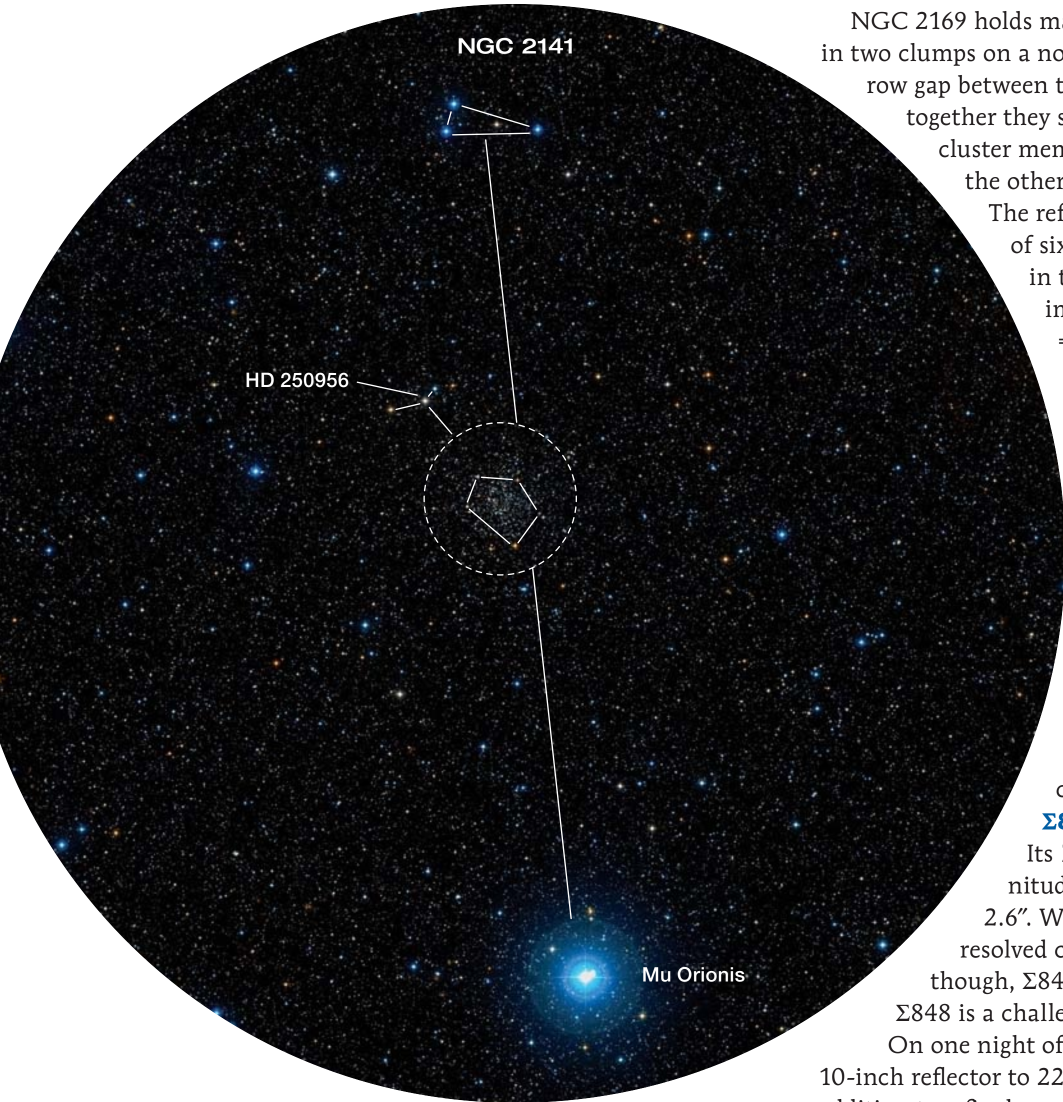
In fairness, NGC 2194 gifted me something completely unexpected. Examining the image at 169×, I noticed a meandering, 10′-long tail of 11th- to 13th-magnitude stars, perhaps a dozen in all, extending southwestward out of the main body of the cluster. The tail terminated at a barb created by three closely spaced stars. Subtly distinctive, the starry appendage slowly became unmistakable. So did the cluster. The entire entity — body, tail, and barb — was a satisfying, high-power payoff.

Surprisingly, NGC 2194 was visible in my 180-mm (7.1-inch) f/15 Maksutov-Cassegrain reflector at 90×, provided I eased the scope carefully from 73 Orionis to the cluster's exact location. At 113×, the Mak-Cass registered a teeny pale powder dotted with a few faint flecks. Ghostly, yes, but another hard-won victory for this die-hard observer.



MASIL IMAGING TEAM

▲ **COMPLEXITY AND CONFUSION** Uncertainty clouds the identification of the emission nebula NGC 2175, about 6,500 light-years away, and its associated cluster, Collinder 84. Some loosely scattered stars provide scant evidence of the cluster, but an asterism resembling the Big Dipper is visible near the center of the image. Two double stars in this Dipper are named SCA 36 and SCA 37. The star left of 8th-magnitude HD 42088 is shrouded in a knot of nebulosity known as Sh2-252 E. Another bright knot is NGC 2174 — a label often mistakenly applied to the entire nebula. Only the bright central portion of the nebula close to HD 42088 was visible in the author's 10-inch reflector. Note the tiny cluster C0607+206 on the eastern edge of the nebula. All images have North up.



▲ **FAR, FAR AWAY** The open cluster NGC 2141 is packed with at least 300 suns, but it's more than 13,800 light-years from Earth and therefore challenging to observe in a light-polluted sky. NGC 2141 appears larger here than it does in backyard telescopes. Thankfully, the pale cluster isn't difficult to locate, as it's framed by an attractive pentagon-shaped asterism.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Numerals in Space

To reach my third stop, I followed 74 and 73 Orionis northwestward to 4.5-magnitude Xi (ξ) Orionis and its near twin, Nu (ν) Orionis, 1.2° farther northwest. Conveniently, Xi and Nu make an almost equilateral triangle with the 6th-magnitude open cluster **NGC 2169**, which lies within a degree of both stars. The triangular threesome is a quick catch in finderscopes; the cluster itself is a glittery smudge in my 6×30 and 8×50 finders. Indeed, NGC 2169 is the only specimen in my Club Tour boasting stars bright enough to plot on the *Uranometria* charts. Better yet, it's sufficiently prominent to appreciate in small telescopes. I began investigating it using a 102-mm (4-inch) f/6.5 achromatic refractor.

NGC 2169 holds maybe 30 stars, most of them arranged in two clumps on a northwest-southeast slant, with a narrow gap between them. Each clump is about 2½′ wide; together they span 6′ of sky, gap included. Half of the cluster members shine at 7th- to 10th-magnitude; the others are much fainter. Not a deluxe deal.

The refractor at 100× presented a grand total of six stars in the northwest clump, eight in the opposite clump. You might not be impressed until you discover that 6 + 8 = 37. Strange but true: The bare bones of this odd duck resemble the numeral 37, as eyed in an erect field, which (thankfully) the refractor's prism star diagonal gave me. Check it out for yourself. (In a Newtonian reflector, the 37 will be upside-down.)

My hefty Mak-Cass operating at 90× brightened up the ragged 37, yet added very few extra stars to the barren cluster. However, the long-focus scope rewarded me with one delightful detail: NGC 2169's 7th-magnitude lucida, in the southeastern clump (the 3 in 37), is a binary star. **Σ848** (Struve 848) is a tight tandem: Its 7.3-magnitude primary and 8.2-magnitude secondary are separated by a scant 2.6″. When the air was steady, the uneven duo resolved cleanly at 113×. On turbulent nights, though, Σ848 rarely obliged me. Give it a try — Σ848 is a challenge worth attempting.

On one night of perfectly calm seeing, I cranked up my 10-inch reflector to 227× and stared hard at NGC 2169. In addition to a finely resolved Σ848, the high power picked up 10 very faint suns around the 37 formation. The bigger aperture helped confirm that the population shines blue-white, with three evident exceptions. A 9.9-magnitude star on the eastern periphery of the southeast group was yellowish. An 8.4-magnitude star atop the northwest group seemed deeply yellow. Beside it, a 9.1-magnitude star (northernmost in the cluster) burned orange. I suspect the orangey outlier isn't physically part of NGC 2169.

The Low-Power Look

An especially pleasing aspect of NGC 2169 is its picturesque setting, which was fabulous in the wide-field refractor. Reducing the 4-incher to 20×, I nudged northwestward toward Nu Orionis. Two-thirds of the way there, I noticed the ruddy hue of 7.1-magnitude **HD 41676**, a red giant star. West of it, I spotted two doubles within 10′ of each other. **AG 321** comprises 7.8- and 8.8-magnitude stars 36″ apart, while its nameless neighbor sports 9.4-magnitude twins 63″ apart. The refractor captured all this near-to-Nu stuff (and the cluster) in a single field of view.

After taking in Nu and Co., I shifted southeastward, past NGC 2169, along a ragged star chain to a slender parallelogram of 7th- to 9th-magnitude stars, measuring 8′ by 2′, oriented east-west. Something blurry at the parallelogram's western end caught my eye. Briefly upping to 100× clarified it as a dim double star of approximately 20″ separation. I'd have thought such an obvious duet would warrant an entry in the Washington Double Star Catalogue — but it doesn't. Returning to 20×, I hopped northward to Xi Orionis, then veered northeastward through a shorter chain to a narrower parallelogram. Its brightest member is a legit binary — called **Σ877**, it displays 7.6- and 8.0-magnitude stars 5.7″ apart. The petite pairing resolved cleanly at 100×.

No telescope? No problem. Binocular users will love the broader 37 region. Starting at NGC 2169, I casually scanned the abovementioned ragged star chain hand-holding my 7×50s. I kept going, since the chain curved eastward in a gentle arc of 6th- and 7th-magnitude stars. The fourth star in this extended section, a variable identified as **HD 44033**, exuded a strongly orange sheen. East of it, the stronger variable **BL Orionis** (magnitude range 5.9 to 6.6) glowed rosy-red in the binocs.

Just south of that graceful array of stars are three binocular doubles. **OSS 73** features 6.9- and 7.7-magnitude stars, 72″ apart, aiming at 5th-magnitude 73 Orionis to the southwest. A pair exhibiting 6.7- and 7.4-magnitude stars 189″ apart — **HD 43873** and **HD 43840**, respectively — points close to 74 Orionis. Finally, southwest of 74 Orionis, **OSS 71** consists of 7.2- and 7.6-magnitude stars 90″ apart. The binoculars framed all three generously separated sets in one field of view. In the refractor, the components shone various shades of white, blue, and orange.

In sky lore, Nu and Xi Orionis correspond more-or-less to where the Hunter clutches his club. This sector of the constellation is not in the same league as the famous Sword of Orion, but it offers lots of pretty celestial scenery for low-power looking. I suggest you scan slowly, using your binoculars or a wide-field scope, all the way from Nu Orionis to BL Orionis — and don't miss those colorful doubles to the south.

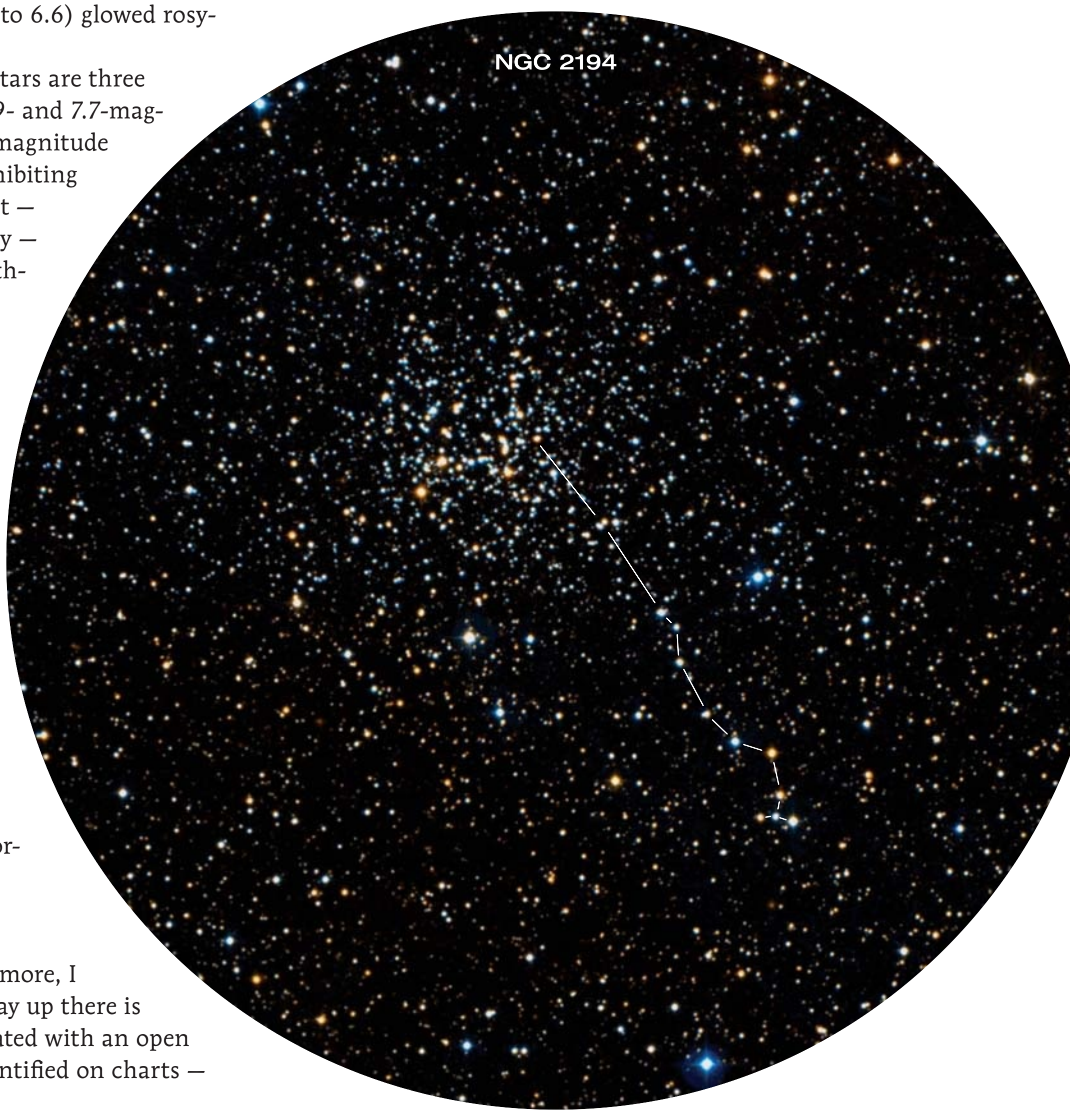
Dim and Mysterious

Engaging my 10-inch Dobsonian once more, I advanced to the top of Orion's club. Way up there is **NGC 2175**, an emission nebula associated with an open cluster. Both objects are usually misidentified on charts — my trusty *Uranometria* included.

The nebula is often incorrectly designated NGC 2174. *S&T* former contributing editor Sue French has reported that NGC 2174 is a prominent knot in the northwestern part of the sprawling nebula. Sue has stated there doesn't appear to be an obvious concentration of stars within NGC 2175, though "clumps of stars loosely scattered across most of the nebula" might be **Collinder 84**, an obscure cluster suggested by Swedish astronomer Per Collinder in 1931.

My route to NGC 2175 followed a sequence of stellar steppingstones of increasingly fainter magnitude, starting at a quadrilateral-shaped asterism, 2¼° by ½° in extent, outlined by the 4th- to 6th-magnitude stars Chi^1 (χ), Chi^2, 57, and 64 Orionis. After placing 4.6-magnitude χ^2 Orionis in the crosshairs of my finderscope, I star-hopped northward to

▼ **CLUSTER CREATURE** At a distance of almost 8,700 light-years, the open cluster NGC 2194 isn't a conspicuous object in backyard telescopes. However, this fairly rich cluster displays subtle character in the form of a body and tail. The string of faint stars forming the tail is visible in mid-size suburban scopes at medium to high magnification.



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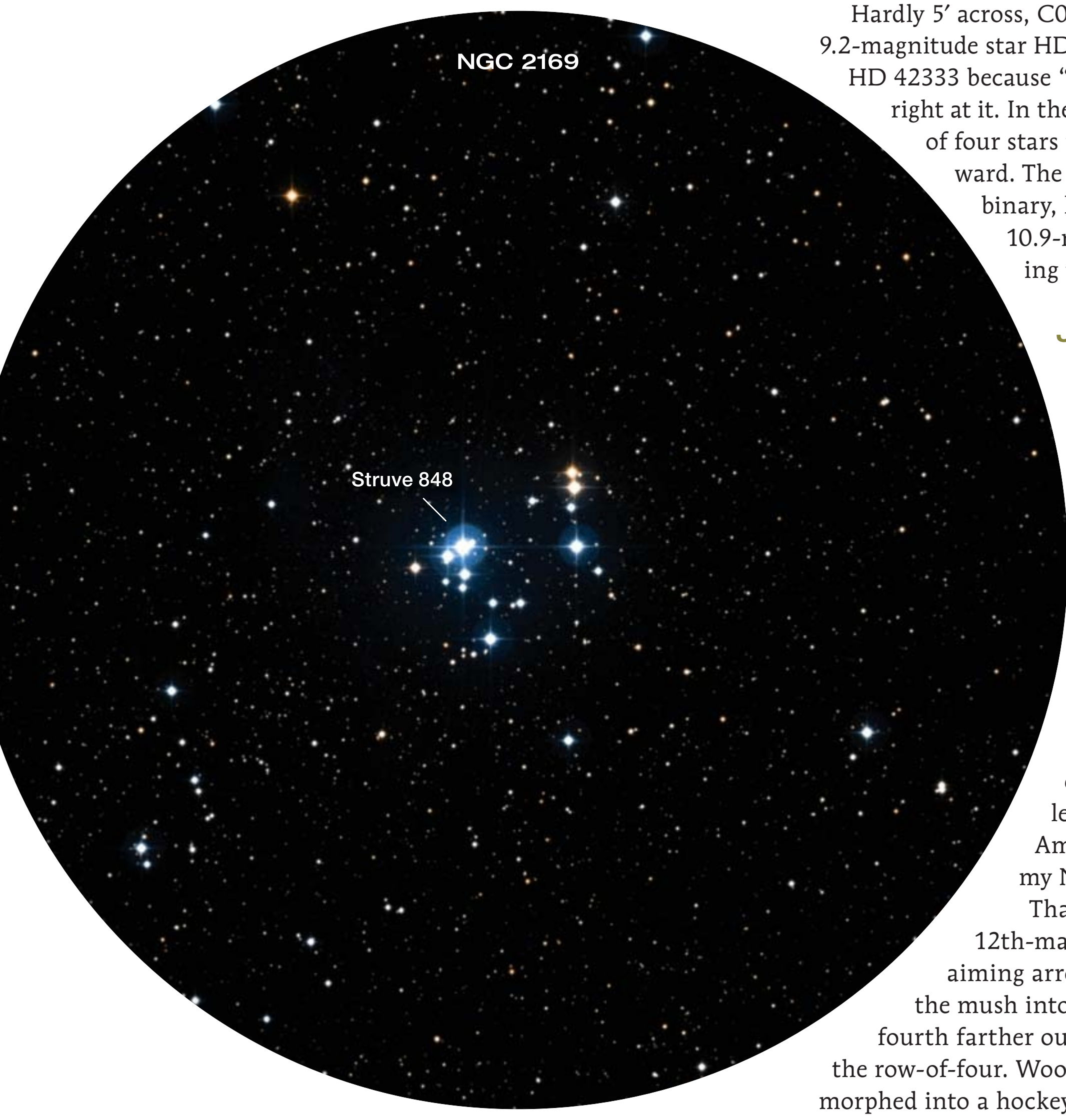
6.9-magnitude HD 40981, then turned eastward to 7.1-magnitude HD 41657, and finally southeastward to 7.6-magnitude HD 42088, which, according to the *Uranometria*, sits inside the nebula.

Observing at 64×, I detected no nebulosity until I applied an Ultra-High Contrast (UHC) narrowband filter. Bingo! A tenuous, spherical haze, perhaps ¼° in diameter, magically materialized around HD 42088. (Focusing on stars of similar magnitude confirmed I was experiencing nebulosity, not eyepiece fog.) A doubly ionized oxygen (O III) filter provided excellent contrast — the round haze was unmistakable — but the O III field at higher magnifications was a bit dark. A broadband light-pollution filter proved only marginally helpful at any magnification. Of the various combinations I tried, the winner was the UHC used at low power.

The above combo in place, I noticed a 10′-long, seven-star asterism (evidence of Collinder 84?) stretching northeastward out of the spherical haze. I dumped the filter and bumped up the power. Aha! To my eye, the pattern resembled the Big Dipper. HD 42088, mentioned earlier, plays the role of Alkaid (η Ursae Majoris) at the end of the handle. A dimmer star is Mizar (ζ UMa). A nicely balanced, 10.6-magnitude double, 24.8″ wide, called **SCA 37**, is Alioth (ε UMa). A star corresponding to Phad (γ UMa) in the bowl is **SCA 36**, an unequal binary whose 10.3- and 12.8-magnitude components, 13.5″ apart, split beautifully at 218×.

I was intrigued by a cluster, which the *Uranometria* labels **NGC 2175.1**, on the eastern edge of the nebula. In their authoritative book *Star Clusters*, Brent Archinal and Steven Hynes caution that the identifier 2175.1 is not original to the *NGC* catalogue; "where possible this cluster should probably be referred to as **C0607+206**." Fine by me — I just wanted to know if the plotted object would appear in my scope.

Hardly 5′ across, C0607+206 lies 2′ northwest of the 9.2-magnitude star HD 42333. I had no difficulty finding HD 42333 because "the pointers" in the mini-Dipper aim right at it. In the Dob at 169×, the cluster yielded a row of four stars northward, plus a clumping southward. The clump possesses one bright star. It's a binary, listed as **J 1922**, featuring 10.5- and 10.9-magnitude pinpricks 6.6″ apart. Cracking that nut at 218× was super satisfying.



▼ **THE NUMBER CLUSTER** Roughly 3,000 light-years distant, thinly populated, and distinctly odd-looking, NGC 2169 has been dubbed the 37 Cluster due to its appearance in an upright (not inverted or mirror-reversed) telescope field. The numerical name was coined by Kentucky amateur Alan Goldstein in 1981. Light-hearted observers also picture NGC 2169 as the Shopping Cart Cluster. Can you configure a cart in these stars?

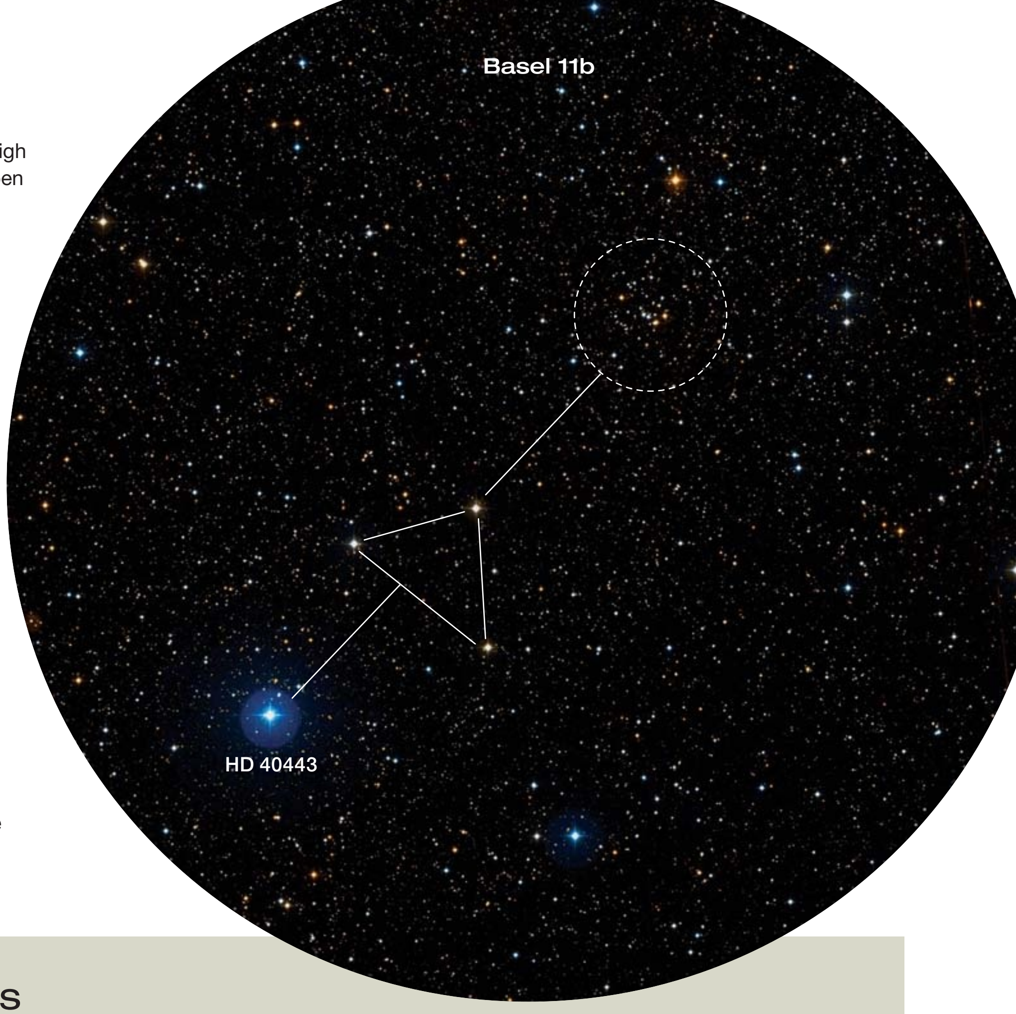
POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Join the Club

Finally, I pushed farthest north, to the top of the Hunter's club, where the cluster **Basel 11b** resides near Orion's border with Gemini. My star-hop to the 8.9-magnitude target again involved increasingly fainter steppingstones, this time beginning at 4.2-magnitude 1 Geminorum. From there, I swept past the 6.4-magnitude variable star HD 40724, to 6.9-magnitude HD 40443 in Orion. Immediately northwest of HD 40443, an equilateral triangle of 9th-magnitude stars led me to 3′-wide Basel 11b further on. Amazingly, the little blighter showed in my Newtonian at 64×.

