EXOPLANETS:
A Tale of Two Suns
PAGE 34

TELESCOPE DIY:
Make Your Own Mirror
PAGE 58

ASTRO OUTREACH:
From Street to Streaming
PAGE 84

SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

JULY 2022

CLUSTER HOP

Globulars for Summer Nights

Page 20

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07

CONTENTS

SKY & TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

JORDI L. COY

FEATURES

OBSERVING

S&T TEST REPORT

COLUMNS / DEPARTMENTS

ON THE COVER

The globular cluster NGC 6717 dazzles in Sagittarius.
ESA / HUBBLE, NASA, A. SARAJEDINI

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Joining an Elite Club

IMAGINE DISCOVERING a new planet. I'm not talking an extrasolar planet — we've identified thousands of those in recent years — but a new planet in our own solar system.

The last time that occurred is coming up on a century ago, when Clyde Tombaugh collared Pluto. Of course, Pluto lost its planet status in 2006, so officially the last time someone sighted a new planet was in 1846, when the French astronomer Urbain Le Verrier mathematically predicted the location of Neptune and, soon after, his German counterpart Johann Galle became the first person to knowingly lay eyes on it.

Before that came British astronomer William Herschel's discovery of Uranus in 1781. Thus, just two planets have turned up in our star's domain in the last quarter millennium. All the other planets beyond our own — Mercury, Venus, Mars, Jupiter, and Saturn — have been known since antiquity.

Astronomers have roped in dozens of moons and minor planets over the centuries. Galileo kicked things off with his discovery of the four Galilean moons of Jupiter in 1610. Then followed Titan (Huygens, 1655), four more Saturnian moons (Cassini, 1670s and '80s), and two each for Uranus and Saturn (Herschel, 1780s). Since 1800, myriad other small worlds beholden to the Sun have come to our attention, including some you might never have heard of, such as the dwarf planets Orcus, Quaoar, and Gonggong.

▲ Artist's impression of Planet X, with Sun in distance

NAGUALDESIGN / TOM RUEN / WIKIMEDIA COMMONS / CC BY-SA 4.0

But no new major planets. Isn't it high time to find the next one in our far-flung system, if such exists?

That's a big if, as Christopher Crockett spells out in his article about the feverish search for the so-called Planet X (page 14). Some of today's leading discoverers of minor planets in the outer solar system contend that an undiscovered world perhaps two to four times Earth's diameter might be lurking there. It's based on the way *something* seems to be corralling a bunch of those minor planets in a certain way. As Crockett explains, other, equally qualified researchers doubt such a planet exists.

If it does, imagine the impact its confirmation would have: All those illustrations depicting the eight official planets would need revising again — except this time, the ninth planet would lie roughly 10 times farther out than Pluto. Planetary scientists would suddenly have another quarry to study. The IAU would have to decide on a name, which would quickly become a household one.

The hunt is on, and it's a nail-biter. If a new world does turn up, would it change how we view our place in the cosmos? It's been so long since another of its ilk was found, who can say?

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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The image on the right is the famous Pillars of Creation (M16) taken with the Wide Field Planetary Camera of the Hubble Space Telescope. The image on the left is taken with a QHY600M-PH Camera through a 7-inch refractor from the author's backyard in Buenos Aries. Courtesy Ignacio Diaz Bobillo. To see the original composition, resolution and acquisition details, visit the author's Astrobin gallery at https://www.astrobin.com/users/ignacio_db/

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- CMOS Chamber Pressure and Humidity Sensor
- Up to 4 Frames/second at 61 MP and 16-bits *
- Linear Response - Photometric Quality
- Optional 2x10GB Optical Fiber Interface *
- Multiple Readout Modes
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Reading Through the Years

Recently, I completed reading all issues of *Sky & Telescope* back to the first issue in November 1941. It took me 42 years. It took some time to locate all the paper issues. Since I retired in 2014, I've had more time to read.

It was something I'd wanted to do for quite a long time. *S&T* published a short note some years ago about how I came to begin reading them in February 1966 during my 9th-grade math class (*S&T:* June 2006, p. 12). It has been quite an adventure reading back through the years. It really helps one gain a perspective of what was happening at the time. I'm now reading its predecessor magazines, *The Sky* and *The Telescope*. I've really wanted to have all those in paper also, but they are exceedingly hard to find. I have some paper issues of *The Sky*, but only one of *The Telescope*. I'll have to read most of both of these magazines off the DVD disks on my computer.

Keep up the good work!

Larry Black • Cedar Rapids, Iowa

◀ Charles A. and Helen Spence Federer published the first issue of *Sky & Telescope* in November 1941 after merging its two predecessor magazines, *The Sky* and *The Telescope*.