That said, Bas 11b at 64× was a mush of 12th-magnitude suns forming a southward-aiming arrowhead. Powering up to 218× resolved the mush into a short row of three stars, plus a fourth farther out, and a fifth at a sharp angle to the row-of-four. Woohoo! Somehow, the arrowhead had morphed into a hockey stick. (As a winter-ravaged Canadian,

▶ **SMALLEST MEMBER OF THE CLUB** Perched high atop the Hunter's brandished club is the obscure open cluster Basel 11b. Situated about 4,900 light-years from Earth, Basel 11b is hardly a marquee deep-sky object — the tiny cluster isn't densely concentrated and spans just a few arcminutes of sky. Yet the little splash of starlight was easily visible in the author's 10-inch Dobsonian.



imagining a hockey stick was inevitable.) Fleetingly visible at the threshold of vision were several additional cluster members. One of them, I'm sure, was the puck.

I always get a kick out of capturing faint fare in my modest backyard telescopes. Enjoying these Orion extras in your own scope is easy — simply join the club!

■ Contributing Editor **KEN HEWITT-WHITE** has kept his eye on Orion since he was a teenaged stargazer in Ottawa, Ontario, in the mid-1960s.

Orion's Club Members

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 2141	Open cluster	9.4	10′	$06^h\ 02.9^m$	+10° 27′
NGC 2194	Open cluster	8.5	10′	$06^h\ 13.8^m$	+12° 48′
NGC 2169	Open cluster	5.9	6′	$06^h\ 08.4^m$	+13° 58′
Struve 848	Double star	7.3, 8.2	2.6″	$06^h\ 08.5^m$	+13° 58′
HD 41676	Red giant	7.1	—	$06^h\ 07.1^m$	+14° 27′
AG 321	Double star	7.8, 8.8	35.8″	$06^h\ 05.4^m$	+14° 35′
Struve 877	Double star	7.6, 8.0	5.7″	$06^h\ 14.7^m$	+14° 35′
HD 44033	Variable star	5.7 – 5.8	—	$06^h\ 20.1^m$	+14° 39′
BL Orionis	Variable star	5.9 – 6.6	—	$06^h\ 25.5^m$	+14° 43′
OSS 73	Double	6.9, 7.7	72″	$06^h\ 19.4^m$	+13° 27′
HD 43873 / 43840	Double	6.7, 7.4	189″	$06^h\ 19.0^m$	+12° 43′
OSS 71	Double	7.2, 7.6	90″	$06^h\ 14.5^m$	+11° 48′
NGC 2175	Emission nebula/open cluster	—	40″ × 30″	$06^h\ 09.7^m$	+20° 30′
Collinder 84	Open cluster	6.8	22′	$06^h\ 09.6^m$	+20° 29′
SCA 37	Double star	10.6, 10.6	24.8″	$06^h\ 09.9^m$	+20° 32′
SCA 36	Double star	10.3, 12.8	13.5″	$06^h\ 09.8^m$	+20° 37′
NGC 2175.1	Open cluster	—	5′	$06^h\ 10.9^m$	+20° 37′
J 1922	Double star	10.5, 10.9	6.6″	$06^h\ 10.9^m$	+20° 37′
Basel 11b	Open cluster	8.9	3′	$05^h\ 58.2^m$	+21° 58′

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.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Sky-Watcher's Evostar 150 APO Refractor

ED glass and advanced optical coatings push this two-element objective design to its full potential.

◀ The Sky-Watcher Evostar 150 APO Refractor is a 150-mm (5.9-inch) f/8 with a two-element objective, including one element made with ED (extra-low dispersion) glass. Fitted with typical accessories for observing, the tube assembly weighs about 20 pounds. Its rugged carrying/storage case weighs 36 pounds and holds the tube assembly with mounting rings and dovetail bar attached and has extra room for accessories.

Evostar 150 APO Refractor

U.S. Price: $2,350
skywatcherusa.com

What We Like

Excellent optics

Smooth, dual-speed 2-inch focuser

Rugged carrying/storage case

Eyepieces, star diagonal, and finder not included (but see below)

What We Don't Like

Tube slips in its mounting rings

Eyepieces, star diagonal, and finder not included (but see above)

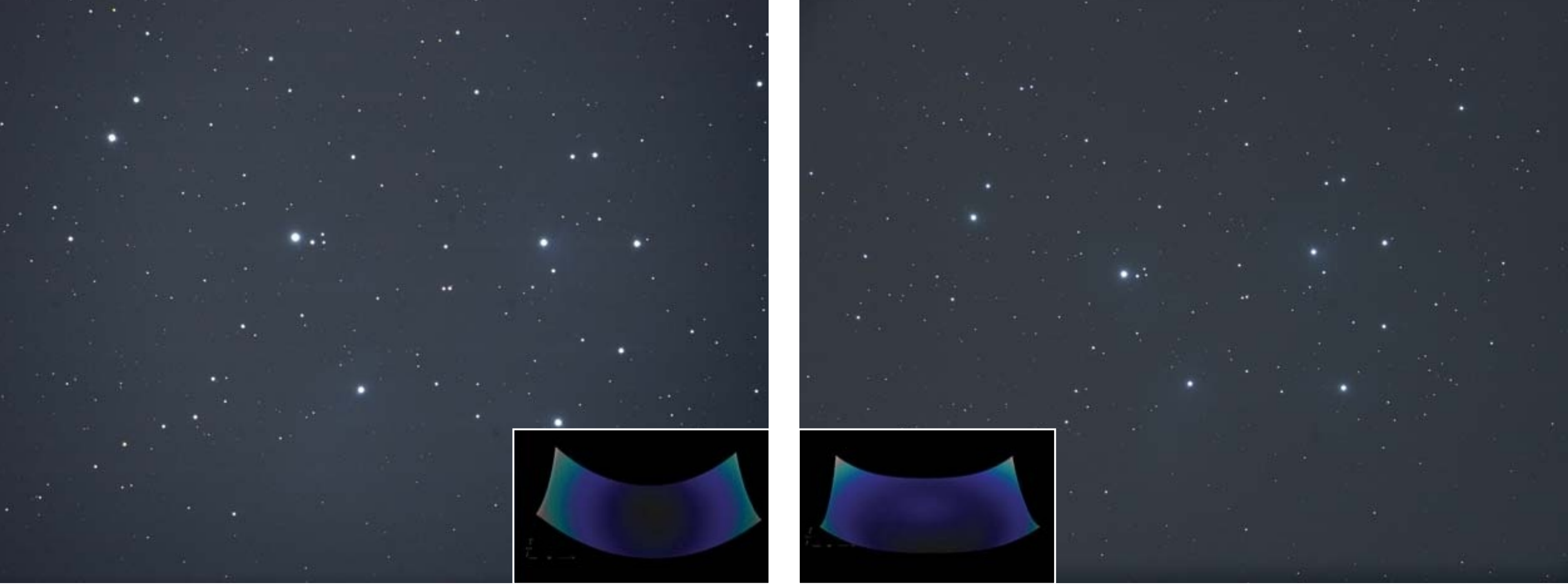
IT'S UNUSUAL TO JUDGE the quality of a telescope after only a few nights under the stars, so it's really rather extraordinary to form a strong opinion after just an hour or so. But that's all it took for me to realize that the 5.9-inch f/8 Sky-Watcher Evostar 150 APO Refractor is an exceptional telescope for visual observing. And it's an opinion that grew stronger in the weeks of testing that followed.

If anyone needs proof that amateur astronomy's love affair with refractors has not abated in recent years, they can simply tally up the number of refractors on the market today with apertures between 60 and 150 mm. It has to be hundreds. Among them is Sky-Watcher's Evostar line, featuring two-element objectives with one element made of ED (extra-low dispersion) glass. As such, these objectives produce images with far better color correction for a given focal ratio than typical two-element achromats made of traditional crown-and-flint glasses. There are currently six models in the Evostar line ranging from 72- to 150-mm aperture (read our review of the 72-mm Evostar in the February 2009 issue, page 58). There's also a 50-mm version (Evoguide) that's mainly intended as a finder- or guidescope.

The Evostars are a step down from Sky-Watcher's premier Esprit ED Triplet APO Refractors, which have three-element objectives and are aimed at observers who are also interested in high-end astrophotography. (The 150-mm Esprit is reviewed in this magazine's February 2020 issue, page 68.) But that's not to say that the Evostar scopes aren't suited for astrophotography, espe-

▶ For observers with an interest in deep-sky imaging with the telescope, there's an upgraded version called the Evostar 150DX APO Refractor, which replaces the tube rings, dovetail bar, and focuser on the standard model with the items shown here. At right is the optional f/6.2 focal reducer made specifically for the Evostar 150, which only attaches to the heavy-duty, 3.4-inch focuser.

ALL PHOTOS BY AUTHOR UNLESS OTHERWISE NOTED; SCOPE IN CASE: SEAN WALKER / *S&T*



▲ These 30-second exposures of the Pleiades star cluster on a hazy, moonlit evening were made with the Evostar and 2-inch focuser working at f/8 (left) and with the 3.4-inch focuser and f/6.2 focal reducer (right). Insets show analysis of the images with *CCD Inspector,* revealing that the focal reducer also flattens the scope's focal plane compared to the curved field inherent to the f/8 objective, and that it would be good for an APS-format detector.

cially in the case of the 150-mm model, which is available in two flavors.

Hardware

For this review we asked to borrow the Evostar 150 APO, which is the basic version of the two 150-mm models. It's equipped with a dual-speed 2-inch focuser, lightweight tube rings, and a Vixen-style dovetail mounting bar. The other model is the Evostar 150DX APO Refractor. It has the same objective and tube assembly but comes with the heavy-duty, dual-speed focuser found on the Esprit 150-mm scope, and it's supplied with heavier tube rings and a Losmandy-style dovetail bar. These upgrades cost an additional $850 over the price of the basic 150-mm scope. The more-robust focuser on the DX model brings the advantage of accepting the new f/6.2 focal reducer designed specifically for the Evostar 150-mm scope. Because swapping the focusers on the main Evostar 150 tube assembly takes only minutes, Sky-Watcher sent along the upgraded items available with the DX model so that I could try them out. Let's start with the basic model.

The Evostar 150 APO is a handsome scope with its dark, metal-flake painted tube, white dew cap and focuser, and Sky-Watcher's signature green trim. With the focuser retracted its overall length is 50 inches, and it weighs 17 pounds (3.2 kg). It comes with a very solid, metal lens cap. The supplied carrying case is also particularly noteworthy for its solid, high-quality construction. It alone weighs 36 pounds and is made for transporting as well as storing the scope. The scope is sold without a finder, star diagonal, or eyepieces. This might be a negative for a first-time scope buyer, but for observers who already own these items it helps keep the cost of the instrument down, which I found a plus. There's a dovetail base for mounting a finder on the focuser body. While not universal, this format is relatively common, and I used it to attach a finder that I commandeered from another scope.

From the standpoint of visual observing, I was very happy with the 2-inch Crayford-style focuser. It has slightly more than 5¼ inches (133 mm) of travel, and easily accommodated every eyepiece I tried with and without a 2-inch star diagonal. I was especially impressed with the light touch required to operate the fine-focus knob — something that I really appreciated when focusing at high magnifications where a heavier touch would be prone to jiggling the telescope.

▼ The author found the 2-inch Crayford-style focuser to be excellent for visual observing and even astrophotography with cameras as heavy as a DSLR. The robust focuser on the DX model is the same one used on Sky-Watcher's premium 150-mm Esprit refractors and is capable of handling much heavier imaging setups.

▼ The optional f/6.2 focal reducer also significantly flattens the Evostar's focal plane for deep-sky astrophotography. Fitted with a 48-mm (large aperture) T-ring, the setup provides even illumination across a full-frame camera sensor with only a little vignetting in the very corners of the image. The focal reducer can be rotated to aid with framing images.

The 2-inch focuser is also very good for imaging the Moon and planets with the small planetary cameras designed to fit into 1¼-inch eyepiece holders. And while I wasn't planning to do photography with large cameras, I was pleased to find that the 2-inch focuser did not slip when my heavy DSLR camera was attached, even when the scope was pointed at the zenith. In my opinion this focuser serves well for visual observing and astrophotography with cameras up to and including DSLRs.

The only hardware issue I had with the Evostar 150 APO involves the tube rings. With their clamping knobs fully tightened, the tube sometimes slipped when the scope was pointed at high elevations. My solution was to add a couple of small cork strips around a portion of the inside of each felt-lined tube ring to add a little friction.

As mentioned above, the DX model's hardware upgrades include the heavy-duty 3.4-inch focuser. There's no question that this focuser is very nice, and it really is a must-have upgrade if you intend is to use the Evostar 150 with a heavy imaging setup, but I didn't find it a significant advantage for strictly visual observing. The rack-and-pinion-driven drawtube has 3½ inches of travel, with its midpoint being where many eyepieces come to focus when using a 2-inch star diagonal. For straight-through viewing some eyepieces may need a short extension tube. The fine-focus knob has a firmer feel than the 2-inch focuser, and there's a small lever that adds friction on the rack-and-pinion drive, which virtually guarantees it will not slip regardless of the load on the focuser. This focuser has the same style dovetail mounting base for a finder that's included on the 2-inch focuser.

▼ As described in the text, the author mounted the Evostar scope together with his homemade 6-inch f/10 refractor assembled with a conventional achromatic objective made by A. Jaegers in the early 1970s. While both scopes were evenly matched in critical resolution tests, the Evostar consistently delivered images that were brighter and more contrasty than the 6-inch.

The biggest optical advantage of the DX focuser is that it accepts the new Evostar f/6.2 focal reducer and makes the scope more attractive to people interested in deep-sky imaging. While it's called a focal reducer, this accessory also flattens the field quite a bit. At f/6.2, the Evostar 150 has an effective focal length of 930 mm and a field of view covering about 2¼° × 1½° on a full-frame (36 × 24-mm) sensor. With a 48-mm T-ring on my full-frame DSLR, there was only minimal vignetting in the corners of the frame. And though it's a somewhat subjective call, I found star images to be very good over more than 80% of the sensor's long dimension. The bottom line with the focal reducer is an imaging circle with good star images approaching 30 mm in diameter (covering a 1.8° field) and almost no vignetting. It may not be in the same class as today's elite astrographs, but it's still an impressive setup for deep-sky astrophotography.

Optical Performance

There's a bit of a backstory as to why I passed judgement so quickly on the Evostar 150 APO's optical quality, and it involves another telescope. Earlier this year I began an observing project with a 6-inch f/10 refractor that I cobbled together using an A. Jaegers' objective that had sat on my workshop shelf for more than 40 years. The project was a departure from my typical just-for-fun observing, which usually involves deep-sky objects and reflectors with apertures of 12 inches and up.

▲ While the Evostar 150 models are sold without a finder, there's a common-style dovetail shoe on the focusers for attaching one.

I gained a lot more appreciation for observers who rave about refractors and how they excel for viewing the Moon, planets, and double stars (the latter being a big part of my observing project). It also helped that our New England astronomical seeing accommodates a 6-inch scope far more often than it does a large reflector. The A. Jaegers lens proved to be very sharp and clearly capable of resolving double stars around the aperture's 0.75-arcsecond Dawes limit when the seeing permitted. Its main weakness is color fringing, which is to be expected for an f/10 crown-and-flint achromat.

Given this 6-inch scope's aperture and performance, it was an excellent benchmark for comparing to the Evostar 150 APO, and as such I mounted both scopes side by side on the same Sky-Watcher EQ8-R Pro German equatorial mount that was reviewed in last October's issue, page 66. And to help level the playing field, I selected sets of eyepieces that gave similar magnifications when paired with the respective scopes, often using the same brand and design, including eyepieces from the Burgess/TMB Planetary Series and Tele Vue's Radian family.

My first look through the Evostar 150 APO was an eye-opener. Despite its slightly smaller aperture (5.9 vs. 6 inches), it gave a view of the brilliant star

▲ Although the telescope's 10-inch-long dew shield does not retract, it can be unscrewed from the lens cell to make it easier to blow or gently brush off any dust and tree pollen from the objective. The metal lens cap fits on the dew shield and offers significant protection.

Arcturus in deepening twilight that was clearly brighter and more contrasty than the one produced by the 6-inch. The modern multi-coatings on the Evostar objective likely account for much of the difference, but the scope's three internal light baffles offered better suppression of scattered light than did the baffling I used for the 6-inch. As the night wore on, same-magnification views in both scopes always seemed brighter and more contrasty in the Evostar, and it wasn't just a subtle difference.

Indeed, the only aspect of the two scopes that was evenly matched involved resolution. During weeks of observing under varying seeing conditions and moonlight, there was never a time when one scope outperformed the other for resolving tight binary stars or lunar and planetary details.

The Evostar always came to a crisp focus even with magnifications between 500× and 600×. Only the slightest touch on the fine-focus knob was enough to show the difference between an image being in and out of focus. For a two-element objective, the Evostar's color correction is noteworthy. There is only a slight hint of color fringing around out-of-focus star images. In focus there were no noticeable color halos around bright stars. Spherical aberration was also well-corrected. Stars showed similar diffraction patterns on both sides of focus. The only exception occurred during autumn evenings when the temperature was rapidly falling and I could sometimes detect a hint of spherical aberration in the out-of-focus images, which is not unusual for a refractor objective acclimating to temperature changes. Even so, it was never enough to degrade in-focus views.

The Moon was a particularly good target for the Evostar, especially when the seeing permitted using high magnifications. The scope produced excellent, high-contrast views along the lunar terminator without a hint of scattered light washing over the deep shadows. And while timing of the observation was as important as the telescope, on the evening of last October 24th I had one of my most memorable views of the famed Straight Wall and the top of the adjacent crater Birt catching the first rays of lunar sunrise.

During the fall, Jupiter and Saturn barely made it above the treetops as seen from my observatory, but there were times when I had decent views of both and several instances when Jupiter's moon Ganymede clearly appeared as a tiny disk rather than just a point of light. The highlight of the season was, of course, Mars, and here the Evostar did not disappoint. I was able to identify dozens of dark albedo features and the shrinking south polar cap as I followed the Red Planet on nights when the seeing was decent.

Overall, I was extremely pleased with the Evostar's optical performance.

▼ Even with the tube rings fully tightened, the telescope tended to slip when pointed to high elevations. The author solved the problem by adding several thin cork strips between the ring's felt lining and the telescope tube.

I can't speak for everyone, but it's difficult for me to imagine anyone nitpicking the views this scope is capable of producing. It is a very fine instrument for serious visual observers and delivers everything I expect from a 150-mm-aperture telescope.

A Word about Mountings

Because of their length, refractors put more demands on a telescope mounting than instruments with compact tube assemblies. As such, it's desirable to use a mount rated for a greater weight capacity than the telescope. My observing setup with the two refractors mounted together totaled about 60 pounds, or slightly more than half of the rated capacity of the Sky-Watcher EQ8-R Pro. That might seem like overkill, but it really was a pleasure using such a solid platform with responsive slow-motion controls. A mount with twice the weight capacity of the Evostar 150 would certainly be a good choice for the scope.

If owning a high-quality, large-aperture refractor is on your bucket list, I can highly recommend the Evostar 150 APO. Its optical performance for visual observing is on par with some of the finest refractors I've ever used, including ones costing three and four times the price of the Evostar. The light touch needed to operate the 2-inch focuser's fine-focus knob is a real plus for observing at high magnifications. The focuser was also more than adequate for all kinds of astrophotography with cameras even as heavy as today's typical DSLRs. The biggest advantage that the heavy-duty focuser on the Evostar 150DX APO brings to astrophotography is its potential for using the optional f/6.2 focal reducer. While that setup is a notch below the capability of Sky-Watcher's 150-mm Esprit astrograph, it's more than enough for a lot of serious deep-sky photography. Needless to say, I'm impressed with the 150-mm Evostar refractor.

■ **DENNIS DI CICCO** spends a lot of clear nights testing equipment from his backyard observatory in Boston's western suburbs.


McDONALD
OBSERVATORY
TELESCOPE

Magic Nights on Mount Locke

McDonald Observatory in Texas is a mecca for research astronomers . . . and for lucky amateurs.

One of the first things you learn as an amateur astronomer is that deep-sky objects don't quite look like you imagined. What you see in your telescope's eyepiece definitely doesn't match pretty Hubble Space Telescope photographs. Even on a good night, the Crab Nebula is just a pale smudge in the average backyard scope. The Whirlpool Galaxy? A diffuse patch of light lacking clearly defined spiral arms. And you've probably never seen the Horsehead Nebula.

But what if you could harness the aperture of one of the world's premier research telescopes under pristine dark skies?

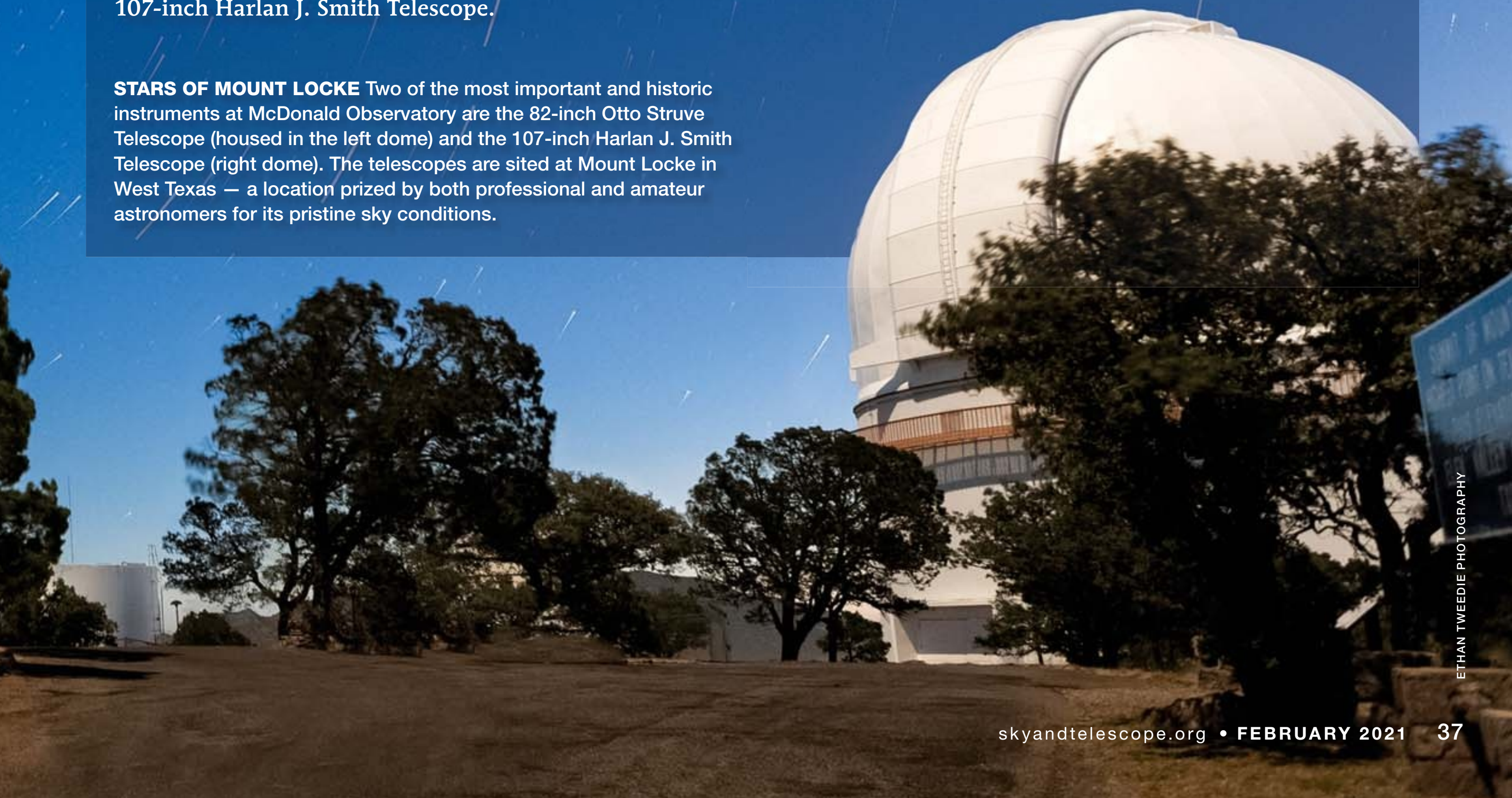
Amazingly, you can.

Splendid Texas Skies

Deep in the Davis Mountains of West Texas, situated atop 2,070-meter (6,790-foot) Mount Locke, stands McDonald Observatory. Here, the same telescopes that astronomers often wait months to gain access to are periodically made available to the general public on Special Viewing Nights. These are rare but well worth waiting for since they provide the opportunity to view the heavens through historic observatory instruments, including the 82-inch Otto Struve Telescope, or even the 107-inch Harlan J. Smith Telescope.

However, getting to McDonald Observatory requires serious commitment. The closest municipal airport is 177 miles away in Midland, Texas. If you travel by car, be prepared for a 5- to 7-hour drive from the nearest major city. (Those who attend the annual Texas Star Party, which is held nearby, will be familiar with the observatory's remoteness.) Roads can become icy in winter, and at night you have to watch out for the ubiquitous javelina, a kind of wild pig that runs in herds. Despite these obstacles, the observatory continues to attract more than 40,000 visitors each year. Astronomers often call McDonald the "tourist's observatory."

Why do people continue to make this pilgrimage? Probably for the same reason that Otto Struve, the observatory's first director, was initially attracted to the region. The Davis Mountains in West Texas have some of the darkest and clearest night skies in the United States and so are ideal for astronomical research. McDonald is also a great destination for amateurs, as outreach has always been a part of the observatory's story. In addition to the Special Viewing Nights, observatory staff and volunteers host star parties three times a week at the nearby Frank N. Bash Visitors Center.



STARS OF MOUNT LOCKE Two of the most important and historic instruments at McDonald Observatory are the 82-inch Otto Struve Telescope (housed in the left dome) and the 107-inch Harlan J. Smith Telescope (right dome). The telescopes are sited at Mount Locke in West Texas — a location prized by both professional and amateur astronomers for its pristine sky conditions.

ETHAN TWEEDIE PHOTOGRAPHY

Beating the Odds

I was determined to attend a Special Viewing Night myself. Of course, for a night of observing to truly be "special," you need clear skies — something that's never guaranteed. After several tries, I realized that my chances would improve dramatically if I didn't count on just a single night, particularly one scheduled well in advance. Since I'm not a professional astronomer, the best way for me enjoy an extended visit *and* gain access to the big scopes was to become an on-site volunteer. During peak travel periods, the observatory looks for people able to commit to spending several weeks on Mount Locke helping with facility tours and star parties.

Becoming an on-site volunteer isn't as simple as you might guess, however. After a phone conversation with the volunteer coordinator, I received an application form and submitted to an extensive background check. Some six weeks later I was approved and soon received my first volunteer request, for a two-week stay beginning on March 8, 2020. When the date finally arrived, I packed my bags and headed for the Davis Mountains.

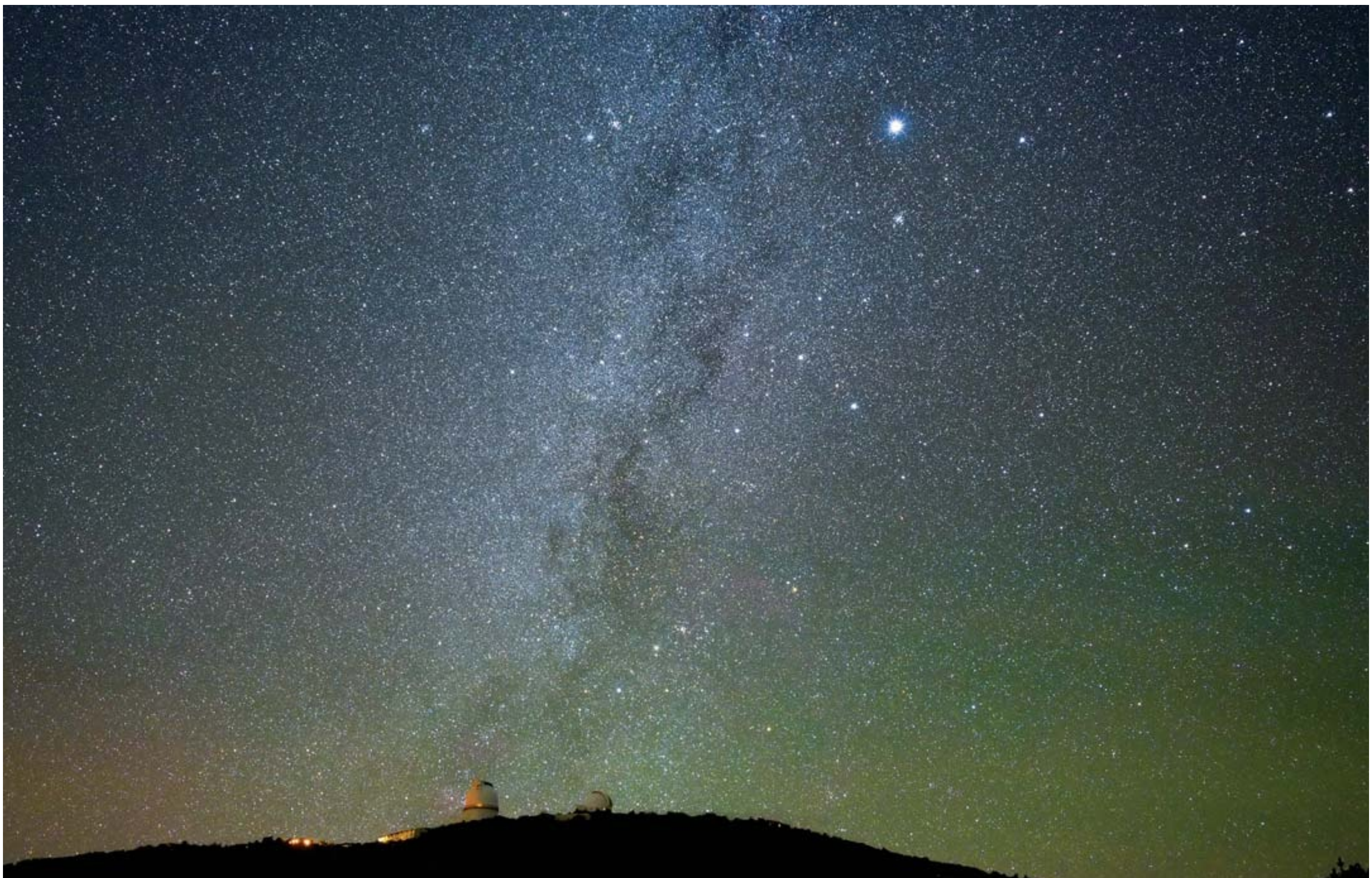
The Astronomers' Lodge at the top of Mount Locke became my home away from home during my stay. Over the years, the Lodge has hosted some of the world's most renowned astronomers, and there's almost always someone very familiar with the telescopes in residence. I quickly got to know an engineering team that was in the process of upgrading the Robert G. Tull Coudé spectrograph on the 107-inch telescope.

My own duties were simple by comparison. I would be operating an 8-inch Meade LX90 telescope at the visitor's center during star parties and helping with observatory tours during the day. On star-party evenings, a wide variety of scopes are set up, each aimed at a specific object. My assigned target was the lovely Canis Major open cluster M41. (In case of stray clouds, M35 in Gemini served as my backup cluster.)

During my visit I was able to enjoy the site's amazingly dark skies. I could clearly see the zodiacal light and the winter Milky Way. But what I really wanted to do was observe familiar deep-sky objects with one of the giant scopes on top of Mount Locke.

Making Good from Bad

My big chance came on an evening when uncertainty was in the air. As fate would have it, my time at the observatory coincided with the start of the COVID-19 pandemic. In the beginning, concern was muted, but as the days went by we began hearing rumors that public events at the observatory



MOUNT LOCKE LUMINOSITY The sky above the telescope domes atop McDonald Observatory is lit by the winter Milky Way and airglow in the upper atmosphere, which adds a green and red luminance to the night sky, especially near the horizon.

STEPHEN HUMMEL

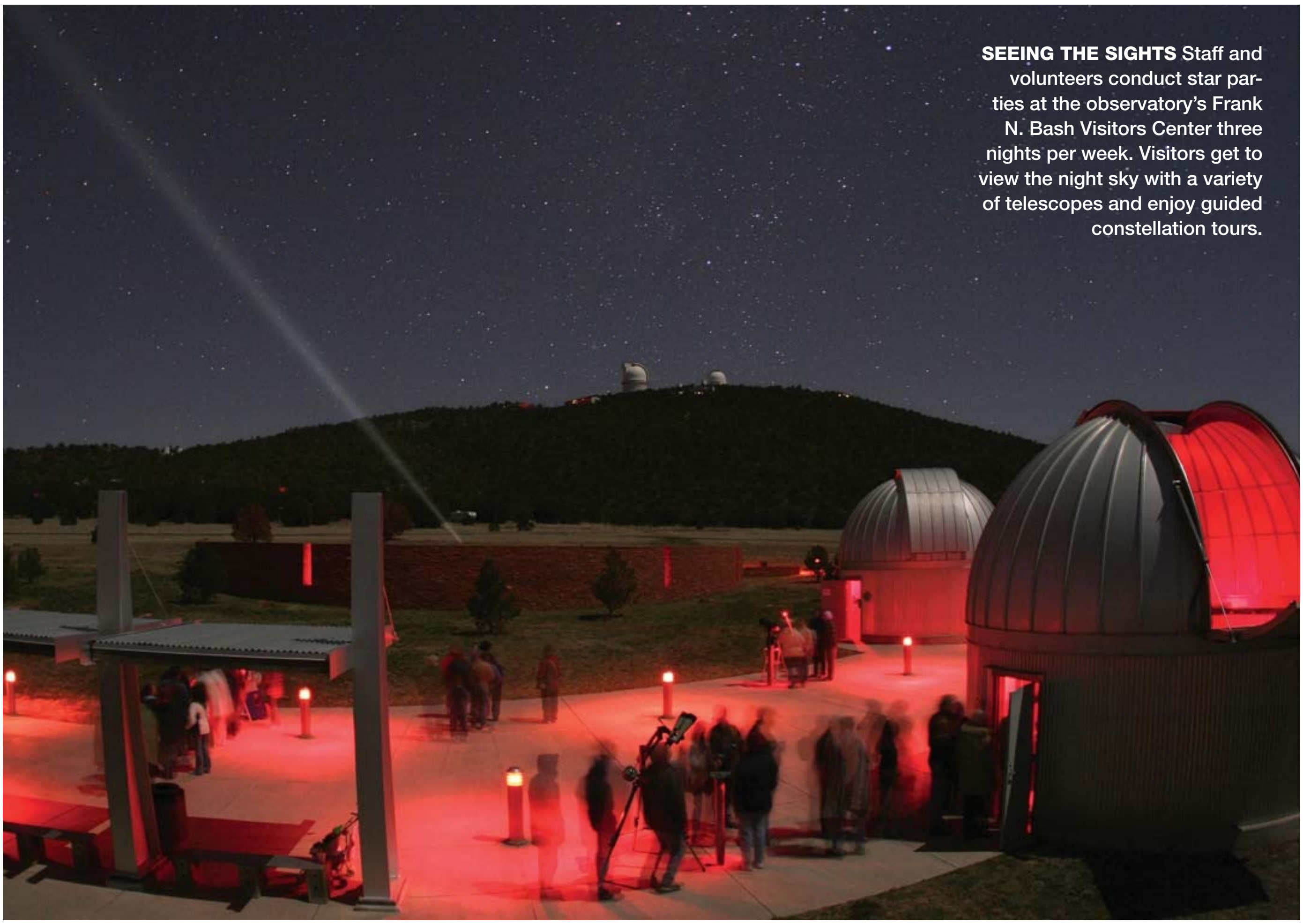
might be curtailed or even canceled. I didn't believe it at first. After all, it seemed that the summit of a remote mountain was the safest place one could be. But, sadly, as the situation rapidly worsened, the University of Texas at Austin (which operates the visitor center and observatory) decided to cancel all public activities, including our star parties. We got the news on a clear, moonless night, and everybody was disappointed.

One of my fellow volunteers, Stephen Hummel, happens to be a resident astronomer and serves as the observatory's Dark Sky Specialist. We'd gotten to know each other during the star parties and often traded views in our respective telescopes. On the night we got word of the cancellations, Stephen told me that the facility's 36-inch Dall-Kirkham reflector was available and asked if I'd like to tag along and view our star-party targets through a much bigger telescope. Yes! This was exactly what I had come for.

Over the next four hours, I got to see things as I never had in a lifetime of observing with backyard telescopes. The Crab Nebula wasn't just a smudge — in the 36-inch it had clearly defined structure. The Orion Nebula was amazing, too, and for the first time I could not only see the nebula's pale green hues, but also subtle reds at the edges.

▲ **REACHING OUT** The 36-inch Dall-Kirkham reflector telescope at McDonald Observatory is used for public outreach programs, including the facility's Special Viewing Nights. Completed in 1956, the telescope was designed primarily for photometry.

The 36-inch's long focal length seemed especially made for planetary nebulae. Cleopatra's Eye (NGC 1535), in Eridanus, looked spectacular. I was able to see the central star for the first time. At higher magnifications, I could easily discern the



SEEING THE SIGHTS Staff and volunteers conduct star parties at the observatory's Frank N. Bash Visitors Center three nights per week. Visitors get to view the night sky with a variety of telescopes and enjoy guided constellation tours.

STAR PARTY: FRANK CIANCIOLO / MCDONALD OBSERVATORY; RED-LIT DOME INTERIOR: STEPHEN HUMMEL & STEVEN JANOWIECKI bright, slightly oval nebulous ring that gives the object its name. Gemini's famed planetary NGC 2392 was equally impressive. I couldn't detect the colors presented in Hubble images, but the planetary's intricate features were clearly evident. The Owl Nebula (M97) in Ursa Major even looked like its namesake. I could appreciate why Lord Rosse compared its features to the face of an owl when he observed it with his 72-inch telescope in 1848.

One of the most exciting objects we viewed that evening was M46. This bright open cluster in Puppis is beautiful, but what makes it a fine target for the 36-inch is NGC 2438, a small planetary nebula seemingly embedded within the cluster. The juxtaposition of the distant open cluster with the much closer planetary was fascinating.

I could have easily spent the rest of the night observing familiar targets, but eventually the Moon rose and viewing faint deep-sky objects became difficult. It looked like conditions might be better later in the week, so Stephen and I agreed to return to the 36-inch then to continue observing. There was even a good chance that the 82-inch scope might be available if I was willing to stick around. Since I had already waited years for this opportunity, staying on the mountain a little longer seemed like a very good plan.

▲ **OLD GIANT** Completed in 1939, the 82-inch Otto Struve Telescope is one of the last large telescopes designed primarily for visual observing. When it saw first light, the Struve ranked as the world's second-largest telescope — only the 100-inch on Mount Wilson, in California, was bigger. In 1966, the instrument was named after McDonald Observatory's first director.

◀ **BRIGHT INTRUDER** For deep-sky enthusiasts, the Moon is a notoriously unwelcome presence, lighting up the night. Even mountaintop observatories far from city lights aren't immune, of course. While visiting McDonald, the author captured this view of the dome of the 107-inch telescope partially eclipsing the lunar disk.

Biding My Time

There was certainly a lot to see while I waited. I was allowed to tag along with the engineering team I'd met at the Lodge when they upgraded the spectrograph on the 107-inch. They were installing a new pivoting mirror at the base of the telescope to allow astronomers to easily choose which spectrograph slit to use. I got to see the telescope moved into unusual positions as the engineers tried to correct a slight shift in alignment that occurred when the telescope's orientation changed.

Although clear skies are the site's main attraction, rainy nights can prove interesting, too. On one such occasion I was invited to visit the Hobby-Eberly Telescope on nearby Mount Fowlkes for a close-up look at the 91 hexagonal mirrors that make this 433-inch instrument so unique. It's rare to get an opportunity to see the scope up close and walk around on the observatory floor. Everything about the Hobby-Eberly is different. Unfortunately, one difference is that there's no eyepiece to look through!

At the end of my week on Mount Locke I'd managed to see every nook and cranny of the observatory's four major telescopes. The dark skies of the Davis Mountains were everything I'd imagined they'd be. The only thing left was to peer into the eyepiece of the 82-inch.

Sadly, this wasn't meant to be. Shortly after I finished my first week on the mountain, the university decided to close the entire facility to visitors and non-essential staff. The coronavirus ended my quest. I was disappointed, of course, but I was also extremely grateful that everything worked out as well as it did. As I said my goodbyes and prepared to leave, I realized that if my visit had been scheduled for just one week later, I probably wouldn't have gotten to see anything.

The night the university canceled the star parties turned out to be the best observing opportunity of my life. I can understand why the 36-inch is a favorite among the resident astronomers. It's a remarkable instrument — I can't wait to get behind the eyepiece again.

The observatory is quiet now, but the telescopes are still there, waiting. When the world returns to normal, I'll be back. There's so much more to see.

■ **JOHN SEALANDER** is a writer and photographer based in Dallas, Texas. After a 40-year career in the advertising industry, he now spends his time rescuing Dalmatians, visiting observatories, and attending rocket launches at the Kennedy Space Center.

JOHN SEALANDER (2)

3 DAWN: Look high in the south-southwest before the Sun rises to see the waning gibbous Moon about 6½° from Virgo's lucida, Spica.

6 DAWN: The waning crescent Moon climbs in the south-southeastern sky in tandem with the red supergiant Antares. About 4° separates the pair.

6 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:46 p.m. PST (see page 50).

9 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:35 p.m. EST.

18 DUSK: High in the southwest, the waxing crescent Moon and Mars hang about 3½° apart. Watch as they sink toward the west where they disappear from view around midnight.

19 DUSK: The first-quarter Moon is in Taurus, prettily placed between the Hyades and the Pleiades, while Mars lurks right of the tableau.

23 EVENING: Look to Gemini to see the waxing gibbous Moon around 4° from Pollux.

24 EVENING: The Moon, now in Cancer, is only a couple of degrees from the Beehive Cluster (M44).

25 DAWN: Make sure you're up before the Sun rises to catch the lovely sight of Jupiter, Mercury, and Saturn in a wide triangle rising in the east-southeast. You can enjoy this sight the next several mornings.

26 EVENING: The almost-full Moon rises in Leo, trailing the bright star Regulus by about 7°.

27 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:31 p.m. PST.
— DIANA HANNIKAINEN

▲ Messier 35 in Gemini is a large open cluster covering an area the size of the full Moon. If you point your binoculars at it, spend some time in the area and see what else you can espy — including neighboring cluster NGC 2158 at lower right. Go to page 43 for more tips. And on February 22nd the waxing gibbous Moon will occult the cluster for the West Coast (see page 50). RON BRECHER

FEBRUARY 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						

LAST QUARTER

February 4
17:37 UT

NEW MOON

February 11
19:06 UT

FIRST QUARTER

February 19
18:47 UT

FULL MOON

February 27
08:17 UT

DISTANCES

Perigee	February 3, 19^h UT
370,116 km	Diameter 32′ 17″
Apogee	February 18, 10^h UT
404,467 km	Diameter 29′ 32″

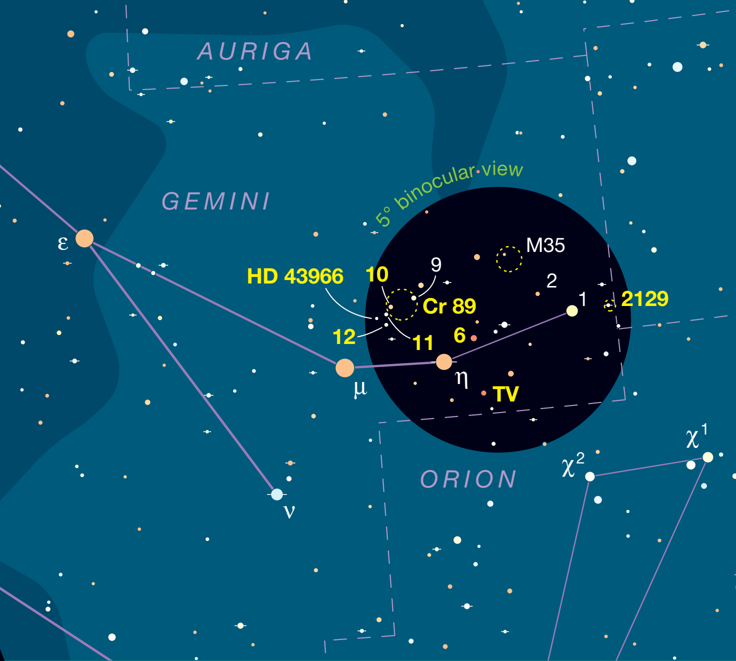
FAVORABLE LIBRATIONS

- Hausen (Crater) — February 1
- Le Gentil (Crater) — February 2
- Cabeus (Crater) — February 3
- Hayn (Crater) — February 15

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

In the Twins' Toes

You're probably familiar with Messier 35, at the western foot of Gemini, the Twins. But have you gotten to know the neighbors of that famous cluster? Start by picking out two chains of 6th-magnitude stars running west of Mu (μ) Geminorum. The more northerly chain runs over toward M35, and the southerly one runs across to 1 Geminorum. The two chains define an area a little more than 5° across that is positively packed with good stuff.

A smidgen west of 1 Geminorum you'll find a compact open cluster, **NGC 2129**. This cluster is compressed by its great distance — more than 7,000 light-years — to an apparent diameter of only 5′. But at 7th magnitude it should show up in moderately dark skies. The bright stars of the cluster make an H shape, but you'll probably need a telescope to see that level of detail.

If you'd like a big, easy cluster instead, try **Collinder 89**. It's at the eastern end of the northern star chain, between 9 and 12 Geminorum. In particular, look for a couple of oddly dark patches, seemingly empty of stars, on either side of the central band, and for the Y-shaped asterism formed by **HD 43966** and **10**, **11**, and **12 Geminorum**.

While you're in this area, check out the stars **6** and **TV Geminorum**. Both are deeply red supergiants, and they're true leviathans. Both stars are more than 600 times larger in diameter than our own Sun, which means if they were placed at the center of the solar system, each one would swallow Mercury, Venus, Earth, Mars, and a good chunk of the asteroid belt. That's a big thought to fire your imagination on a cool winter evening.

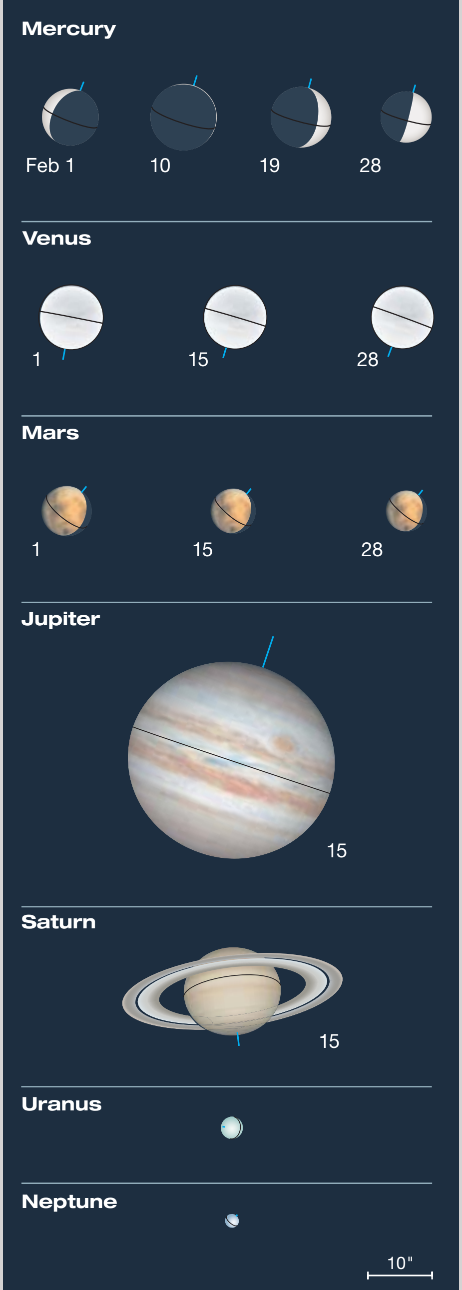
■ **MATT WEDEL** is checking out a lot of celestial real estate that is Messier-adjacent. Watch this space for more listings.

WHEN TO USE THE MAP

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

These are standard times.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is visible at dawn after the 19th • **Venus** is visible at dawn until the 7th • **Mars** transits at sunset and sets around midnight • **Jupiter** is visible at dawn after the 18th • **Saturn** is visible at dawn after the 20th.



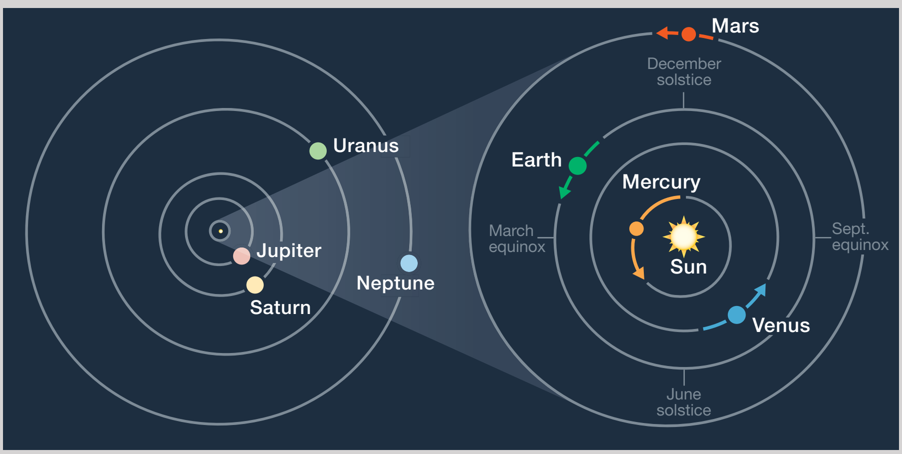
▲ **PLANET DISKS** have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

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

February Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	20^h 58.1^m	–17° 11′	—	–26.8	32′ 28″	—	0.985
	28	22^h 43.6^m	–8° 04′	—	–26.8	32′ 18″	—	0.991
Mercury	1	21^h 50.2^m	–10° 51′	14° Ev	+1.1	8.8″	18%	0.760
	10	21^h 17.3^m	–11° 54′	5° Mo	+4.8	10.4″	1%	0.648
	19	20^h 50.8^m	–14° 58′	19° Mo	+1.1	9.5″	22%	0.710
	28	21^h 01.6^m	–16° 12′	26° Mo	+0.2	8.0″	45%	0.843
Venus	1	20^h 05.0^m	–20° 58′	13° Mo	–3.9	10.1″	98%	1.652
	10	20^h 51.9^m	–18° 34′	11° Mo	–3.9	10.0″	98%	1.672
	19	21^h 37.2^m	–15° 26′	9° Mo	–3.9	9.9″	99%	1.689
	28	22^h 20.9^m	–11° 44′	7° Mo	–3.9	9.8″	99%	1.703
Mars	1	2^h 37.6^m	+16° 44′	90° Ev	+0.4	7.9″	89%	1.192
	15	3^h 08.4^m	+19° 03′	84° Ev	+0.7	7.0″	89%	1.329
	28	3^h 38.7^m	+20° 57′	78° Ev	+0.9	6.4″	90%	1.457
Jupiter	1	20^h 49.5^m	–18° 19′	2° Mo	–2.0	32.5″	100%	6.070
	28	21^h 14.9^m	–16° 34′	23° Mo	–2.0	33.0″	100%	5.972
Saturn	1	20^h 29.8^m	–19° 26′	7° Mo	+0.6	15.2″	100%	10.959
	28	20^h 42.5^m	–18° 41′	31° Mo	+0.7	15.4″	100%	10.811
Uranus	15	2^h 18.7^m	+13° 24′	71° Ev	+5.8	3.5″	100%	20.072
Neptune	15	23^h 22.9^m	–5° 09′	23° Ev	+8.0	2.2″	100%	30.831

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



Evenings with the Stars by Fred Schaaf

In Praise of Procyon

Alpha Canis Minoris is a serious underdog.

Procyon is the one bright star in Canis Minor, the Little Dog. It's often called the Lesser Dog Star because, at magnitude +0.4, it shines two full magnitudes fainter than the night sky's most brilliant star, Sirius, the Dog Star in Canis Major, the Big Dog.

Procyon suffers in almost every category of comparison with neighboring Sirius. But the Lesser Dog Star has many of its own merits, including its fascinating position both on star maps and in space.

Terrific tip of the tail. Procyon is the eighth brightest nighttime star and sixth brightest visible from latitude 40° north. It also utterly dominates its constellation, though that's not difficult considering Canis Minor has only two additional stars brighter than 5th magnitude within its borders. The Little Dog is usually pictured on star charts as a single short line connecting Procyon to Gomeisa (Beta Canis Minoris), which glows modestly at magnitude 2.9. The two-star line is more like a dog's tail than a whole dog. And since Canis Major and Canis Minor face west as they follow Orion, Procyon can be thought of as the brilliant tip of the Little Dog's tail.