Friction is $F = \mu N$

Thanks for the interesting article "Derrick's Mission to Mars" (*S&T:* Feb. 2022, p. 26), about an astronomer's community outreach program in Philadelphia. In the article, the author Nicole Nazzaro uses basic equations from physics to explain how to encourage a "Wow!" reaction from youngsters. She cites the equation for force as an example.

That immediately brought back a 50-plus-year-old memory from my 9th-grade physics class at Cass Technical High School in downtown Detroit, Michigan. The teacher introduced the unit on friction with the statement "Friction is *FUN*!" and then wrote the formula $F = \mu N$, which was also mentioned (though in a slightly different form) in the *S&T* article.

I can still picture that formula on the chalkboard five decades later. I must have said "Wow!" at the time. It certainly got this kid involved in a lifetime of physics, astronomy, and technology.

Thanks, Derrick Pitts and Nicole Nazzaro!

Chuck Plachetzki
Suttons Bay, Michigan

Lunar Reconnaissance

In his article titled "Chang'e 5 and the Age of Lunar Lavas" (*S&T:* Feb. 2022, p. 52), Charles A. Wood says he "can't wait for more dated samples from the Moon to fill in the crater curve gaps." I believe that we need to obtain samples from the entire Moon, especially the farside. The farside of the Moon may differ considerably from the nearside, and its crater curve needs to be developed so that we can more fully understand lunar and solar system history.

James Scott
Vernon, New Jersey

Cosmologically Complex

I found the article "The Hubble Constant: Tension and Release" by Arwen Rimmer (*S&T:* Mar. 2022, p. 14) an interesting, informative summary that touches upon numerous important cosmological concepts. I especially enjoyed the intellectually open manner in which Rimmer presents how various research groups are attempting to clarify varied, complex cosmological questions.

Philip Levine
Randolph, Massachusetts

I always read with great interest the articles on developments in cosmology, such as the recent piece "The Hubble Constant: Tension and Release." This article mentioned a concept that I feel could use further explanation, the *sound horizon*. The article defines it as "the maximum distance that a sound wave could have traveled [in the primordial universe] before recombination occurred."

Though it's been a while, if I recall from freshman physics, a sound wave is a longitudinal wave of varying pressure fronts that assume air molecules as the medium of transmission. I must admit I'm at a loss as to how this translates to plasma in the primordial universe. I'm sure I'm missing something.

Marc Pfeiffer
Washington, D.C.

Camille Carlisle replies: *The sound horizon can indeed be a complex concept. I asked Arwen Rimmer your question, and here's what she said:*

"The primordial plasma was not of uniform density. Gravity acted on these variations, causing expansions and contractions in the medium. These motions in turn caused oscillations in the plasma that are analogous to the way sound waves travel through air. So the phrase "sound horizon" is kind of a metaphor.

Here's an Astrobites article that has a pretty good description of the sound horizon: ***https://is.gd/the_early_universe****."*

Blast from the Past

Peter Tyson's inaugural Spectrum article, "High Standards" (*S&T:* Jan. 2015, p. 6), solicited advice from the readership on improving the magazine. I simply could not resist the offer! My input resulted in a follow-up inquiry from Mr. Tyson, which I readily answered. In a nutshell, I recommended the magazine adopt an even more intense practitioner orientation. I suggested that the core readership wanted to learn how to better participate in this hobby.

Since that interchange, I've been wowed by *S&T*'s content, both thematically and application-wise. Each issue seems to develop new perspectives on how to aid and educate the subscription base. The February issue contains a stellar (pun intended) example, "Ultra-Deep Imaging" by Rolf Wahl Olsen (*S&T:* Feb. 2022, p. 60). The New Zealand author provides a unique perspective on how and, more importantly, why to "go deeper" in astronomical imaging. I had recently launched my own deep-dive campaign, but this entertaining, informative, and inspirational piece just moved me into hyper overdrive.

No, I am not taking credit for this editorial supercharge, but it is nice to know the voice of the reader is alive and well at *S&T*. The *S&T* staff seem to make it happen issue after issue!

Frank P. Puzycki
Long Valley, New Jersey

Mason and Dixon's Great Adventure

I am grateful for Ted Rafferty's "Mason and Dixon's Great Venus Adventure" (*S&T:* Mar. 2022, p. 28). The extent of my knowledge concerning Charles Mason and Jeremiah Dixon was a vague memory of that appropriately named boundary line from an American history class years ago — and more recently, and more memorably, the great song by Mark Knopfler, "Sailing to Philadelphia," which always piques my interest to learn more about them. I will order the book mentioned in the article, Edwin Danson's *Drawing the Line*. Thank you for your periodic inclusion of historical subjects.