Procyon's part in sky patterns. Procyon is accompanied by numerous bright stars as it climbs high in the sky on February evenings. Amazingly, this region contains nine of the 15 brightest stars visible from mid-northern latitudes. Much of Procyon's beauty is due to its placement within two large patterns of bright winter stars.

Check our star map (pages 42–43) to trace out the giant asterisms known as the Winter Hexagon and the Winter Triangle, both of which include Procyon. The Winter Hexagon is formed by connecting Aldebaran, Capella, Pollux (along with Castor sometimes), Procyon, Sirius, Rigel, and back to Aldebaran, with orange-gold Betelgeuse roughly in the middle of the Hexagon. The Winter Triangle comprises Sirius, Betelgeuse, and Procyon. This latter asterism is an almost perfect equilateral triangle. Procyon is 26° from Betelgeuse and 26° from Sirius, while Sirius is 27° from Betelgeuse. Remarkably, Procyon is a similar distance from two more bright stars — it's 27° from Castor and 23° from Pollux.

Most amazingly, Procyon is very nearly due east of Betelgeuse and due south of Pollux. Betelgeuse is 7.4° north of the celestial equator, but Procyon is 5.2° north of that key line — closer than any other 1st-magnitude or brighter star. In last month's column we noted that Capella is almost exactly due north of Rigel. Similarly, Procyon is positioned due south of Pollux and just a hair (1/10°) farther west.

Procyon's place in space. Both Dog Stars are among the nearest stars to Earth. Procyon's distance is 11.5 light-years, while Sirius is 8.6 light-years away. Another interesting aspect of the previously noted Procyon-Pollux connection is that Pollux is 33.8 light-years away — almost exactly three times farther than Procyon.

But what is especially interesting about Procyon's place in space is illustrated by considering the appearance of familiar stars as viewed from Procyon. For example, our Sun would be a 2.5-magnitude star in southern Aquila in the Procyonic sky. Nearby Sirius, situated 5.2 light-years from Procyon, would gleam at about magnitude –2.5, and Procyon's white dwarf companion would shine brighter than the full Moon! Remarkably, a red dwarf called Luyten's Star is only 1.2 light-years from Procyon yet wouldn't be bright enough to see with the naked eye. But, as seen from Luyten's Star, Procyon would dazzle at around magnitude –7!

AKIRA FUJII

▲ **HUNTER AND DOGS** Mighty Orion is trailed by his faithful companions, Canis Major and Canis Minor. The winter Milky Way flows between brilliant Sirius (lower left) and Procyon (upper left), and just north of golden-orange Betelgeuse.

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

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

Three Planets Emerge at Dawn

The morning sky features plenty of solar system activity late in the month.

SATURDAY, FEBRUARY 6

Early risers can see the 30%-illuminated, waning crescent **Moon** situated less than 4½° from 1st-magnitude Antares at dawn. Binoculars will enhance the star's orange hue and will make *earthshine* — sunlight reflecting off the Earth and illuminating the Moon's unlit portion — easier to see.

SUNDAY, FEBRUARY 7

It's time to say farewell to **Venus** for now. After this morning, it will be very difficult to glimpse the brilliant planet without optical aid. This brings to a close Venus' long reign as Morning Star, which began all the way back in June, 2020. The planet will return to the dusk sky in mid-April.

MONDAY, FEBRUARY 8

Today **Mercury** is in conjunction with the Sun. However, the fast-moving planet won't be absent for long — it reemerges as a naked-eye object at dawn, around February 20th.

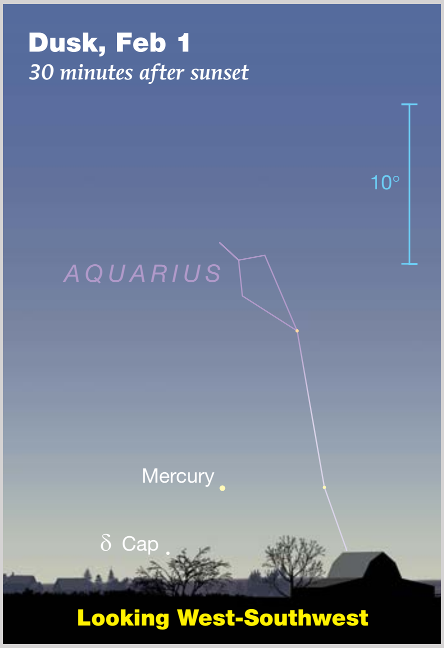
TUESDAY, FEBRUARY 9

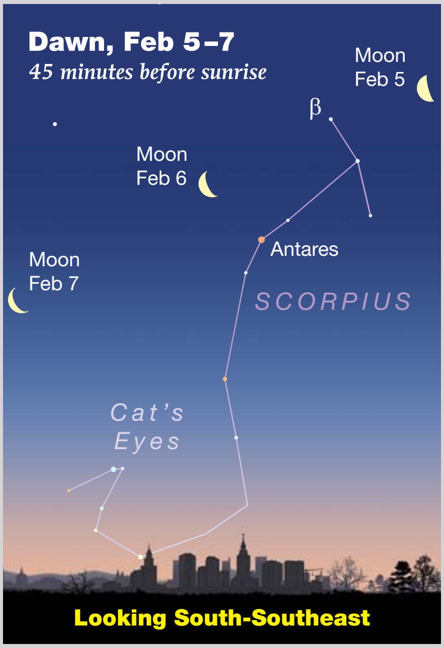
This evening, **Uranus** is positioned between 6.9-magnitude SAO 92882 and 7.8-magnitude SAO 92879 in southern Aries. The pale planet is 24′ from the former and 5′ from the latter. Uranus shines at magnitude 5.8, so there's almost exactly one full magnitude increments between the planet and each star. All three objects are within range of binoculars, though depending on the magnification, the faintest star might be too close to Uranus to be easily seen. (A detailed finder chart for Uranus appeared in the October issue, on page 51.)

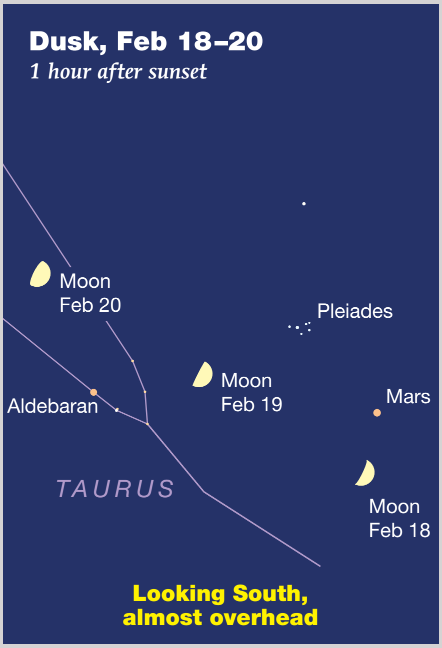
THURSDAY, FEBRUARY 18

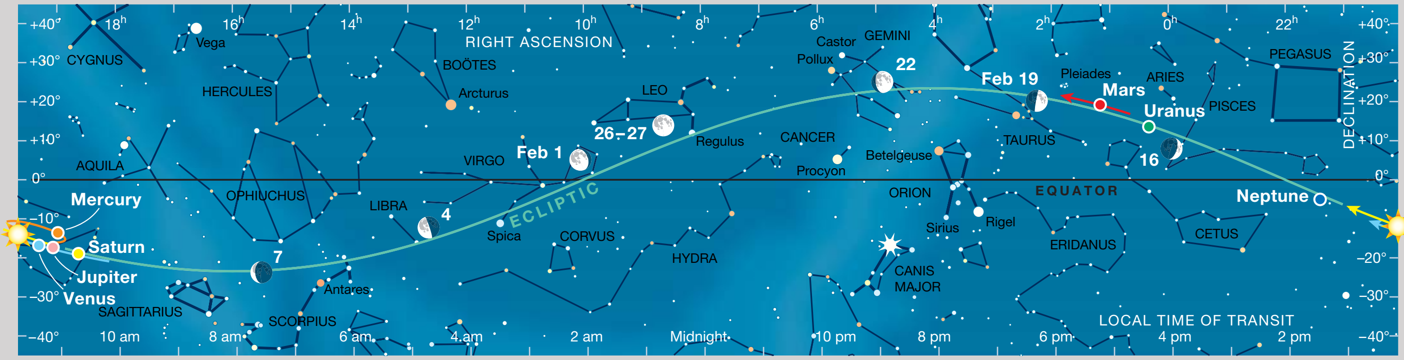
This evening finds **Mars** and a fat crescent **Moon** separated by slightly less than 3½°. (They're at their very closest at 9:49 p.m. EST.) The duo will be a fine naked-eye sight and close enough together to fit into the field of view of ordinary binoculars. The proximity of the neutral-toned Moon seems to enhance the Red Planet's distinctive ruddy hue. Although four months removed from its remarkable October

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









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

opposition, Mars still shines brightly at magnitude +0.8.

FRIDAY, FEBRUARY 19

Its eastward motion along the ecliptic positions the **Moon** between Aldebaran and Pleiades this evening. A 20°-wide swath of sky in Taurus includes Aldebaran, the Hyades, the Moon, the Pleiades, and **Mars**, presenting a very attractive naked-eye scene. Coincidentally, the Moon reached first-quarter phase earlier the same day.

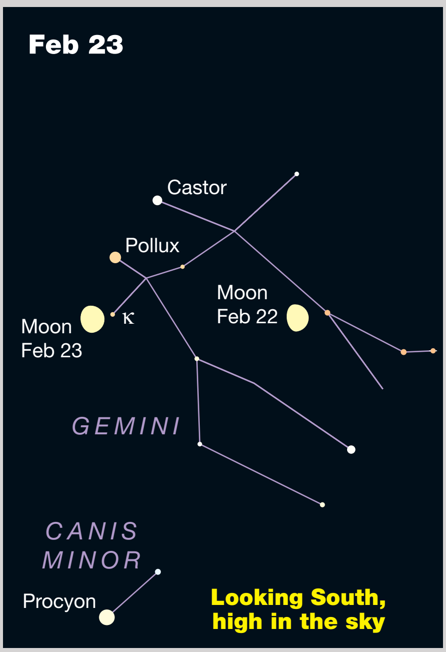
TUESDAY, FEBRUARY 23

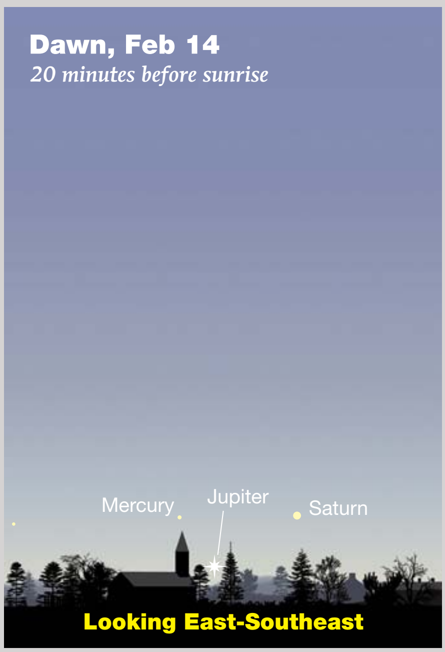
Look high overhead this evening for a fat gibbous **Moon** situated 4° south of 1st-magnitude Pollux in Gemini. Train your binoculars at the Moon and you might notice 3.6-magnitude Kappa (κ) Geminorum just north and west of the lunar disk. And if you're prepared to stay up late, you can also see the Moon form an evenly spaced, three-in-a-row configuration with Pollux and Castor. The 10°-long row is nearly perfectly aligned around 3 a.m. EST (February 24th).

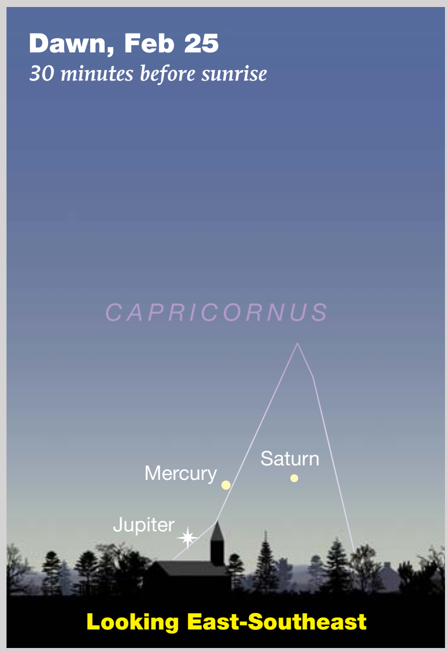
THURSDAY, FEBRUARY 25

Arguably, the most visually interesting planetary sight of the entire month occurs at dawn today when a trio of planets gather to form a tidy triangle, low in the east-southeast. **Jupiter**, **Saturn**, and **Mercury** have been gradually gaining elevation as they emerge from recent conjunctions with the Sun. On this date, Jupiter is brightest at magnitude –2.0, followed by Mercury at +0.3, and Saturn at +0.7. The trio of worlds remains tightly grouped for several days, though the triangle will begin to distort as Mercury sinks lower while Jupiter and Saturn climb higher. Appealing geometry aside, the end of February also signifies the start of new apparitions for both Jupiter and Saturn.

■ Consulting Editor **GARY SERONIK** has been watching the sky for five decades but still isn't a "morning person."







Australian imager Dylan O'Donnell created this remarkable photo of the International Space Station transiting the Moon on June 28, 2017. He used a C9.25 SCT and composited seven frames made with a Canon 70D DSLR camera set to ISO 1800 and a shutter speed of 1⁄1600 second.

Catch an ISS Transit

Being in the right place at (exactly) the right time pays exciting dividends.

The International Space Station is often one of the brightest objects in the night sky. Many of us enjoy its regular appearances during morning and evening twilight when it passes silently across the sky, ferrying its human cargo at more than 27,600 kilometers (17,100 miles) per hour. The space station makes evening passes during the first week of February, then returns to the dawn sky towards the end of the month. For current pass times tailored to your location, go to **heavens-above.com** or google up a free app such as *ISS Spotter* (iPhone) and *ISS Detector* (Android).

Much less frequently, the ISS transits across the face of the Moon or Sun. Such events are quite rare because the disks of the Moon and Sun are only ½° across. As a result, the track of visibility is a narrow one that requires the observer to be in precisely the right spot at the right time. Thanks to the website ISS Transit Finder (**transit-finder.com**), you can easily get a 30-day forecast of lunar and solar ISS transits visible in your area in just seconds.

Visit the site and set your precise latitude and longitude manually, or by clicking either "Auto-detect" or "Select from map." Next, set your preferred time interval using the calendar feature, choose how far you're willing to travel to get to the transit center line, then press "Calculate." A list of upcoming events pops up along with details including the space station's path (with near misses included), transit time, and distance to the center line, where the ISS will appear to transit directly across the center of the Moon or Sun.

If you don't see a transit listed for your location during the specified time frame, click the "Show on Map" button. The red pin gives your location, and the green pin indicates the closest site the center line crosses. Sometimes a transit is just a half-hour drive away.

During a typical transit, the silhouette of the ISS spans about one arcminute and takes around one second to cross the disk of the Sun or Moon. (Be sure to use a suitable solar filter when attempting to observe a solar transit.) Binoculars show the space station as a dark speck while a telescope magnifying 50× will clearly show its shape. If you're lucky, the ISS will pass in front of the crescent Moon, and you'll see it dramatically illuminated against the dim, earth-lit portion of the lunar disk.

To photograph an ISS transit, attach your camera to a telescope or long telephoto lens. Because these events are so brief, the trick is to shoot multiple images centered on the predicted transit time. You can either use your camera's burst mode, or record a video sequence. For an excellent tutorial on the subject, go to **is.gd/isstransitimage**.

R Virginis and Chi Cygni Top Out

A YEAR AGO, Betelgeuse kept us in a thrall as it faded to magnitude 1.8 — its faintest in recorded history. Observations made with the Hubble Space Telescope revealed that a large convection cell of super-hot stellar gas had welled up inside the bright Orion variable, and as the material ascended, it cooled and condensed to form a cloud of dust that partially dimmed our view of the star.

Variable stars can be full of surprises, which is one reason they're so fascinating to watch. On February 24th, Mira-type variable R Virginis reaches its maxima of around magnitude 6, making it an easy binocular target. R completes a full pulsation cycle every 145.6 days, so if you start watching then you'll see the star fade to around 12th magnitude later this spring before it returns to maximum again in late July.

In the morning sky, look for Chi (χ) Cygni — another bright Mira-type variable. The star is expected to reach maximum brightness (typically around magnitude 5) on March 4th, but you'll want to start watching earlier than that to see it brighten. Chi has been known to rise as bright as magnitude 3.3 and plummet to as faint as magnitude 14.2 over its 408-day cycle.

You'll find detailed maps and additional information for both stars at the website of the American Association of Variable Star Observers: **aavso.org**.

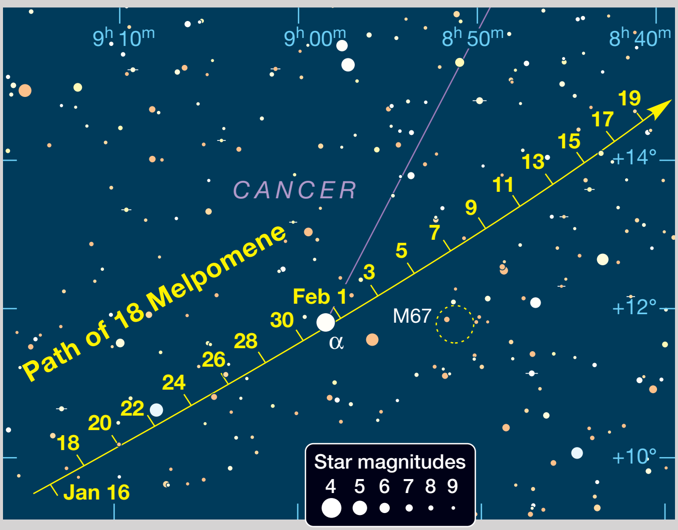
A Pair of Evening Asteroids

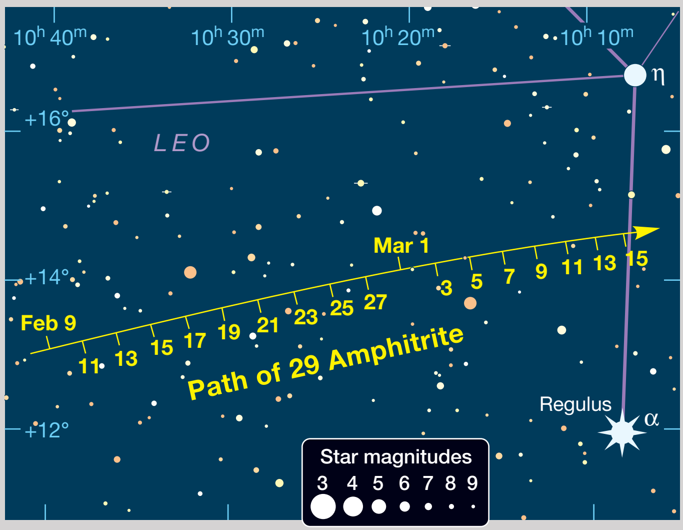
TWO LESSER-KNOWN bright asteroids reach opposition this month: 18 Melpomene (February 1st) and 29 Amphitrite (on February 21st).

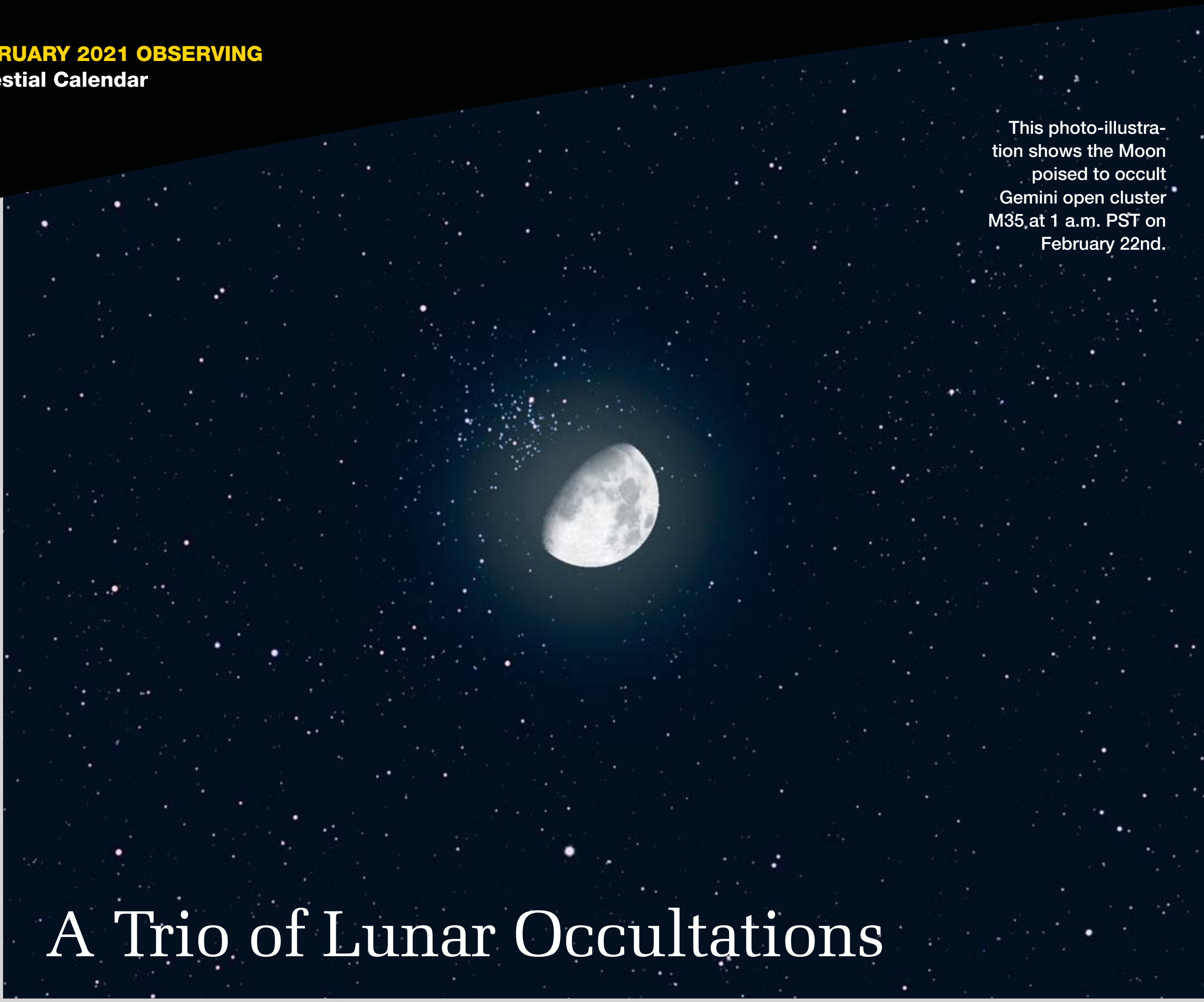
Melpomene shines at magnitude 9.4 in Cancer and will be in the same medium-power telescope field as Alpha (α) Cancri on and around opposition night. Amphitrite is a smidgeon brighter at magnitude 9.2 and located in central Leo. Both are easy catches in a small telescope. (The paths for both objects are depicted in the charts below.)

The two objects are members of the S-type or "stony" asteroids. Amphitrite is one of the largest of its kind, with a diameter of about 200 kilometers, while Melpomene is slightly smaller at 140 kilometers. Their light curves indicate that these space rocks have approximately spherical shapes.

In the early days of the solar system, Jupiter's powerful gravity stirred up the material orbiting between it and Mars, preventing millions of individual bodies from coalescing into a single, larger one. Had those pieces come together, we'd instead have one additional dwarf planet about 1.4 times the size of Ceres. A nod to Jupiter — I think we got the better deal!







This photo-illustration shows the Moon poised to occult Gemini open cluster M35 at 1 a.m. PST on February 22nd.

S&T ILLUSTRATION / M35 IMAGE: GARY SERONIK / MOON: STELLARIUM

A Trio of Lunar Occultations

DURING FEBRUARY, the Moon will cover 4.4-magnitude Omega (ω) Ophiuchi early on the morning of February 6th, Gemini open cluster M35 early on the 22nd, and 3.6-magnitude Kappa (κ) Geminorum on the evening of the 23rd.

The Omega Ophiuchi event will be visible in its entirety from the southeastern U.S. and most of Central America. Observers in the lower Midwest will miss the star's bright-limb disappearance but will be able to catch the best part: Omega's sparkling return from behind the dark lunar limb at around 9^h UT (3 a.m. CST), when the Moon is low in the southeastern sky.

The waxing gibbous Moon (74% illuminated) will make beautiful mischief early on the 22nd when it eclipses M35 for observers in the western half of the U.S. and Canada. The event starts at approximately 9^h UT (1 a.m. PST) when the Moon's unlit edge encroaches on the bright open cluster's western perimeter. Telescope users may witness multiple occultations over the next hour as the Moon creeps across the rich stellar swarm. The brightest cluster stars are around magnitude 7.5, but most are much fainter. The event wraps up around 10:20 UT.

On the next evening (the 23rd), observers in the southeastern U.S. and parts of Central America can watch the Moon hide Kappa Geminorum. Skywatchers from Dover, Delaware and southward along the U.S. coast will see the star disappear on the Moon's dark limb around 7:40 p.m. EST and reappear on the Moon's bright limb a few minutes to approximately an hour later. Since exact times for occultations vary depending upon location, check **https://is.gd/iotabstar** for details.

Minima of Algol

Jan.	UT	Feb.	UT
3	19:55	1	12:07
6	16:44	4	8:57
9	13:33	7	5:46
12	10:22	10	2:35
15	7:12	12	23:25
18	4:01	15	20:14
21	0:50	18	17:03
23	21:39	21	13:53
26	18:29	24	10:42
29	15:18	27	7:31

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**.

Action at Jupiter

JUPITER WAS IN CONJUNCTION with the Sun on January 29th, rendering it unobservable for the latter part of January and for much of February. (Both Jupiter tables and the Jupiter's Moons diagram presented here omit dates when the planet is out of view.) Jupiter returns to the dawn sky as a naked-eye object around February 19th, when it will shine at magnitude –1.9 and present a disk 33″ in diameter. Binocular users will likely be able to spot the planet earlier.

Any telescope shows 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 at right to identify them by their relative positions on any given date and time.

All the observable February interactions between Jupiter and its satellites and their shadows are tabulated in the table below right. Find events timed for dawn in your time zone when Jupiter is at its highest. For much of February, the events listed here will be difficult to view, owing to the planet's low altitude.

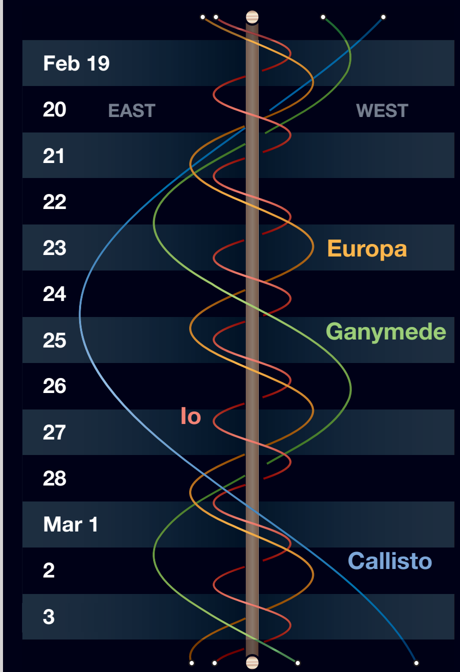
Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.)

January 1: 4:47, 14:43; **2**: 0:39, 10:34, 20:30; **3**: 6:26, 16:22; **4**: 2:18, 12:14, 22:09; **5**: 8:05, 18:01; **6**: 3:57, 13:53, 23:48; **7**: 9:44, 19:40; **8**: 5:36, 15:32; **9**: 1:28, 11:24, 21:19; **10**: 7:15, 17:11; **11**: 3:07, 13:03, 22:59; **12**: 8:55, 18:50; **13**: 4:46, 14:42; **14**: 0:38, 10:34, 20:30; **15**: 6:26, 16:21; **16**: 2:17, 12:13, 22:09

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

These times assume that the spot will be centered at System II longitude 353° on February 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 353° and 1²/₃ minutes later for each degree more than 353°.

Jupiter's Moons



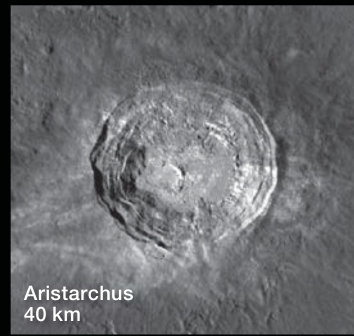
The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites'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

▲ Perseus approaches the zenith during evening hours in February. 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).

Phenomena of Jupiter's Moons, February 2021

Feb. 19	1:28	II.Sh.E
	2:13	II.Tr.E
	16:11	I.Ec.D
	18:52	I.Oc.R
Feb. 20	12:53	IV.Ec.D
	13:22	I.Sh.I
	13:45	I.Tr.I
	15:39	I.Sh.E
	16:03	I.Tr.E
	16:57	II.Ec.D
	20:37	II.Oc.R
	21:28	IV.Oc.R
Feb. 21	0:47	III.Ec.D
	6:04	III.Oc.R
	10:39	I.Ec.D
	13:23	I.Oc.R
Feb. 22	7:50	I.Sh.I
	8:16	I.Tr.I
	10:08	I.Sh.E
	10:33	I.Tr.E
	11:52	II.Sh.I
	12:44	II.Tr.I
	14:47	II.Sh.E
	15:39	II.Tr.E
Feb. 23	5:08	I.Ec.D
	7:53	I.Oc.R
Feb. 24	2:19	I.Sh.I
	2:46	I.Tr.I
	4:36	I.Sh.E
	5:03	I.Tr.E
	6:14	II.Ec.D
	10:02	II.Oc.R
	14:41	III.Sh.I
	16:34	III.Tr.I
	18:19	III.Sh.E
	20:13	III.Tr.E
	23:36	I.Ec.D
Feb. 25	2:24	I.Oc.R
	20:47	I.Sh.I
	21:16	I.Tr.I
	23:05	I.Sh.E
	23:34	I.Tr.E
Feb. 26	1:10	II.Sh.I
	2:10	II.Tr.I
	4:05	II.Sh.E
	5:05	II.Tr.E
	18:05	I.Ec.D
	20:54	I.Oc.R
Feb. 27	15:16	I.Sh.I
	15:46	I.Tr.I
	17:33	I.Sh.E
	18:04	I.Tr.E
	19:32	II.Ec.D
	23:26	II.Oc.R
Feb. 28	4:47	III.Ec.D
	10:33	III.Oc.R
	12:34	I.Ec.D
	15:25	I.Oc.R
	20:26	IV.Sh.I

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.



A Lunar Main Sequence

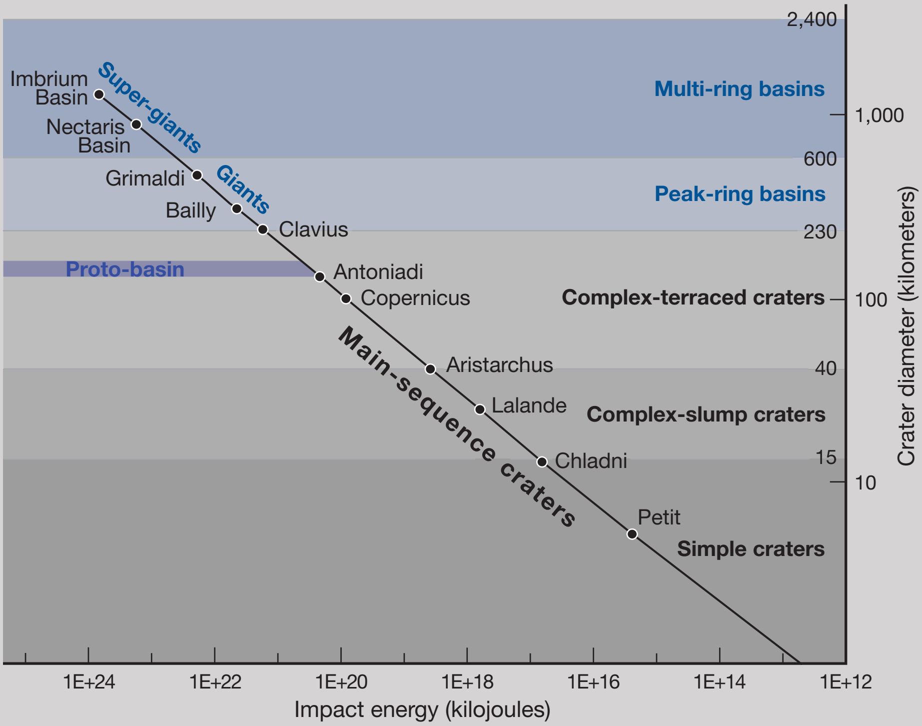
Understanding lunar crater formation based on appearances.

In astronomy, the main sequence is the continuous band of stars spanning the Hertzsprung-Russell diagram, which plots stellar color and intrinsic brightness. When a large main-sequence star runs out of hydrogen fuel, it becomes cooler, redder, and radically expands in size as it moves off of the main sequence.

Unlike stars, impact craters do not dynamically evolve. But, based on size and morphology, they often have parallels to the distribution of stars on the H-R diagram. For example, one can consider the main sequence of impact craters as the systematic morphological difference from small conical pits such as the 13-km-diameter (8-mile) crater **Chladni**, to mid-sized craters with partial wall collapses as seen in 24-km **Lalande**, and on to large craters with terraced walls and central peaks, like 96-km **Copernicus**. Crater diameters increase and morphology changes as the size and/or velocity of the impactors increase, delivering more energy for fracturing, melting, excavation, and ejecting lunar crustal rocks.

Crater-wall morphology stems from how the impacted target rocks deform as the initially excavated hole — the *transient cavity* — becomes deeper and wider. For small transient cavities, the impacted rocks are strong enough to withstand collapse into the resulting depression, and a simple, conical crater forms. With medium-sized transient cavities, sections of the surrounding walls collapse, creating complex-slump craters. And for large cavities, the entire surrounding wall slides into the hole, creating complex-terraced craters. Rim collapses significantly increase the crater's overall diameter. Central peak sizes also change across the main sequence. Simple craters don't have central peaks at all because the pressure of the impact didn't compress the subsurface rocks sufficiently to cause a rebound. As the impact energy increases, the compressed target rocks rebound, transporting deeper rocks to the surface to form a central peak.

Inspired by the H-R diagram, I've created a graph that tracks diameter and morphology differences arising from increasing impact energy. The horizontal axis represents the kinetic energy produced by the impacting body, and the vertical axis plots the resulting crater diameter. I've also included approximate transitional stages, from Simple to Complex-slump craters at around 15-km



◀ The main sequence of lunar impact features showing the relationship between morphology and the energy required to create each

ALL PHOTOS: NASA / GSFC / ARIZONA STATE UNIVERSITY; GRAPH: LEAH TISCIONE / S&T

◀ Crater morphology is highly dependent on the mass and velocity of the impacting object, as seen in this comparison among several progressively smaller lunar depressions.

diameter, and on to Complex-terraced craters at about 40-km diameter.

With a diameter of 231 km, **Clavius** is the largest lunar crater, but the graph also plots the much larger lunar basins. These features are formed by projectiles that are more massive or moving at higher velocity than those that formed craters. The additional impact energy strongly transformed the resulting formations, making them the largest features on the Moon — 10 to 20 times larger than complex craters.

Morphologically, basins are as different from craters as giant and supergiant stars are from their stellar main-sequence counterparts. The energy that formed lunar basins caused more intense deformation of the target rocks than what occurred in the creation of main-sequence craters. The transient cavities of basins were deeper and wider, and the surrounding terrain slid down deeper and across a greater distance, creating multiple mega-terrace rims, like **Rupes Altai** and **Montes Apenninus**. These large basins have three or more rings and are called *multi-ring basins*. Some of their outer rims are low and hard to trace, and their inner rings appear as mostly concentric mare ridges. All circular maria on the lunar nearside reside within multi-ring basins.

Smaller basins have only two rings — typically a distinctive outer rim and a smaller, inner ring. The relatively young, 326-km-wide farside depression **Schrödinger** is the best example of a *two-ring* or *peak-ring* basin. Of the Moon's 17 peak-ring basins, only three are visible from Earth — **Bailly**, **Schiller-Zucchius**, and **Grimaldi** — and all have indistinct inner rings.

A few small depressions called *proto-basins* are caught in a transitional state with a crater-like central peak as well as an inner ring of small hills, like those found on larger peak-ring basins. The farside features **Antoniadi** (127 km) and **Compton** (162 km) are the Moon's only examples. They're well within the diameter range of complex-terraced craters, but for unknown reasons have features associated both with craters and peak-ring basins. Compton's floor is flooded with dark lava, as is the circular patch within Antoniadi's peak ring.

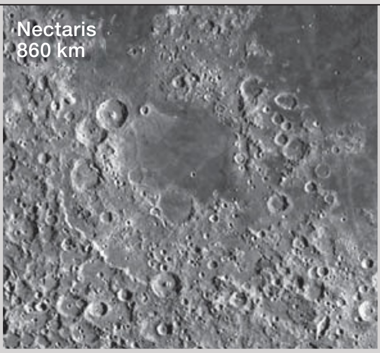
Theoretical models and observations suggest that the interior structure differences seen in complex craters, peak-ring basins, and multi-ring basins are strongly influenced by the depth and volume of the melt created below the basin floor during an impact event. Both melt size and depth increase as the energy produced by the impact rises. As the melt zone grows, it influences the deformation of the target rocks, preventing central peaks from forming. Instead, the rebounding material expands into an inner ring. Impacts of even greater energy produce even deeper basins with more expansive melt zones. As the main rim collapses and slides inward, it rips interior floor material into multiple, low-angle ring faults. The inward collapse of the rim wall releases pressure on the surrounding crustal rocks, which break into one or more external, concentric faults, creating the multi-rings we see in the largest basins. This theory is complex, but it explains many crater-to-basin transitional features.

As you look at any lunar depression you should be able to place it in one of the five classifications I've described. Note the morphology as you observe complex craters of the main sequence and then inspect two-ring basins (lunar "giants") and then the much broader and shallower multi-ring basins (lunar "supergiants").

Unlike stars on the main sequence, craters and basins work in reverse, exploding into existence and then weathering away over billions of years, challenging the understanding of observers and theorists alike.

■ Contributing Editor **CHUCK WOOD** has studied the Moon for more than 50 years.

▶ Multi-ring basins, such as Orientale (left), Nectaris (middle), and Schiller-Zucchius (right), are analogous to the supergiant stars on the H-R diagram, though explosive events marked their creation rather than their demise.



So You Want To Take an Astrophoto . . .

Let us help you enter the world of astrophotography.

You can record a lot in the night sky with a DSLR camera and a decent wide-angle lens. This image of the southern Milky Way was recorded in Chile in a 20-second exposure at ISO 1600 with a modified Canon T3i DSLR camera and a 14mm f/2.8 lens.

Just admit it. Being socially distanced for the majority of 2020 led you to think of new ways to entertain yourself. The brief appearance of bright Comet NEOWISE last summer certainly made a lot of people look up and think, "Wow! How can I take a picture of that?" Since you're reading *Sky & Telescope*, you're probably aware that recording great photos of astronomical events is easier than ever. Chances are you don't even need to buy any new equipment to get started. But you may need a little guidance with some of the things advanced imagers often take for granted. And that's what this new bimonthly column is all about.

So what exactly is astrophotography? Sure, it's taking pictures of subjects in the sky above — and not just at night — but a closer look reveals that astrophotography is a multifaceted niche of amateur astronomy that encompasses many different targets and techniques. For example, you'd use a radically different setup to record a detailed, high-resolution image of Jupiter than, say, to photograph the Milky Way arching over a distant mountain range. So, here's a quick overview of the range of subjects, equipment, and approaches that fall under the general heading of "astrophotography."

Starting Wide

A great way to get started is by taking photos of a twilight conjunction with just a basic camera and tripod. You can even use your smartphone.

Ever since cellphones began including tiny cameras, amateurs have been using them to take photos of the Moon and brightest planets by aiming the camera at their telescope eyepiece.

ALL PHOTOS BY AUTHOR UNLESS OTHERWISE NOTED

The resulting images were alright at a casual glance but didn't stand up to close scrutiny. Thankfully, times have changed, and the latest phones have cameras that can record a truly decent picture of stars over a pretty landscape, and much more.

The addition of a few simple accessories will ensure you come away with a good shot on your very first attempt. A tripod and clamp to hold your smartphone steady, and a remote shutter button, make a world of difference. With these accessories, modern smartphones can do all sorts of basic astrophotography, including capturing constellations, the Milky Way, aurorae, meteor showers, and even bright comets.

While your phone is convenient, it does have significant limitations. A modern DSLR or "mirrorless" camera fitted with a good, wide-angle lens opens up additional possibilities. Such a combination can do everything mentioned so far — and do it better. For one thing, you're not limited to short exposures, so you can take images many minutes long. This allows you to record the paths of stars across the sky, creating *star-trail photographs*. You can even choose cameras designed with astrophotography in mind. Both Nikon and Canon offer models with extended spectral sensitivity, which are well-suited to recording the faint nebulosity that permeates the Milky Way and other galaxies.

▲ Smartphone cameras have come a long way. This 10-second shot of Comet NEOWISE (C/2020 F3) was recorded with a Samsung Galaxy 9 mounted on a tripod from the author's home in Litchfield, New Hampshire, on the evening of July 21st, 2020.

Getting Closer

Astrophotography is also about taking close-ups of nebulae, star clusters, galaxies, or bright comets. Adding a tracking mount to your setup dramatically increases the number of subjects you can record and facilitates the use of telephoto lenses (and even small refractor telescopes) for greater detail. The better the mount you have, the larger the lens or telescope you can use.

Close-up shots of the Moon and bright planets require a telescope (preferably on a solid tracking mount) for a specialty called *planetary photography*. Snapshots of lunar craters made with a smartphone or DSLR are fine, but if solar system closeups are your goal, a dedicated planetary camera is certainly a worthwhile purchase. The good news is that they often cost less than a premium eyepiece.

These compact planetary cameras connect to a computer and are used to record video sequences of the Sun (through a safely filtered telescope), Moon, and planets. The technique is to capture a video sequence, which increases the chances that some of the individual frames will coincide with moments when Earth's atmosphere settles down enough to reveal intricate details in your target. The video clips are run through computer software that sorts and combines the sharpest frames to get a superior image than what is possible with a single shot. While the process may sound complicated, in practice it's not terribly difficult.

Going Deep

When you think of astrophotography, chances are you have dramatic shots

▲ *Left:* Adding a tracking mount allows longer exposures than what is possible with a simple camera-on-tripod setup. This image of Comet NEOWISE was taken at the same time as the photo at the top of the page, using a Nikon D3300 DSLR camera and a 50-mm f/1.8 lens. A total of 80 one-minute exposures were stacked together to achieve the result presented here. *Right:* Detailed close-ups of the Moon and planets require a telescope on a sturdy tracking mount. The author recorded this view of the lunar crater Clavius with a specialized planetary camera and 12½-inch reflector.

▲ Producing colorful images, like this example of IC 348 and the surrounding nebulosity in Perseus, requires patience and a mastery of your equipment. This image was captured remotely using a Takahashi FSQ-106ED refractor and an FLI ML16803 CCD camera. The exposure totals 16 hours shot through RGB and hydrogen-alpha filters.

of nebulae and galaxies in mind. This is the niche known as *deep-sky imaging*. Typically, a camera — be it a DSLR or even an imaging device designed specifically for long-exposure images — is attached to a telescope in place of an eyepiece. Photographing faint nebulosity or distant galaxies usually requires acquiring sets of long-exposure frames that are later added together in a computer using specialized software. The results can be stunning, revealing color and detail that's simply impossible to match visually even with a big scope. Deep-sky imaging is perhaps the most challenging astrophotography of all as it requires precision tracking for hours on end, which can tax the capabilities of most mounts. But when you get everything working together, the resulting images can rival (and even surpass) the quality achieved by professional astronomers.

But what if your sky conditions aren't great? Thankfully, some types of astrophotography are still perfectly doable. For example, planetary imaging is essentially impervious to light pollution — the Moon and major planets are all bright enough to outshine the background sky. You can even pursue deep-sky imaging by employing light-pollution filters, or specialized narrow-band filters. These pass only the specific wavelengths of light emitted by nebulae and block the majority of light from artificial light sources.

◀ Imaging the planets doesn't require dark, country skies. The author captured this detailed image of Jupiter from Manchester, New Hampshire, with the same telescope and camera used for the image of Clavius on page 55.

Back Indoors

At a certain point you'll likely need to get acquainted with image-processing software and techniques. That's because there's no good "autoexposure" setting for night photography. To get the most out of your images, you have to learn how to perform post-processing. Understanding the basics of color balance and what a histogram shows helps inform your decisions as you convert raw image data into a presentable astro-portrait. Indeed, many experienced astrophotographers spend more time working on their images indoors than they did acquiring the photos in the first place.

I've briefly touched on the main types of astronomical photography here, but each one has numerous subsets and different approaches to explore. For example, you might develop an interest in scientific astrophotography (like photometry and spectroscopy), or perhaps in time you'll join the growing number of astrophotographers who use remote imaging setups controlled over the internet. With some of these you might never see (let alone touch) the telescopes and cameras used to acquire your images!

Each category of astronomical imaging comes with its own set of challenges to surmount. Our goal here is to focus on those challenges and help you gain a better understanding of your gear and its capabilities. We'll still feature in-depth articles on advanced imaging techniques elsewhere in the magazine, but our aim is to use this space to take some of the steepness out the learning curve and put you on track to getting great images of celestial targets.

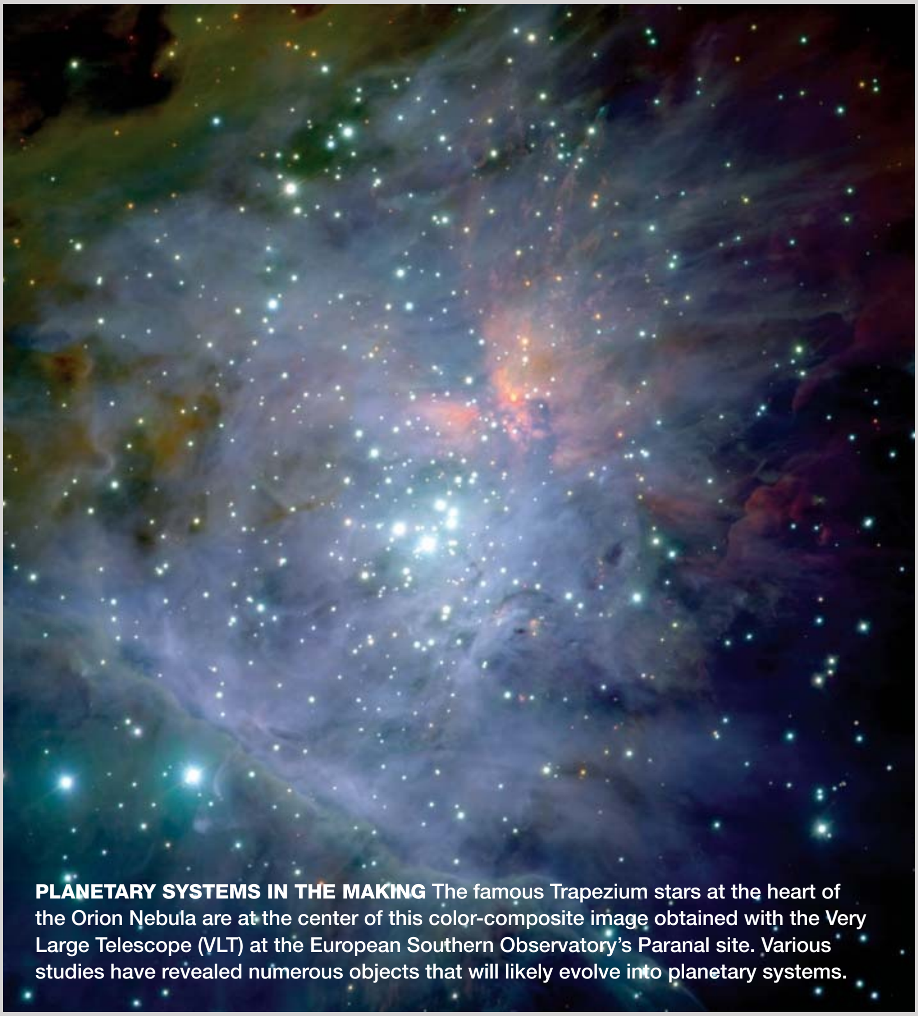
If you have suggestions for topics you'd like to see covered in this column, please send a note to **editors@skyandtelescope.org**.

■ *Sky & Telescope* Associate Editor **SEAN WALKER** continues to dabble in every facet of astrophotography from his home in southern New Hampshire.

NEBULAE: SEAN WALKER / MDW SKY SURVEY

The Newborn Nursery of Orion

Up for a challenge? Point your telescope toward M42 to spot newly born planetary systems.



PLANETARY SYSTEMS IN THE MAKING The famous Trapezium stars at the heart of the Orion Nebula are at the center of this color-composite image obtained with the Very Large Telescope (VLT) at the European Southern Observatory's Paranal site. Various studies have revealed numerous objects that will likely evolve into planetary systems.

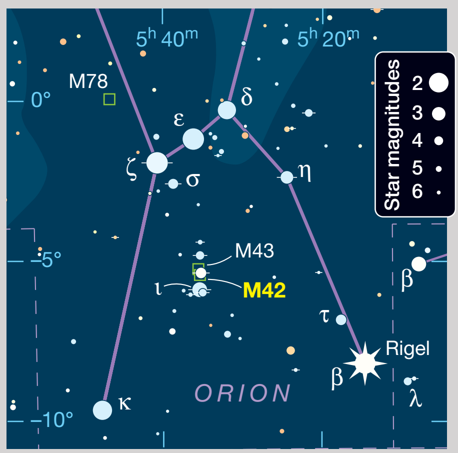
ESO / M. MCCAUGHREAN

When we look up into the night sky each star has its own story, each is at a different stage in its life. If we are very fortunate, as with Supernova 1987A, we may find ourselves in the right time and place to witness a massive star announce the end of its life with great fanfare. The last supernova visible to the unaided eye in our own galaxy was in AD 1604. These events, albeit rare, require little effort on the part of the observer. Indeed, some are hard to miss, such as the AD 1054 supernova that resulted in the Crab Nebula — that stellar explosion was visible in daylight for weeks after the event. Conversely, observing stars at the beginning of their lives takes great effort, as they're born shrouded by gas and dust that obscure our view. Powerful winds from massive nearby stars can blow away some of the nebulosity surrounding newborn stars, allowing us to peer at this otherwise hidden process. These newborn stars might be sculpting and illuminating nascent planetary systems. The heart of the Orion Nebula (M42) harbors such a site of celestial fecundity in the form of *proplyds* (from "ionized protoplanetary disks"). At a distance of around 1,300 light-years, the Orion Nebula is the closest large stellar birthplace in the night sky. And some of these proplyds are within the reach of amateur telescopes.

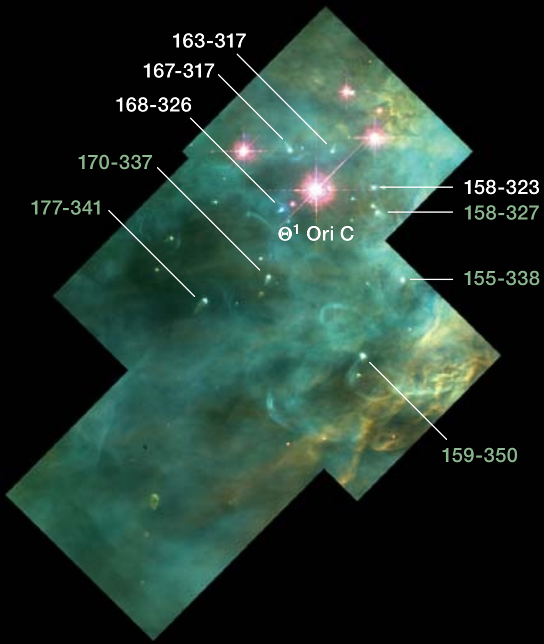
What Are Proplyds?

In 1979, French astronomers Pierre Laque and Jean-Louis Vidal discovered emission line objects they described as "compact photoionized knots" near the center of the Orion Nebula. Several years later, radio emissions were observed from these objects, prompting speculation that they might be stars in the process of being born. Hubble Space Telescope (HST) observations in 1993 confirmed this scenario, and these knots were recognized as a distinct, new class of object.

Specifically, the term proplyd refers to highly irradiated protoplanetary disks surrounding newly born stars. They exist within (or near) an H II region and are ionized courtesy of nearby hot, young



▲ **NURSERY IN ORION** M42 is easy to locate in the Sword of the mighty Hunter, Orion. However, you'll need a big telescope to spot the embedded newly born planetary systems known as proplyds.



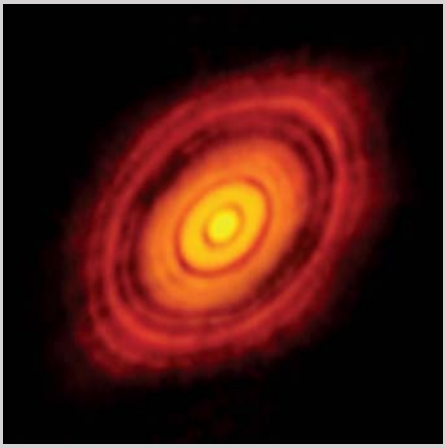
IDENTIFYING PROPLYDS The term "proplyd" is specifically used to describe the highly irradiated protoplanetary disks that have cometlike tails, such as those found in the Orion Nebula. In one of his discovery papers, C. R. O'Dell termed them "flattened circumstellar clouds of dust and gas surrounding stars collapsing toward the main sequence." The author referred to this image taken in Hα to cross-correlate with a visible-light image, similar to the one at right, in order to locate proplyds in his telescope.

stars. Seen edge-on against the background of an H II region, their dark silhouettes suggest planets forming around a nascent sun — particularly those disks with a star peeking over the top or face-on with the star in the middle.

Hubble images of the heart of the Orion Nebula (such as the one above) show objects several hundred astronomical units across — disks containing about five times the mass of Jupiter. Many appear to have protruding "tails" pointed away from the central object, like a swarm of comets converging on the star. They're distinct from the classic star-forming Herbig-Haro objects, as they lack bipolar jets.

The largest and brightest star in the Trapezium is Theta[1] (θ) Orionis C, a binary comprising *O* and *B* main sequence stars, and a third fainter and smaller companion. At magnitude 5.1 it's one of the most energetic stars visible to the naked eye, producing 200,000 times the energy of our Sun. Theta[1] Orionis C and its Trapezium companions light up the nebula's nearside. Proplyds close to this massive star have tails pointing away from it. The star's powerful wind ablates and sweeps away the proplyds' outer layers, a process that likely dissipates some of their available planet-forming material. Protoplanetary disks farther away aren't ionized (and hence aren't classified as proplyds) and appear as dark objects against the bright background of the surrounding H II region. In total, the HST detected nearly 180 proplyds among the 3,000 or so stars of M42.

The high-resolution imaging of proplyds by the HST was one of the motivating factors for constructing the Atacama Large Millimeter/submillimeter Array (ALMA). ALMA, as its name suggests, is an array of movable telescopes located in the northern Chilean desert at an altitude of 5,000 meters (16,000 feet). The telescopes' detectors are sensitive to submillimeter wavelengths with a resolution 10 times better than HST (around 5 milliarcseconds). This sensitivity provides the ALMA telescopes with a clearer view through the gas and dust that enshroud these objects. In 2014, a team using the ALMA array detected 21 of the 22 proplyds that the HST had previously identified at visible wavelengths. Of those 21 objects, concentric "rings" — disks that are likely precursors to planetary formation, as in the case of HL Tauri — were identified in eight of them for the first time.



▶ **PLANETARY GENESIS** ALMA's telescopes pointed toward HL Tauri, a Sun-like star some 450 light-years from Earth, and acquired this image. It was the first ever to show a protoplanetary disk in such exquisite detail. The bright, concentric rings and gaps in the disk are most likely the signatures of planets in the making.

The Scarcity of Proplyds

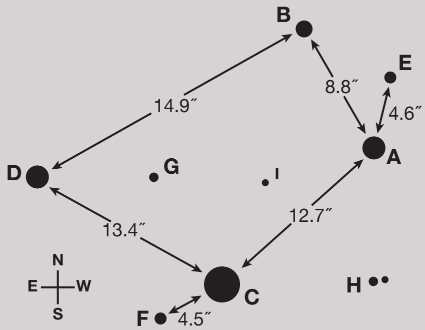
Proplyds are rare to find and difficult to see, and there are several reasons for this. To become an observable proplyd, newly formed stars and their circumstellar disks must survive the strong winds and powerful ultraviolet radiation from the nearby massive, energetic stars. These processes, responsible for blowing away the enshrouding clouds and dust, are extremely destructive. A program in 2006 to search for proplyds in other emission nebulae identified some in M17, M8, M16, M20, and NGC 2467. But these nebulae generally contained only one or at most a few proplyds.

Distance from the ionizing star is crucial for planet survivability. Studies show that the strong stellar wind of Theta[1] Orionis C inhibits planet formation in systems closer than about one-tenth of a light-year. Systems farther out are largely unaffected and retained greater amounts of gas and dust within their disks (up to 80 Jupiter masses) — and hence are more conducive to planetary formation.

Take the Challenge

The Orion proplyds are small and difficult targets for the amateur observer, but some of them *can* be seen. Though brightened by ionization, they appear

PROPLYDS: C. R. O'DELL; HL TAU: ALMA / ESO / NAOJ / NRAO



stellar and compete with the glow of the H II cloud in the background. Astronomer C. R. O'Dell of Rice University published HST Hα data of the Orion Nebula in the January 1998 issue of the *Astronomical Journal* reproduced at left. For my search I compared O'Dell's data with an image in visible light, such as the VLT image above. The four main stars of the Trapezium (A, B, C, and D) are the brightest, ranging from magnitude 5.1 to 8.0, and are readily visible in a small telescope. They are followed by two much fainter companions. Star E is a distinctly reddish-brown, magnitude-11.1 speck. Even though F is a full magnitude brighter than E, it's challenging to spot due to its proximity (a mere 4.5″ away; the diagram above shows relative positions) to C. Three other faint stars are associated with this system: G at magnitude 13.7, H at 15.8, and I at 16.3.

In O'Dell's figure the proplyd **168-326** is 1.5″ east-southeast of a "regular" star, that is, one with no signs of an ionization source and no tail. At first glance the proplyd appears in the position of the Trapezium star F. However, careful inspection shows this isn't the case: Star F is actually the one of the pair closer to C. Though fainter in Hα, star F is much brighter in visible light — but there's no sign of that proplyd in the visible-light image.

Considering these confounding factors, I correlated the two images (in Hα and visible light) and devised an observing plan. At the 2016 Okie-Tex Star Party I observed the area with my 32-inch reflector. In the early hours of the morning of September 26th, using a 5-mm eyepiece yielding magnification 650×, in poor seeing of only 3 (on the Pickering scale) I detected star H and suspected G. Three mornings later, in much better conditions (the seeing was 9/10) with the same equipment and setup, I clearly saw the G, H, and I components of the Trapezium. The respective proplyd designations are **167-317**, **158-323**, and **163-317**. At the Okie-Tex event a year later in 2017, I observed the proplyd **106-417** located about 2.2′ southeast of the Trapezium. It's 34″ northeast of the 6.4-magnitude star Theta^2 Orionis. These objects all appeared stellar, with no asymmetric flaring or tails. Since then, I've detected G and H from my home in Minnesota in fair to poor conditions with the same setup.

▲ **SILHOUETTE**
A proplyd in the Orion Nebula presents an edge-on disk with the central star peeking over the edge.

In comparing the visibility of other proplyds in the Trapezium area I expect several would be within the reach of large-aperture amateur scopes under excellent conditions, particularly 158-327, 155-338, 170-337, 177-341, and 159-350. If you're looking for a challenge in the heart of the northern sky's winter jewel, give this emerging class of objects a try.

■ **DAVE TOSTESON** says the best part of his job as a family physician was delivering more than 2,000 babies and that seeing newborns in the sky is almost as fun.

FURTHER READING: If you're interested in learning more about early Hubble Space Telescope observations of proplyds in the Orion Nebula, see journal papers by C. R. O'Dell. The first was published in 1994 in *The Astrophysical Journal* and was co-authored with Zheng Wen (volume 436, page 194). The second (from which the image on page 58 is taken) is in volume 115 of *The Astronomical Journal* published in 1998 (page 263). See also *S&T:* Dec. 1994, p. 20.

TRAPEZIUM: ESO / M. MCCAUGHREAN; DIAGRAM: GREGG DINDERMAN / S&T; M16: NASA / ESA / HUBBLE / HUBBLE HERITAGE TEAM; ORION PROPLYD: J. BALLY (UNIVERSITY OF COLORADO) / H. THROOP (SWRI)

Other Observations

No other *family* of proplyds has yet been identified outside M42. The best-known correlate might be M16, the Eagle Nebula in Serpens, first observed in detail with the Hubble Space Telescope in 1995. In what some have voted to be Hubble's most beautiful and iconic image, the "Pillars of Star Formation" host stars at the end of thin stalks, protostars whose birthplace has been whittled away. At the Texas Star Party in 1999 I used my 25-inch reflector to observe two of these Evaporating Gaseous Globules, or EGGs.

The Rosette Nebula is an example of a region of ionized hydrogen that has been carved out by strong stellar winds, similar to the environs of Theta^1 C Orionis. In the Rosette Nebula, the star's circumstellar disk was dissipated in only 1,000 years by the powerful radiation of two nearby *O*-type stars. With a 15-inch reflector, I easily detected the "naked" protostar Rosette HH1, with its jet and central, 14th-magnitude star, from my backyard in January 2007.

Double Bubb

Astronomers may be closing in on the culprit behind the structure that sprouts from our galaxy's center.

One of the largest structures in our galaxy is invisible to the human eye. This structure is a dumbbell of dazzling proportions — two humongous bubbles, each roughly 30,000 light-years tall, that balloon out of the Milky Way's core and loom above and below the spiral disk.

The Fermi bubbles have puzzled astronomers since observers found hints of them in the early 2000s. Long controversial, their existence is now a certainty, but their origin is not (*S&T:* Apr. 2014, p. 26). Did the Milky Way's central black hole throw a raging fit? Or did the explosive deaths of a passel of stars together blast out their surroundings? The community split on this question.

Looking at other galaxies for context hasn't helped much. Astronomers see signs of nuclear outflows in many of them, powered either by black holes or starbursts (or with fingerprints of both). Hints of a dumbbell in our closest big neighbor, Andromeda, have been called into question — we're just too far away to make out what's there. To solve the Fermi bubbles' origin mystery, we must stay near the Milky Way.

And in the last several years, astronomers have come closer to an answer. They've changed our view of the bubbles from 2D to 3D, essentially turning what was a flat photo into a moving picture of an expanding exhaust carrying clouds out of the galactic center. Many of these observations indicate that whatever happened, it happened a few million years ago — the same time frame needed to peg the black hole as the culprit. Although astronomers still don't agree that the black hole is the answer, some say that it's becoming harder to argue for anything else.

"I wouldn't say it's 100%," says Andrew Fox (Space Telescope Science Institute), who's worked on several of the recent studies. "But just looking at the different observations and seeing that they all paint this consistent picture, to me that's quite convincing."

Blowin' in the Wind

The Fermi bubbles begin about 300 light-years above the galactic disk. We can "see" them in radio waves, microwaves, X-rays, and gamma rays. The X-rays show us bright edges and a dim interior, indicating the bubbles are less dense than their surroundings. In radio, we detect signs of orderly magnetic fields. In microwaves, the structures look like a barely-there haze that fades with height.

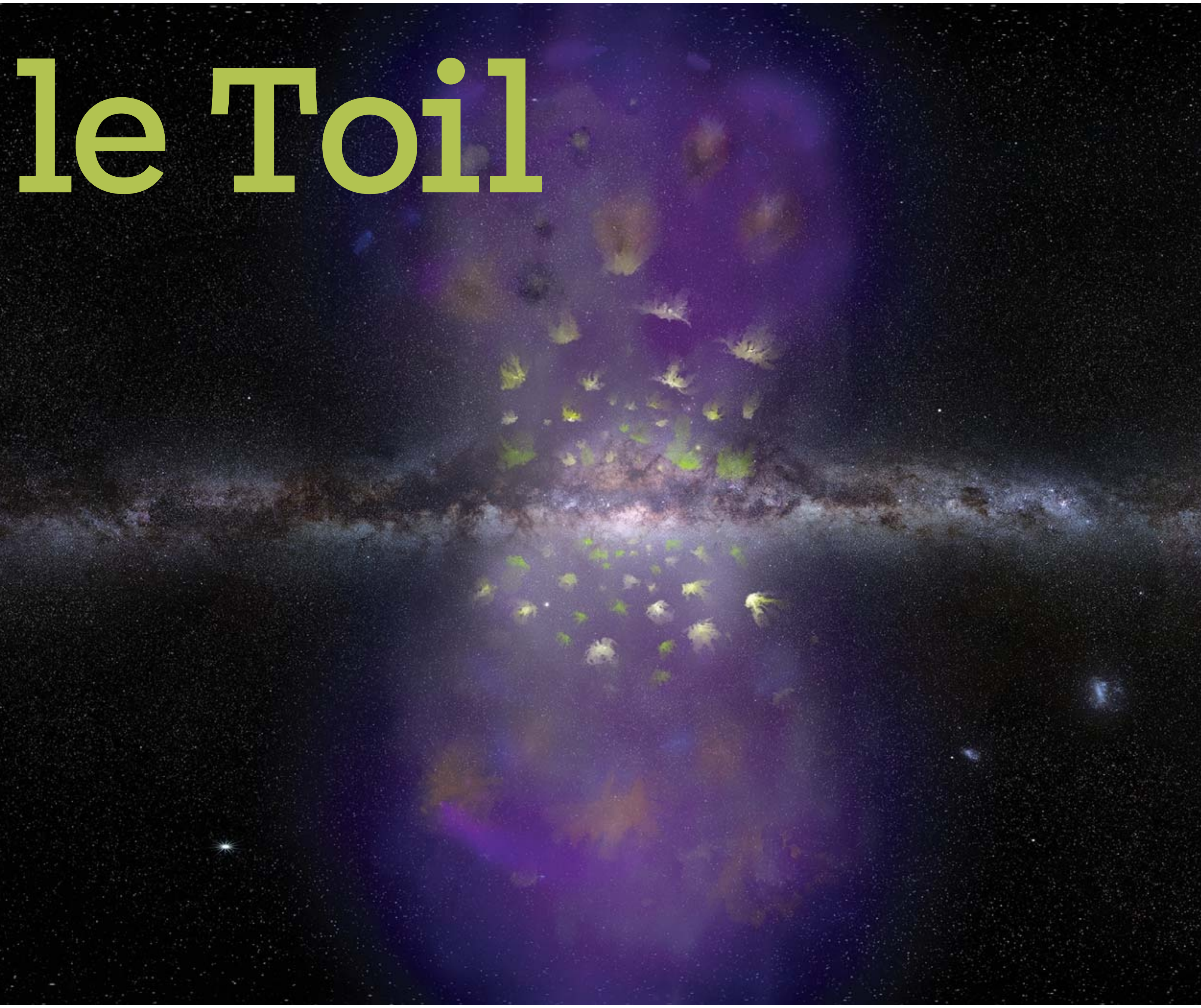
And in gamma rays, the bubbles are at their strangest: smooth and unvarying in brightness, with sharp edges likely created by a magnetic sheath that encases the cavities and traps speedy particles.

Electrons corkscrew along magnetic field lines and spit out the radio and microwave photons.

These particles fill the bubbles and create much of the radiation we see. Electrons corkscrew along magnetic field lines and spit out the radio and microwave photons. Either electrons or protons create the gamma rays — and which particle is to blame remains a key point of contention.

Hsiang-Yi Karen Yang (National Tsing Hua University, Taiwan) lists a battery of observations that the right formation scenario must account for: the sharp edges, the energies of the electrons emitting the microwaves, and the different appearances at different wavelengths, among others. "Any successful model would need to satisfy all these stringent observational constraints," she says.

If the gamma rays and microwaves are made by the same population of electrons — and that's a reasonable possibility, because electrons moving fast enough to emit microwaves would also knock into nearby photons and kick them up to gamma-ray energies — then the Fermi bubbles likely formed a few million years ago, recently enough that the electrons haven't had time to slow down. The best way to shoot a torrent of relativistic electrons thousands of light-years within such a short span of time is a major flare-up from Sagittarius A*, our galaxy's supermassive black hole. If a load of gas dumped onto Sgr A* all those years ago, it could have created a big fluffy disk that fueled jets and a powerful wind, shooting electrons up and out and inflating the bubbles. The scenario might also explain the massive stars clustered around the black hole that are a few million years old: They



could have formed from the disk's outer edges (*S&T:* Sept. 2018, p. 22).

If, however, the gamma rays are made by speedy protons slamming into each other, then the bubbles can be much older, because protons don't chill out as fast as electrons do. Sgr A* could have sent the protons out, or the particles could be from bursts of supernovae in the galactic center. The galactic center is a major star factory, but even so, it could take tens to hundreds of millions of years (or longer) to create the Fermi bubbles this way.

But early observations were like snapshots. None told astronomers about how gas was moving inside the bubbles.

For that, observers needed spectra. Spectra record movement, because the spectral lines shift based on how the gas we're observing moves along our line of sight. So a new wave of astronomers took over. They began doing pencil-beam observations at ultraviolet wavelengths, using distant stars

▲ **LEAVES IN THE WIND** This artist's illustration depicts the giant outflow that emanates from the Milky Way's center, with clouds caught up in the flow. Astronomers are using these clouds to study how material moves inside the Fermi bubbles.

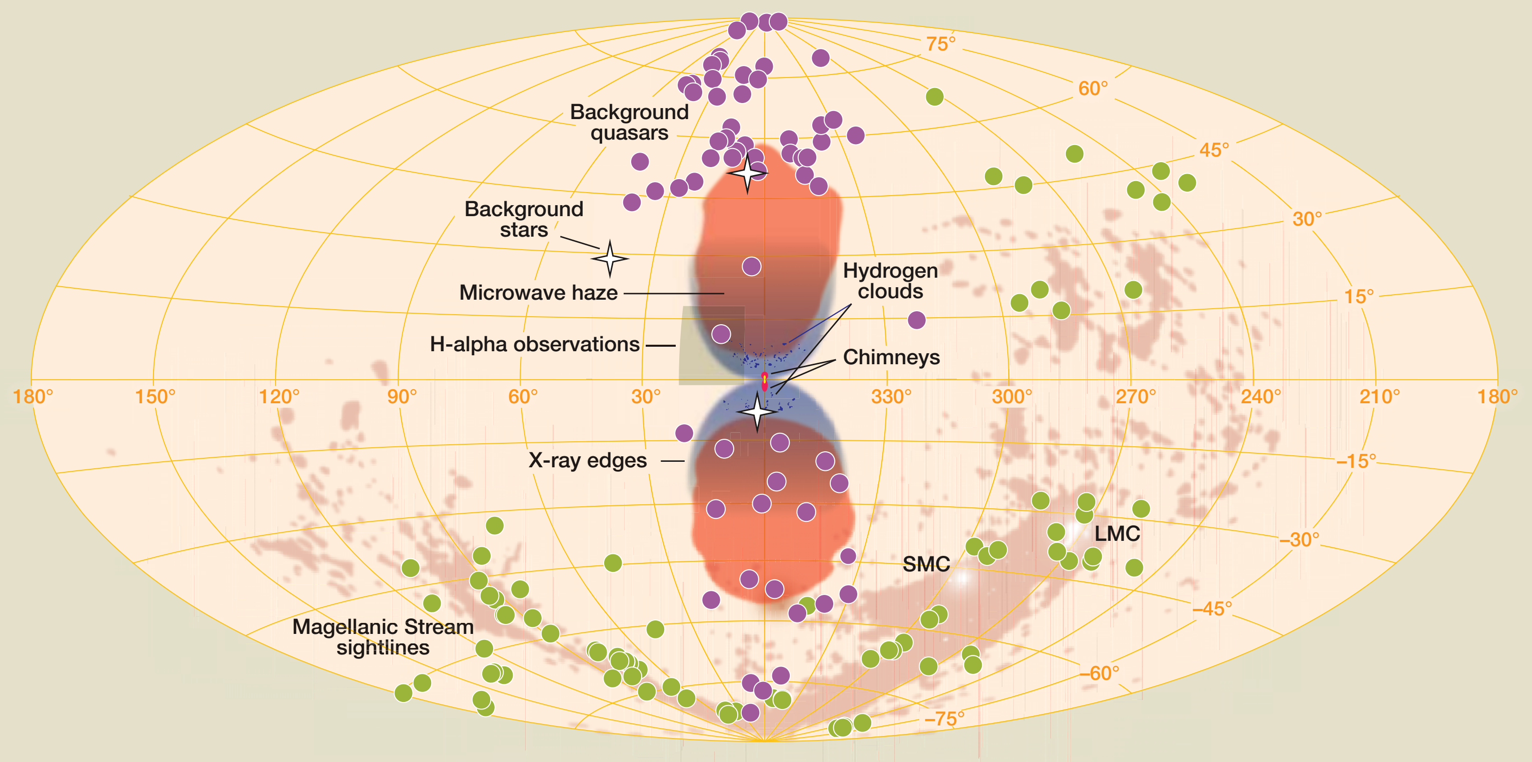
and even more distant quasars as backlights to find clouds within the bubbles.

These clouds are not the same as the plasma and particles picked up by the previous studies, stresses Fox. "What we're really seeing is clouds carried into the Fermi bubbles," he says. The clouds are swept up by the hot plasma in the bubbles, like little leaves blowing around in a wind. "We're using those leaves as a way of tracing the wind."

Fox and his collaborators have taken spectra of nearly 70 stars and quasars, almost a third of which overlap with the Fermi bubbles or their edges and reveal clouds speeding up through the cavities. The motions imprinted on the clouds' spectra show that the clouds aren't moving around randomly but are part of an expanding outflow that may have launched at some 1,000 km/s, Rongmon Bordoloi (North Carolina State University) reported at the virtual American Astronomical Society meeting last June. Based on the travel times needed for the clouds to make it from the galactic center up to their current positions in the bubbles, the wind must have started around 6 to 9 million years ago. "We are very confident from this completely independent measure that it must be something of [a] short event," he said during his presentation.

Although it was fairly obvious from the bubbles' shape that they originate in the galactic center, the connection was an extrapolation.

Such studies are limited to places where astronomers can find a celestial backlight. But Dhanesh Krishnarao (University of Wisconsin, Madison) and colleagues recently expanded observers' reach. Reporting in the same AAS session, Krishnarao used the Wisconsin H-Alpha Mapper (WHAM) to look in the same direction as one of the sightlines that Fox's team uses. WHAM directly detected the visible-light emission of ionized hydrogen and nitrogen — no background star or qua-



▲ **EXPLORING THE BUBBLES** The Fermi bubbles are huge, sharp-edged structures seen in gamma rays, with X-ray-emitting plasma cupping their bases. Astronomers have probed moving gas in the bubbles' upper reaches using background stars and distant quasars, as well as by detecting hydrogen-alpha emission along one edge. Closer to the bases, roughly 200 clouds are flying away from the galactic center. The bubbles connect to the galactic center via two narrow chimneys. Far away, in the debris stream from the Magellanic Clouds, atoms appear to have been ionized by radiation from the galactic center within the last few million years — the same time scale implied by the outflow's motions. (Note that due to projection effects, the Magellanic Stream looks much closer to the Fermi bubbles in this illustration than it actually is.)

sar required. The observations show ions moving at similar speeds to what's seen in ultraviolet.

"That's really exciting," Fox says. Combined, the WHAM and ultraviolet measurements indicate a range of temperatures (roughly 10,000 to 100,000 kelvin) that's cooler than the plasma detected with X-rays. "It really points to this very multiphase, turbulent gas. It's not just a simple bubble that is filled full of plasma all at one temperature."

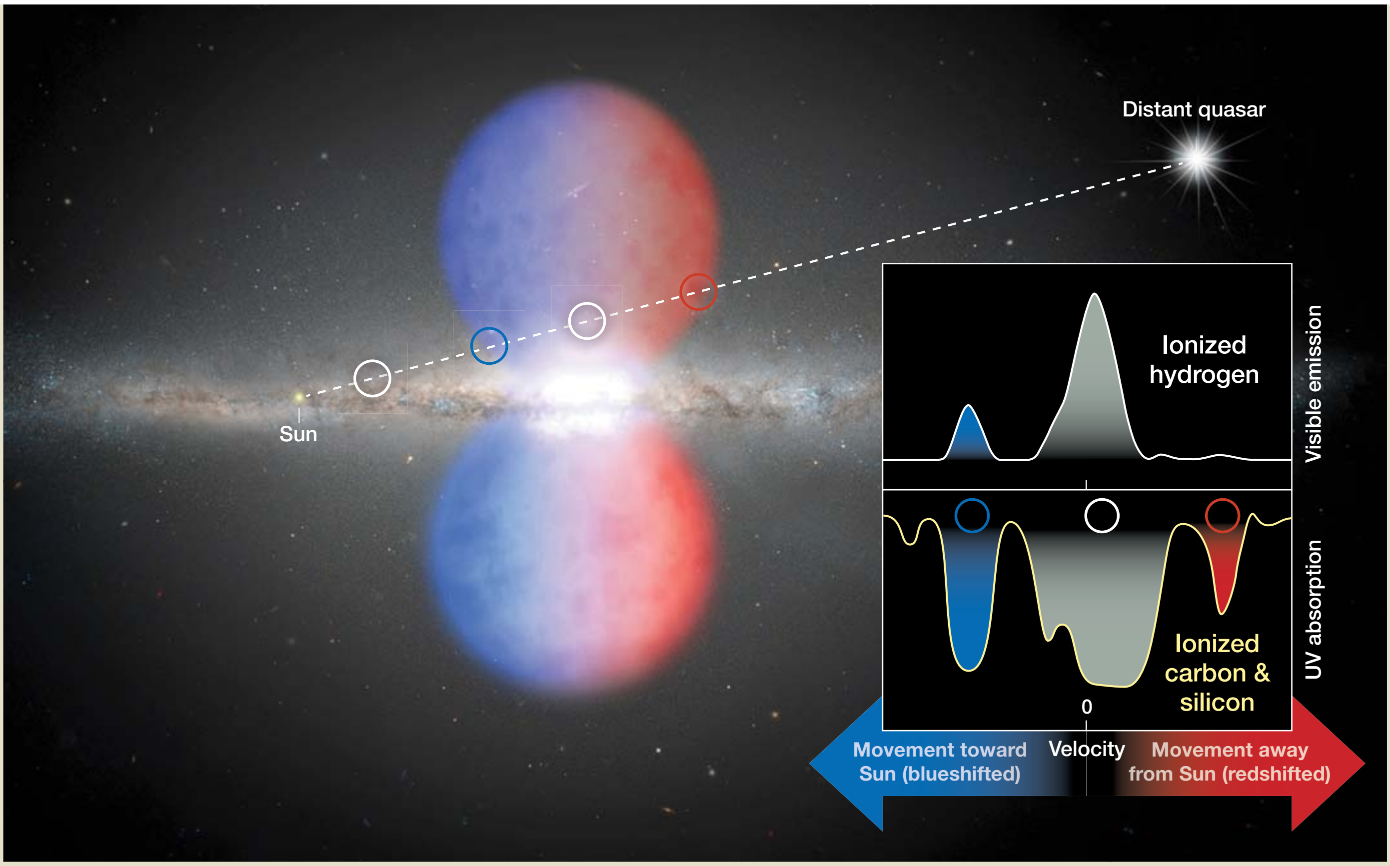
Chimney Sweeping

Part of the mystery of the Fermi bubbles has been how they connect to the galactic center. The spectroscopic observations look at clouds that are at least a few thousand light-years above the disk, and early studies showed the bubbles clearly at high latitudes but had trouble tracing the features down into the messy environment below. Although it was fairly obvious from the bubbles' shape that they originate in the galactic center, the connection was an extrapolation.

Not anymore, says Gabriele Ponti (INAF Brera Astronomical Observatory, Italy). Ponti's team used the XMM-Newton X-ray telescope to peer deep into the galactic center and see if they could find where the outflow comes from. They discovered two "chimneys," channels filled with X-ray-emitting plasma that extend from the center up to the bottom of each of the Fermi bubbles.

If the Fermi bubbles are balloons, then the chimneys are the nozzles: These are the channels by which energy and particles traveled from the galactic center into the Fermi bubbles. "I am convinced of that," Ponti says.

Unfortunately, the X-rays only permit us to see the pathways; they don't tell us what made them. The chimneys span about 150 light-years at their bases, and most of the galactic center's star formation in the last several million years has also concentrated in this area, with many aging, massive stars still in the neighborhood. It could be that the X-rays arise when supernovae's powerful outflows hit the surrounding interstellar medium, meaning that stars' dramatic deaths power the Fermi bubbles. Conversely, if Sgr A* inflated the



▲ **SIGHTLINE** Astronomers study gas moving in the Fermi bubbles by looking at the fingerprints the gas leaves in distant quasars' spectra (inset, bottom spectrum). If the gas is moving toward us, the lines are blueshifted; if it's moving away, the lines are redshifted. Observers also recently detected emission from ionized hydrogen (top spectrum) near one of the same quasar sightlines, and it's also moving toward us. Combined, the examples of these shifts suggest we're actually seeing the bubbles expand up and out. (The gray circles mark gas that is not moving toward or away from us — either gas moving straight up inside the bubbles, or gas much closer that revolves around the galactic center at the same rate that the Sun does.)

EXPLORING THE BUBBLES: GREGG DINDERMAN / *S&T*, SOURCES: FERMI BUBBLES AND UV SIGHTLINES: T. ASHLEY ET AL. / *ASTROPHYSICAL JOURNAL* 2020, NEUTRAL CLOUDS: E. M. DI TEODORO ET AL. / *NATURE* 2020, MAGELLANIC STREAM SIGHTLINES: A. J. FOX ET AL. / *ASTROPHYSICAL JOURNAL* 2014, CHIMNEYS: G. PONTI ET AL. / *NATURE* 2019, H-ALPHA: D. KRISHNARAO ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2020; SIGHTLINE: DHANESH KRISHNARAO AND NASA

There is yet more evidence favoring an age of a few million years, this time in gas far, far away from the galactic center.

bubbles, then the X-ray plasma is a relic of that past activity, slowly cooling long after the outflow ceased.

When asked which scenario he thinks most likely, Ponti laughs. "I would not bet," he says.

The X-ray chimneys also show up at radio wavelengths, identified in 2019 by Ian Heywood (University of Oxford, UK) and colleagues using the MeerKAT radio telescope array in South Africa. Although some astronomers suspect parts of the radio features lie much closer to us than the galactic center, the edges of the structures MeerKAT detected align fairly well with those of the X-ray chimneys, Ponti says — which makes sense, he adds, because when an outflow smacks into the surrounding interstellar medium, the shocked material should also emit radio waves.

However, the MeerKAT data may tell astronomers something that the X-rays do not. The radio glow comes from corkscrewing electrons, and based on the electrons' properties, Heywood's team thinks the event that created the outflows happened only a few million years ago.

Caught in the Headlights

There is yet more evidence favoring an age of a few million years, this time in gas far, far away from the galactic center.

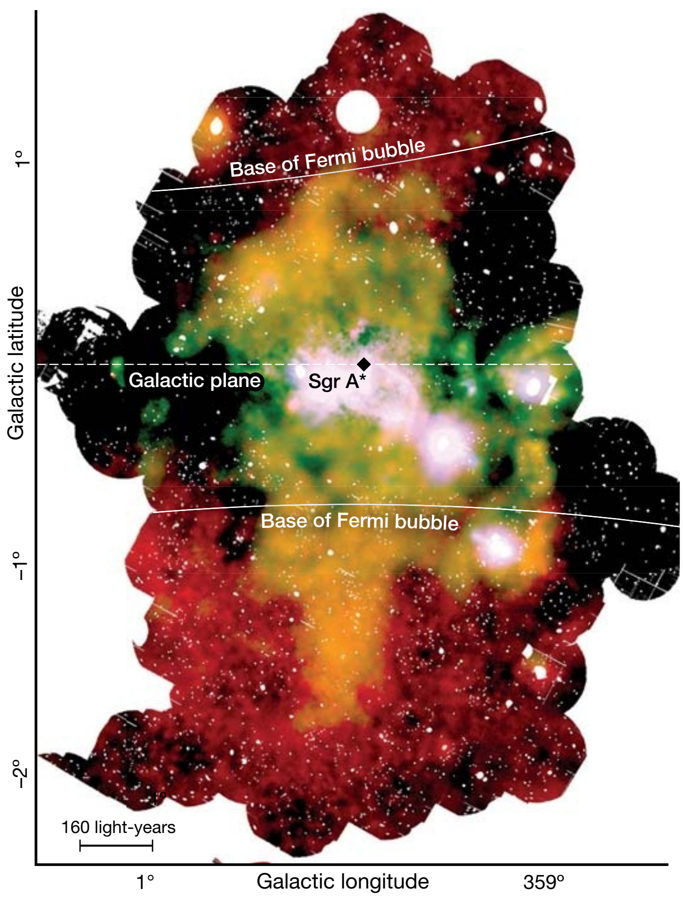
The Magellanic Stream is an immense rivulet of gas that runs through the Milky Way's halo like a ribbon through an upswept hairdo. It's made of gas torn from the Large and Small Magellanic Clouds, trailing along with these dwarf galaxies as they make a daredevil pass around the Milky Way.

In the past several years, Joss Bland-Hawthorn (University of Sydney, Australia) and colleagues have found patches of ionized hydrogen, carbon, and silicon in the part of the stream that passes above our galaxy's south pole. They've also seen hints near the northern pole. Ions are basically heated atoms; after the energy that ionized the atoms is gone, each ion will cool back down at a unique rate. Astronomers can use those rates to determine when the energy source that created all the ions they see in the stream switched off. Based on the data, the team thinks it happened a few million years ago.

Furthermore, ionized clouds have different patterns of spectral lines depending on what ionized them. Follow-up observations reported by Elaine Frazer (Space Telescope Science Institute) at the AAS meeting show that the stream's highly ionized atoms move at about the same speed as the less-ionized atoms, which only *photoionization* — that is, being hit with a really spectacular flash of light — can explain.

The ions appear solely in parts of the stream that are in view of the galactic center, and stars can't supply the necessary energy. Combine that with the time frame and the photoionization, and the team thinks the most plausible explanation is that about 3.5 million years ago, Sgr A* lit up like a spotlight. Over the course of a few hundred thousand years, the gas-guzzling black hole unleashed a surge of ultraviolet radiation so powerful that it kicked electrons out of atoms some 250,000 light-years away in the Magellanic Stream.

Simulations by Yang and collaborators also indicate that Sgr A* is the simplest explanation. If the black hole ate some 10,000 Suns' worth of gas over the course of a few hundred thousand years, it could have produced enough radiation and outflowing particles to ionize the Magellanic Stream and inflate the Fermi bubbles, she says. Assuming the black hole threw its tantrum about a million years ago, the simulations also reproduce the energies of the electrons that would have created the gamma rays and microwaves, as well as the level of orderliness in the magnetic fields, which would be due in part to what's called *magnetic draping*. This effect happens when a solid body (or in this case, an outflow) rams into and



▶ **CHIMNEYS** Astronomers have detected much smaller outflow structures emanating from the galactic center, in both X-rays *(left)* and radio *(center)*. When overlapped *(far right)*, these two features largely align; the white ellipses in the overlap are rough outlines for the chimneys. They connect the galactic center with the bases of the Fermi bubbles and may have served as the channel by which material entered the bubbles.

compresses a weak magnetic field, much like a snowplow, she says. As the bubbles expanded, the galaxy's magnetic field would have piled up along their edges, creating the sheath that traps the gamma-ray-making particles.

But this solution doesn't convince everyone. Relativistic electrons are "fragile," says Felix Aharonian (Dublin Institute for Advanced Studies, Ireland). Even if they shot straight up from the galactic center (which they wouldn't, they'd bop around), they shouldn't even make it halfway into the Fermi bubbles before losing their energy, he says. Protons avoid this problem, but they have other serious issues.

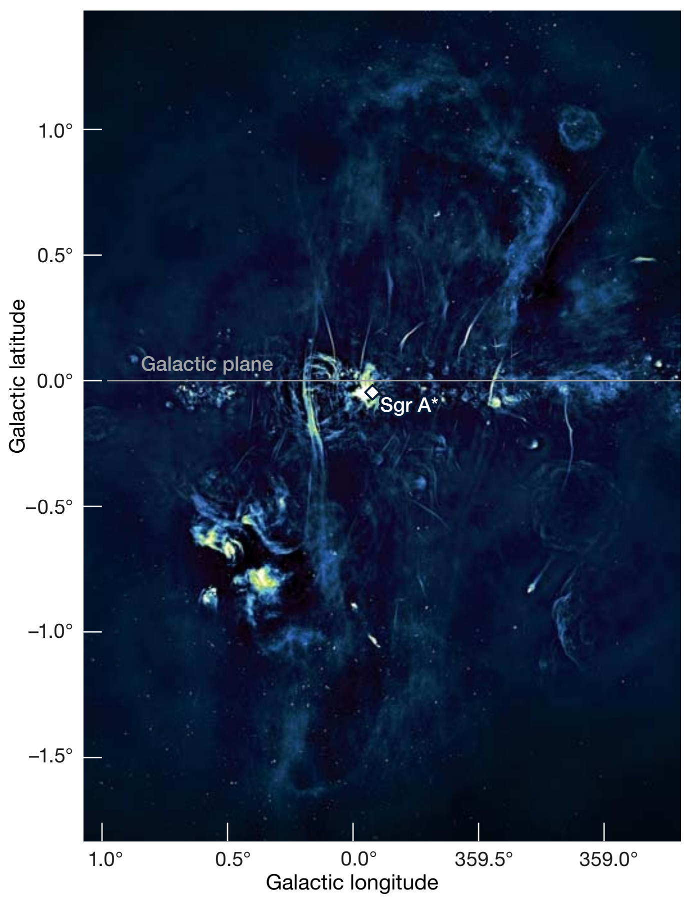
Perhaps the electrons instead got their energy boost from the expanding shell, rather than from a black hole's jets. Philipp Mertsch (Aachen University, Germany) recently worked with Vahe Petrosian (Stanford) to simulate different possibilities for what would happen if relativistic electrons poured out of the galactic center. They found that, in the scenario that best fit observations, the outflow smacked into the surrounding gas, heated it slightly, and created a turbulent magnetic region where the electrons were accelerated. As the outflow expanded and the turbulent shell rose away from the galactic center, the electrons were accelerated higher and higher up. This process would explain the gamma-ray bubbles' smooth appearance and sharp edges, Mertsch says.

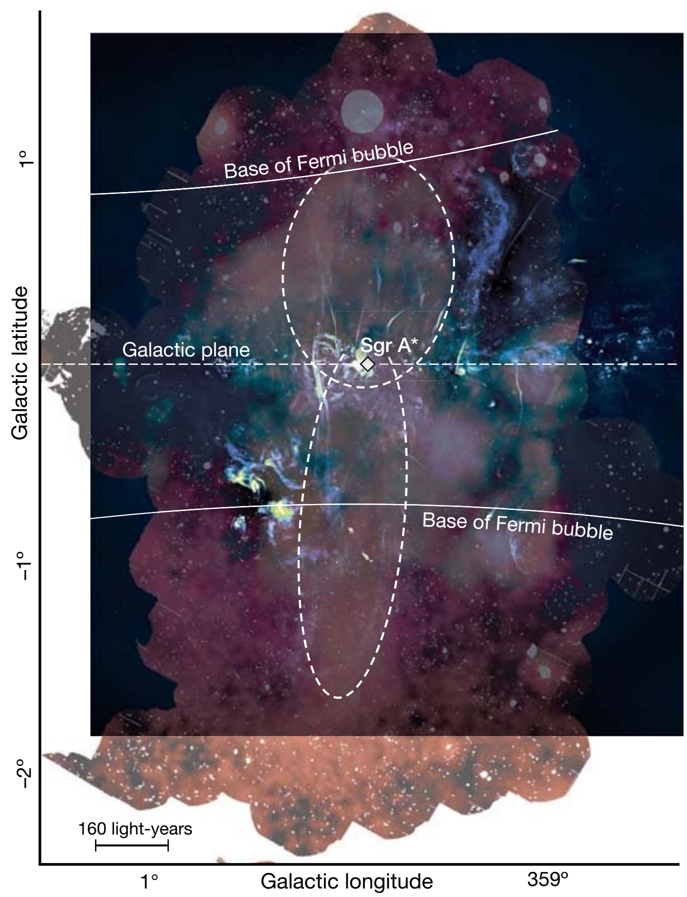
Mertsch, however, isn't convinced Sgr A* shot out the electrons. Instead, he favors star formation.

So does Roland Crocker (Australian National University). Crocker has long argued that starbirth and death are a better explanation for the Fermi bubbles than Sgr A*. To expand roughly 30,000 light-years in only a few million years would mean the outflows slammed into the halo at supersonic speeds, which he'd expect to create stronger X-ray emission than we see. The radio-emitting electrons should also need about 30 million years to cool down to their observed energies, he adds.

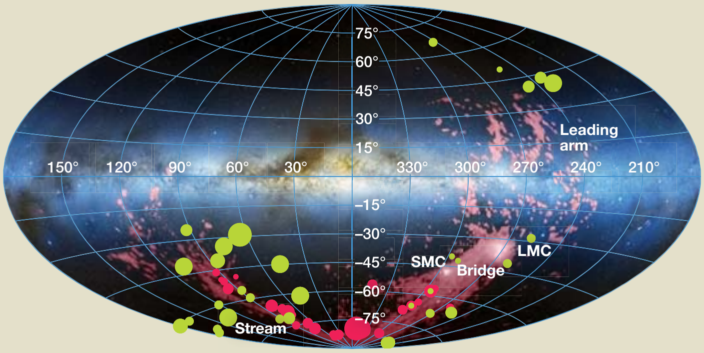
Although the slow-burn star formation he originally thought was to blame is no longer a contender, a burstier wave of starbirth might be the best explanation, he says. Simulations by him and others suggest that the galactic center undergoes episodic starbursts, with surges of new stars followed quickly by supernovae and then quiet periods, like now. It's unclear how often the cycle repeats, perhaps every few tens of millions of years.

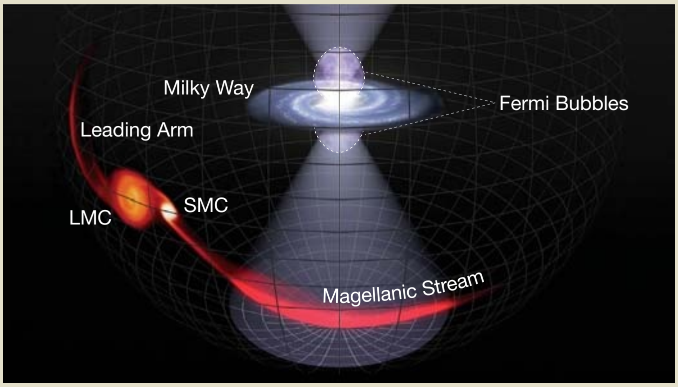
Work in the next few years will hopefully bring clarity about whether this scenario could provide enough energy to create the Fermi bubbles. "At the moment, the numbers are tight," he acknowledges. "I'd say that the star-formation idea — even accounting for burstiness — is certainly being tested."





COMPOSITE: *S&T* ILLUSTRATION; X-RAY: © ESA / XMM-NEWTON / G. PONTI ET AL. / NATURE 2019; RADIO: SARAO / ADAPTED FROM I. HEYWOOD ET AL. / *NATURE* 2019





▲ **CENTRAL FLASH** *Left:* Observations of the gas trailing from the Magellanic Clouds reveal ionized hydrogen (red) and carbon (green). Larger circles indicate sightlines with higher levels of ionization. *Right:* Astronomers suspect a bright event in the galactic center ionized gas in the part of the Magellanic Stream above the galactic south pole.

The Trail Goes Cold

Other observations are also raising questions. Astronomers have found more than 200 cool gas clouds in the lower reaches of the Fermi bubbles, moving a few hundred kilometers per second and speeding up as they whiz away from the galactic center. Recently, follow-up observations by Enrico Di Teodoro (Johns Hopkins University) and colleagues detected molecular gas in two of these clouds. Molecular gas requires dense, cold conditions, and based on the data, the team thinks there's a lot of it.

That's a problem, because it's hard to bring this much molecular gas to such high velocities. The star-formation rate in the galactic center doesn't seem to be high enough to push that much cold gas out, even if it had been higher in the past, says team member Naomi McClure-Griffiths (Australian National University), who has also worked on the cyclic star-formation simulations. And even though the researchers think the clouds would survive less than 10 million years — at face value, a vote for the black hole — it's unclear to her whether, even in tantrum mode, Sgr A* would have the gusto to drive the clouds out.

Perhaps it's a both/and situation, she says. Star formation might drive a slow wind that "loosens up" the surrounding gas, which the black hole could then drive out when it powered a short-lived upheaval. "That's the type of combined simulation that I would like to see!" she says.

Yang also wants more simulations — in her case, 3D ones that look carefully at how shocks and turbulence driven by winds that came off the active black hole might energize the particles, instead of jets. She and her collaborators are developing the code now.

Molecular gas requires dense, cold conditions, and based on the data, the team thinks there's a lot of it. That's a problem.

For Mertsch, the need is *spectral modeling*: simulations that look at the range of energies that each scenario would give to protons or electrons, and what fraction of the particles would be at each energy level. Then astronomers could compare the predictions to observations. Not enough theoretical work has tracked how the particles' energies and locations depend on each other, he says. "I still believe that spectral modeling holds the key to deciphering the origin of the Fermi bubbles."

On the observational side, more gamma-ray data from ground- and space-based detectors will refine what we know about the particles that create the Fermi bubbles' highest-energy photons. And catching more clouds blowing through the bubble breeze will tell us about the conditions inside and in the surrounding halo, and thus about the outflow that created the still-expanding cavities.

In a few years, astronomers may reach an accord on the Fermi bubbles' origin.

Well. You might not want to bet on it.

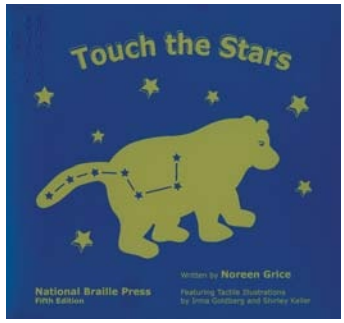
No Mean Feat

To create the Fermi bubbles, Sgr A* would have to have increased its current feeding rate by at least a factor of 10 million. Although astronomers often see the black hole's radiation flicker and have found signs of past flares, none of those comes remotely close to the level needed to explain the Fermi bubbles.

■ Science Editor **CAMILLE M. CARLISLE** would tell you what her vote is for the culprit, but regular readers can probably guess that she's biased.

Global view of Pluto created from images taken by NASA's New Horizons spacecraft during its July 2015 flyby. Courtesy NASA / JHUAPL / SwRI

Getting a Feel for the Firmament



TOUCH THE STARS, FIFTH EDITION

Written by Noreen Grice
Tactile Illustrations and Picture Descriptions by Irma Goldberg and Shirley Keller

National Braille Press
113 pages, ISBN 978-0-939173-84-6
US$35.00, hardcover/large print/braille

TOUCH THE STARS describes this book perfectly. The title not only hints at the eloquent language used throughout but indicates that the reader can literally touch the illustrations, which are magnificently embossed in braille. The writers took great care in both the main body of the text and in the descriptions of how to use the illustrations.

I'm a good judge of that, as I've been blind all my life, and I'm a teacher of the visually impaired. When I was growing up and when my children were little, my visualization of the stars was abysmal. *The Big Dipper — what's that?* I wondered. My knowledge improved enormously after reading this book.

Kent Cullers, the world's first totally blind astronomer, says something similar in his foreword. Cullers, a NASA scientist who developed the signal-detection software that radio astronomers use in the SETI (Search for Extraterrestrial Intelligence) program, says, "The reason I intensely enjoyed [this book] is that I learned so much." While he could calculate the temperature of a star, he writes, "before reading this book I knew nothing about the appearance of the constellations."

I did not grow up being exposed to tactile braille drawings, nor did I have a comprehensive science background, so this book was a bit of a revelation to me. Part of the reason for my dearth of knowledge was that the language of textbooks for the blind and visually impaired didn't bridge the gap between understanding and visualization. When I began teaching this population in public schools in 2004, I was amazed by what was available for students studying math and science compared to when I was in school.

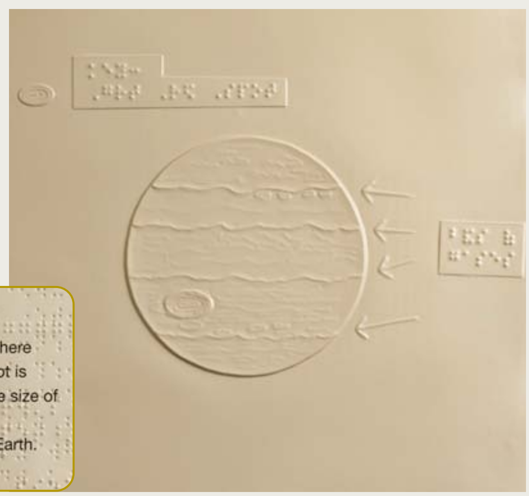
To make sense of a tactile drawing, the blind or visually impaired reader has to learn the nuances of the various textures as well as comprehend the accompanying text, including keys and descriptions of the drawings. Additionally, as the principal author of *Touch the Stars* clearly realizes, certain concepts need explaining when a drawing and its descriptive text, however accurate and helpful, might still leave unanswered questions.

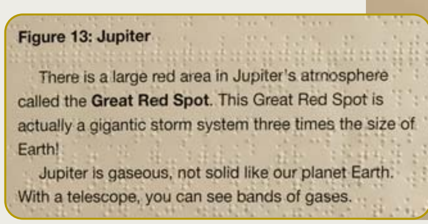
Take, for example, the waxing and waning of the Moon, a particularly challenging process for a blind person to envision. The figure below right illustrates this monthly metamorphosis with a pair of tactile drawings. The author explains that the same side of the Moon always faces Earth. To grasp that aspect, she suggests having a parent or teacher demonstrate it using a beach ball for Earth and a baseball with a piece of heavy tape on it for the Moon. Helping the blind person move the baseball around the beach ball with the taped side always facing the "Earth" nicely illustrates the concept.

The book begins with "Some Things You Should Know About the Illustrations in This Book." The author describes the concept of imaginary lines that connect the stars; how the drawings represent brighter stars using larger and more prominent circular bumps, and fainter stars with smaller bumps exhibiting shallower relief; and the need to explore the entirety of a page, which is a good reminder for the blind or visually impaired reader who might be new to tactile drawings. She suggests viewing each page as a "new adventure."

▼▶ The braille labels for this drawing of Jupiter read "Great Red Spot" and "bands of gases," respectively. In the descriptive text below, note both convex and concave braille text. The concave text is printed in braille on the reverse side of the printed page partially shown here.

Jupiter





I certainly felt that way as I turned the pages in this book.

Nineteen in all, the drawings include various shapes drawn to scale. Raised arrows point to specific parts of drawings, while an × might mark a spot to indicate the relative position of an object of interest, such as the location of our solar system in the Milky Way.

The reader moves on to "What Does the Sky Look Like?" with the mysterious sentences "The sky looks different every time you look up. Clouds move; the sun rises; rain falls." Why mysterious? Because for a blind person, these are intangibles that can be hard to imagine. The book goes on to describe the constellations, legends about the stars, and some famous star patterns, or asterisms. The text is rich with the history and general aspects of astronomy. As readers explore the texture of drawings, they can refer to both the main and drawing-specific texts nearby. (An accompanying booklet features labeled facsimiles of the drawings, so sighted readers can see what the braille labels in the raised-relief drawings say.)

The full-page, roughly 11-by-11-inch tactile drawings are embossed on durable plastic and range from the "Big Dipper in Ursa Major" to "Lyra and the Summer Triangle," from the "Motion of a Planet" to "The Major Planets with Tiny Pluto." Readers can get a literal feel for Jupiter and Saturn, for a comet and a meteor shower, and for a globular cluster and the Milky Way. Total solar and lunar eclipses each get a page. The final drawing depicts the Hubble Deep Field North.

This is the book's fifth edition. Since new braille books are now written in Unified English Braille, which precipitated changes to the original English Braille American Edition, the National Braille Press felt it was important to transcribe the book using UEB. Since creating braille drawings is an expensive undertaking, the press simply had the existing drawings relabeled to expedite the publishing of this edition and obviate the need to make new plates.

I had a long conversation about the book with Kesel Wilson, the current editor and program manager at the National Braille Press. (Full disclosure: I serve on the NBP's Board.) Kesel's excitement was palpable. For my part, as a lifelong user of braille and a teacher, I've always been in awe of NBP's commitment to publishing innovative materials, and this book exceeded my expectations.

The author Noreen Grice has extensive credentials, and her commitment to the book as a lifelong project is apparent. I encourage readers to explore her webpage: **youcandoastronomy.com**. The two illustrators, Irma Goldberg and Shirley Keller, founded Creative Adaptations for Learning, **cal-s.org/history.html**. I had the honor of speaking with Keller. Drawings are a difficult concept for people who are congenitally blind, and the descriptive language she wrote to supplement the drawings is beyond measure. The book's acknowledgments list the many other contributors who assisted in developing the final product.

It's a short text, as books go, but so rich that it felt like a life-changing work, with more details than one can possibly absorb in a single reading. It has definitely changed my understanding of astronomy and expanded my awareness of the importance, for example, of the Moon's phases. I recently read a book about World War II and was amazed to learn how the phases of the Moon contributed to decisions officers made about military missions, a reality I'd never considered.

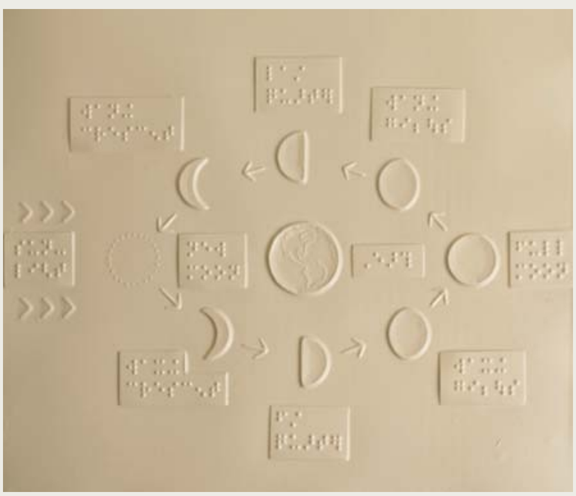
After reading *Touch the Stars*, no longer will I just hear the words "I see the Big Dipper" when I'm out with friends or family at night. I'll be able to imagine the star pattern, too.

■ **KATE CROHAN**, who is blind, is a teacher at Perkins School for the Blind in Watertown, Massachusetts.

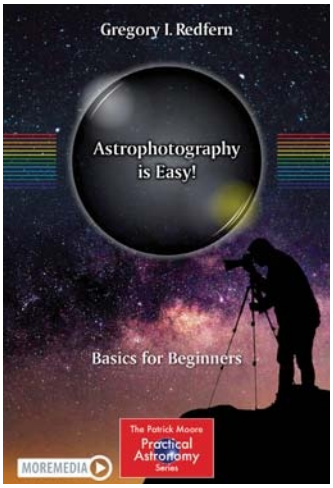
▶ For a blind person, the Moon's phases can be a challenging concept. The labels on the drawing at near right include, for example, "sunlight" (at left between the two rows of arrows), "new moon" (faint circle made with dotted line), and "waxing crescent" (below new Moon).

▶▶ As the braille label in the Milky Way drawing at far right indicates, the raised × marks the "approximate location of our solar system."

Lunar Orbit



Milky Way



◀ EASY ASTROPHOTOGRAPHY

NASA Jet Propulsion Laboratory Solar System Ambassador and *Sky & Telescope* contributor Gregory Redfern releases *Astrophotography is Easy! Basics for Beginners* ($27.99), a book for budding astro-imagers that avoids overly technical jargon in favor of a casual, reader-friendly guide. The tome contains practical advice on photographing everything in the sky from the Sun, Moon, and planets to nebulae, star clusters, and distant galaxies, as well as the best techniques to record each one. Redfern includes chapters on selecting cameras, lenses, and telescopes and other helpful advice such as understanding what you can do depending on your location. Available in paperback, ISBN 978-3-030-45942-0, 442 pages, 7 by 10 inches. Download the eBook for $19.99 (ISBN 978-3-030-45943-7).

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◀ MIRROR CENTERING TOOL

Amateur Bob Schalck offers an innovative, reusable tool to accurately mark the center of your Newtonian telescope's primary mirror. The TELMAT ($19.95) is a laser-cut Baltic Birchwood tool that includes markings and portholes to place the device on mirrors from 4 to 16 inches in diameter and mark the mirror's center, which greatly simplifies the task of collimation. The center includes a removable disk to allow the positioning of a hole-punch reinforcement sticker, and its three measuring bars are removable for convenient storage. The tool is marked for standard mirror sizes of 4, 6, 8, 10, 12.5, and 16 inches.

Bob Schalck
telmatsales@gmail.com

◀ DEEP-SPACE IMAGER

SBIG, a division of Diffraction Limited, adds a new CMOS camera to its line of deep-sky detectors. The SBIG STC-7 ($3,495 USD) is a monochrome camera featuring a 12-bit Sony IMX-428 7.1-megapixel CMOS detector with 4.5-micron-square pixels in a 3,208 × 2,200 array. The sensor boasts high sensitivity and low read noise with a peak quantum efficiency of 78%. Additionally, the unit features Stack Pro, a revolutionary feature that automatically performs stacking inside the camera. The STC-7 includes a built-in, 8-position filter wheel stocked with LRGB and three narrowband filters, and one opaque slot operating as a shutter when recording dark or bias frames. Each purchase also comes with a copy of *MaxIm LT* imaging software, a 2-inch to T-thread nosepiece, power supply, USB 3.0 cable, and deluxe carrying case.

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Finding North by Day

Daylight polar alignment can be simple if you're prepared.

IF YOU'VE EVER TRIED to polar align a telescope during the day, you quickly learn how inaccurate a magnetic compass can be. Even if you correct for the declination in your area, there's no correcting for the rebar in your driveway, the magnetic fields in your telescope, etc. You're lucky to get within a couple of degrees of celestial north.

Florida astrophotographer Alberto Sagüés has come up with a better way. He placed an angle bracket in a fixed, convenient location near where he sets up his telescope, aligned that with true north, then uses an angle-measuring smartphone app (*AngleFinder* for iOS, but there are plenty of Android apps, too) to transfer that heading to his phone. The app uses the phone's internal accelerometer and gyroscope rather than the magnetic compass to hold its reference position, and that's accurate to within half a degree.

When Alberto aligns his telescope, he first levels the mount, then he places his phone against the angle bracket and resets the angle-finding app to zero. He then moves the phone to an angle bracket on his telescope that's aligned precisely with the scope's optical axis. He adjusts the telescope in azimuth until the phone app again reads 0°, and he's aligned. With that simple alignment, he can invariably slew to see Venus in the finder on the first try.

But how to find true north to align your angle bracket? Several ways exist:

1: Do it at night, with Polaris visible.

This is surprisingly difficult (especially in the Southern Hemisphere!). But even in the north, unless you live near the equator, Polaris is quite a ways up in the sky. It's not precisely north anyway, except for twice a day when it's directly above or below the celestial pole. You either have to wait for one of those moments or calculate an offset. Then hang a plumb bob over your work surface and sight past the string, moving your head left and right until the string is exactly north of your eye. Mark your line of sight on the work surface, and you've got north.

2: Survey a north line using a good map and known landmarks. Google Earth is pretty precise. If you can zoom in on your observing site and on a distant landmark that's directly north of you (or at an angle you can measure), you can find north that way.

3: My personal favorite way (because I'm a sundial nut) is to use the Sun.

At solar noon, the shadow of a vertical stick or a plumb-bob string will fall directly north-south. The trick is to determine when it's exactly solar noon. The Sun moves 15° per hour in the sky, so you don't want to be off by more than a minute or so if you want an accurate north line.

You might think you just need to add an hour for daylight saving time. Nuh-uh. It's more ~~complicated~~ fun than that! You also need to add a correction for how deep you are into your time zone. Time zones start on even 15° longitude lines. In the U.S., those lines are 75° (Eastern), 90° (Central), 105° (Mountain), 120° (Pacific), 135° (Alaska), and 150° (Hawai'i). So if you live in, say, Altoona, Pennsylvania, at longitude 78.4°, you'd be 3.4° deep into your time zone. If a time zone is 15° wide and it takes the Sun an hour to

ALBERTO SAGÜÉS (2)

▲ *Left:* The bracket aligned to true north is fixed near Alberto Sagüés's observing spot, where he places his smartphone to record the direction to within half a degree. *Right:* He then transfers the reading to the telescope via an angle-measuring smartphone app.

cross it, that means it takes 4 minutes to cross a degree, so Altoona is 3.4° times 4 minutes per degree, or 13.6 minutes (13:36) into its time zone. You have to add that to your clock noon so the Sun has time to get directly overhead at your longitude.

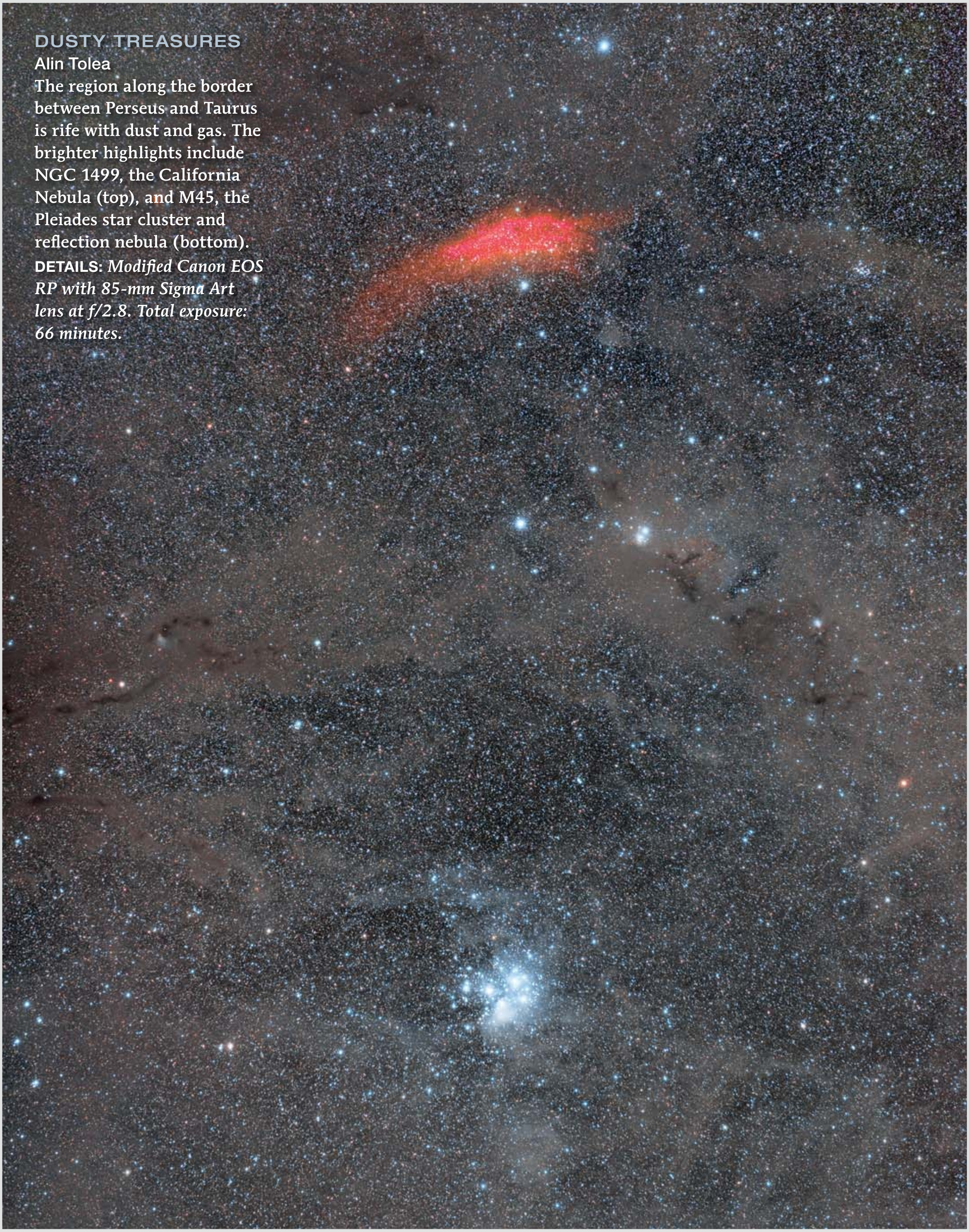
But wait, there's more! The Earth's axial tilt and the Sun's elliptical orbit combine to create another correction called the *equation of time*. That's the little figure eight you sometimes see out in the Pacific Ocean on a world globe. The equation of time tells you how fast or slow the Sun is running that day. So, if it's May 27th, for instance, you'd have to subtract 2:49 from the clock time to get the exact second that the Sun is directly south (or north). So in Altoona on May 27th the moment of north is 12:00:00 plus 1:00:00 for daylight saving time, plus 13:36 for depth into the time zone, minus 2:49 for the equation of time, or 1:10:47. That's when you draw your north-south line along the shadow of a plumb-bob string to record the direction of true north.

Of course, you could just Google the Sun's transit time, but where's the fun in that?

■ Contributing Editor **JERRY OLTION** can find north — sort of — by looking at the moss on a tree.

JERRY OLTION

▲ Marking a true north line is as easy as 12:00 + 1:00 + 13:36 – 2:49.



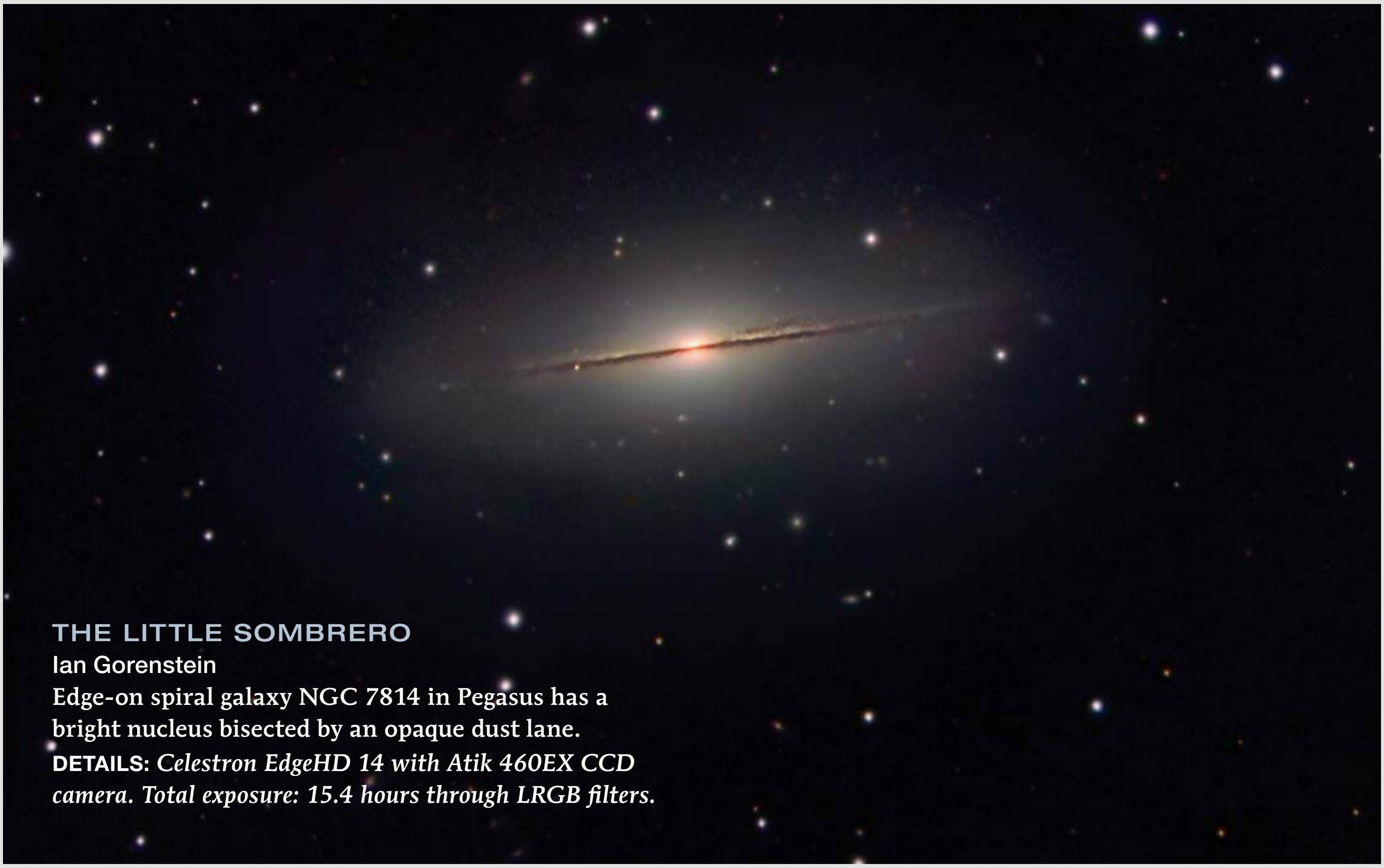
DUSTY TREASURES
Alin Tolea
The region along the border between Perseus and Taurus is rife with dust and gas. The brighter highlights include NGC 1499, the California Nebula (top), and M45, the Pleiades star cluster and reflection nebula (bottom).
DETAILS: *Modified Canon EOS RP with 85-mm Sigma Art lens at f/2.8. Total exposure: 66 minutes.*

DEEP-SKY SQUID

Damien Cannane

Faint bipolar nebula Ou4 in Cepheus displays intricate details in this deep image. Read more about this planetary nebula in the feature beginning on page 18.

DETAILS: *Celestron RASA 8 with ZWO ASI183MC CMOS camera. Total exposure: 19 hours through clear and Optolong L-eNhance filters.*



THE LITTLE SOMBRERO

Ian Gorenstein

Edge-on spiral galaxy NGC 7814 in Pegasus has a bright nucleus bisected by an opaque dust lane.

DETAILS: *Celestron EdgeHD 14 with Atik 460EX CCD camera. Total exposure: 15.4 hours through LRGB filters.*

△ SAGITTARIAN TRIPLET

Alistair Symon

Three emission nebulae in Sagittarius, including M20 (top right), M8 (right), and NGC 6559 (left), appear to be interconnected sections of the same immense cloud of gas and dust in this deep narrowband color composite.

DETAILS: *Takahashi FSQ-106ED refractor with SBIG STXL-11002 CCD camera. Total exposure: 6 hours through narrowband filters.*

△ DESERT SOLITUDE

Amirreza Kamkar

Constellations of the winter Milky Way, including Canis Major (left), Monoceros (top left), and Orion (upper right), arch high above Dasht-e Lut in eastern Iran. Several large nebulae are visible, including the crescent of Barnard's Loop in Orion.

DETAILS: *Canon EOS 6D DSLR with Sigma Art lens at f/2.2. Total exposure: 15 seconds at ISO 5000.*

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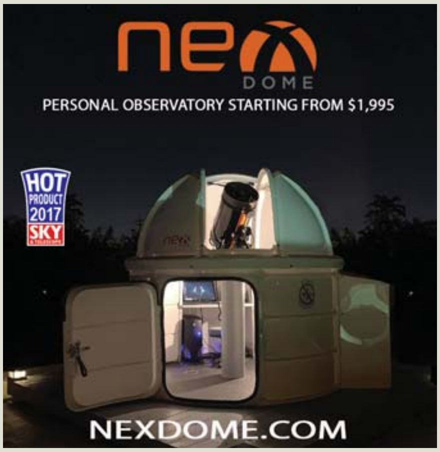

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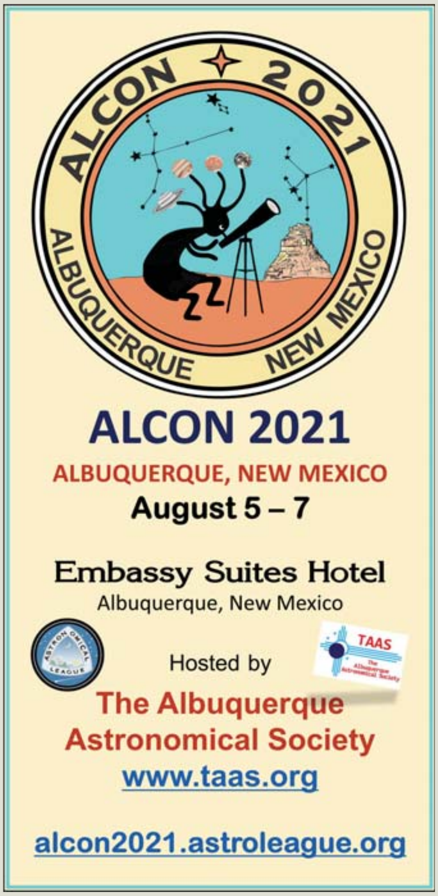

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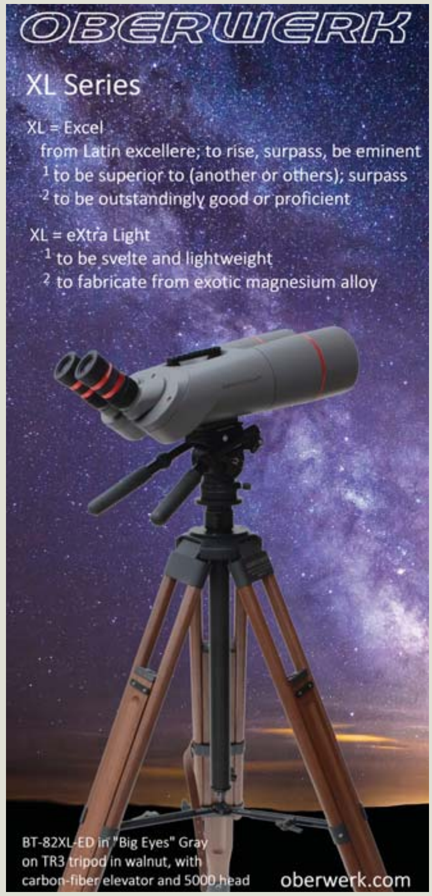

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A Star for Donna

For the author, the red giant Betelgeuse always brings to mind a lost beloved.

WHEN YOU PEER UP to the heavens, do you ever reminisce about loved ones who have passed on? Every night I gaze at Betelgeuse, I reflect on my stepmother, Donna, and the Latin phrase *Et lux in tenebris lucet* ("The light shineth in the darkness") comes to mind.

Donna passed away from pancreatic cancer in 2008, and although I drafted this story soon after, I never felt a sense of urgency to publish. But Betelgeuse's sudden fading in late 2019 triggered a renewed determination to tell my story.

Of all the influences in my life, Donna was most responsible for igniting my fascination with astronomy. It was she who gave me a book on the planets and stars when I was 10 years old. And with my curiosity piqued, it was Donna who suggested to my father that I receive a telescope (a 60-mm refractor) for Christmas. Thus began my lifelong journey in astronomy.

◀ When Betelgeuse, seen here atop Orion, dimmed in 2019, the author couldn't help but wonder, "Is Donna sending me a message?"

GARY SERONIK

Two years later, my parents rewarded my burgeoning passion with a 6-inch Newtonian reflector. Throughout my middle and high school years, I observed from our backyard below their bedroom. A simple "Hey, look at this!" would entice them downstairs to share in my celestial discoveries.

After college, I was commissioned into the Air Force, and my service enabled me to pursue astronomy throughout the world. The next 11 years seemed to pass like a meteor flash.

In Donna's last month, I took leave and returned home to my family. I brought along my signed first edition of Leslie Peltier's *Starlight Nights: The Adventures of a Star-Gazer*, and I read her my two favorite passages: the night of his first comet discovery, and his "extraterrestrial" sighting that turned out to be something entirely different.

During my visit, I enjoyed a full-circle moment when I convinced my father to purchase his own 5-inch Maksutov-Cassegrain. From our familiar backyard haunt, I guided him as he star-hopped to the famous nebula NGC 2392 in Gemini. It was a welcome respite from the looming reality.

The night after Donna's passing, we held a celebration dinner, and afterwards I showed family and friends the rings of Saturn from our backyard. As my stepsister and I looked up at the sky, she suggested we choose a star to name in Donna's honor. "It has to be a red star," I declared, "to represent her fiery red hair." She agreed, and the natural choice was Betelgeuse, which beamed in Orion above our house that night.

> Betelgeuse reminds us that nothing is permanent, and this reality implores us to cherish life.

Astronomy brought our family together, and Betelgeuse shined through our hour of darkness.

Ever since that night, I celebrate the first time every year that Orion rises in the eastern sky and I spot Betelgeuse. On several occasions, I have regaled friends with the red giant's immense size — that it would extend well beyond Mars and possibly as far as Jupiter if it replaced our Sun. That beautiful red star has faithfully shone through good times and bad.

When Betelgeuse began to dim in 2019, I was left with mixed emotions. The astronomer in me was excited about the prospect (however unlikely) that we could witness a spectacular supernova in our lifetime. Yet I also mourned that a visible remembrance of my stepmother was fading. Change is unsettling. It made me wonder: Is Donna sending me a message?

We expect stars to appear every night; we expect them to outlast us. Betelgeuse reminds us that nothing in life is permanent, and this reality implores us to cherish life — and each other — in the short time we have on this planet.

■ **JOE BARRY** is a Tampa, Florida-based amateur astronomer, Air Force veteran, and founder of Deep Sky Coffee Company, which donates proceeds to dark-sky preservation. He is available to talk astronomy and coffee at **joeabarry@gmail.com**.

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TheSky Fusion lets you wirelessly operate your *entire* imaging system from just about any Wi-Fi enabled computer equipped with a Web browser. That includes most tablets, smartphones, laptops, and desktops.

Since TheSky Fusion performs most of the heavy lifting, even older machines should be up to the task of advanced astronomical imaging.

Speedy performance comes from multi-threaded software architecture that takes full advantage of TheSky Fusion's powerful 64-bit, six-core CPU and hardware-accelerated graphics.

TheSky Fusion includes 200 GB of internal storage for your astrophotos, which can be conveniently transferred to another computer or the cloud wirelessly, or through its high-speed USB or Ethernet port.

Instead of needing a power supply for each of your devices, TheSky Fusion powers them all. Eight durable Anderson Powerpole® connectors provide the voltages your equipment needs, using inexpensive, off-the-shelf power-supply cables. TheSky Fusion is also equipped with four expandable high-speed USB 3.0 ports.

To minimize setup time and ensure optimal mount performance, the integrated GPS determines your location and maintains accurate time.

And, its status display even keeps you in the loop during imaging runs.

Make your clear skies more productive with TheSky Fusion. You deserve it!

SOFTWARE BISQUE

Superior imaging solutions for discriminating astronomers.