Nancy Huff
Beverly Hills, Florida

In a caption on page 30 of the March issue, Ted Rafferty describes two Gregorian reflectors made by James Short as having "a focal length of two feet (61 cm) and speculum metal primary mirrors that were likely 4½ inches (114 mm) in diameter." These dimensions give a focal ratio of f/5.3, which is far too fast for a Gregorian design.

The primary mirrors' focal length probably is around 2 feet, but in the Gregorian design, the effective focal length (EFL) of the entire system is amplified by the concave secondary mirror. Therefore, the EFL of a typical James Short Gregorian of this aperture is about 12.75 feet (3.9 meters), according to an article by Robert Royce at **rfroyce.com/short**.

This would make these telescopes f/34 systems.

Tim Black
Edmonton, Alberta

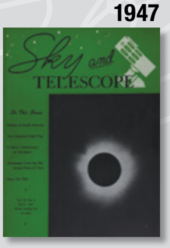
FOR THE RECORD

• The image of NGC 4725 on page 30 of the May issue was taken with a 4-inch f/6.5 refractor.

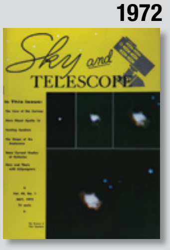
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

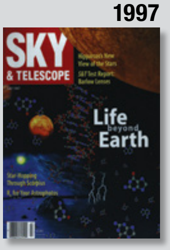
1947



1972



1997



◖ July 1947

Oops "During the shower of Draconid meteors on October 9th last year, many amateurs obtained [photos] . . . At Harvard College Observatory, Carl Bauer [studied a photo] bearing a meteor trail with conspicuous sinuous curves . . . taken by the members of the Jacksonville Amateur Astronomers Club. . . .

"Bauer . . . calculates that the lateral acceleration required to produce the observed trail is about 10,000 times the acceleration of gravity and about 100 times the measured decelerations of meteors . . . due to the resistance of the earth's atmosphere."

Bauer concluded the trail's waviness had a mundane cause: a rapidly quivering camera, accidentally bumped during the exposure.

◖ July 1972

Wandering Sun "The analemma is the closed curve, resembling a fat-bottomed figure 8, that is placed in the tropical zone of many terrestrial globes . . . Since most teachers don't know what the analemma's function is, modern school globes ordinarily omit it. But in my youth it was always present, though many years elapsed before I learned the true significance of this mysterious symbol. [If] the analemma were placed on the Greenwich meridian (longitude 0°), it would show the geographical latitude and longitude of the subsolar point at noon Greenwich mean time, for each day of the year. . . .

"The very slow precession of the earth's axis causes the equinoxes to slip westward along the ecliptic [while other effects] cause the earth's perihelion point to shift gradually eastward along the ecliptic. [As a result,] some 10,000 years from now . . . the analemma's northern loop [will be] broader than the southern, in contrast to the present situation."

Bernard M. Oliver's classic article has inspired sundial makers and creative photographers alike. A true polymath, Oliver was a key figure at Hewlett-Packard Company and promoted development of the first HP pocket calculators.

◖ July 1997

Fleeting Globulars "Favorite observing targets for amateur astronomers are the giant, spherical collections of stars called globular clusters. These ancient star systems orbit around the center of our galaxy in an enormous halo. But they won't be around forever. . . .

"Oleg Y. Gnedin and Jeremiah P. Ostriker (Princeton University) cataloged 119 of the Milky Way's globulars and investigated how quickly the clusters would disperse. [Such clusters] feel the effects of various gravitational tuggings when they cross the disk of the galaxy, pass close to its central bulge, or skirt giant clouds of gas. [During] the next 10 billion years, they say, more than half of all the clusters — perhaps up to 90 percent — will be disrupted."

This artist's concept shows the radio circle expanding out of a central galaxy and into intergalactic space. See the animation online at https://is.gd/ORCart.

SAM MOORFIELD / CSIRO

GALAXIES

New Radio Data Reveal Possible Origins of Odd Radio Circles

GHOSTLY RINGS of radio emission spanning a million light-years, dubbed Odd Radio Circles (ORCs), are a recent discovery. They emit no radiation other than radio waves. And we're only beginning to understand what made them.

Ray Norris (Western Sydney University, Australia) published the discovery of the first four ORCs in 2021, having found three in data from the 36-dish Australian Square Kilometre Array Pathfinder (ASKAP). Another uncovered in archival data brought the tally to five. It took months, he says, to go from the first flush of excitement to confirming that ORCs were a new phenomenon.

Now, in a study to appear in the *Monthly Notices of the Royal Astronomical Society*, Norris and colleagues report that they have taken a closer look at the first-discovered ORC using the 64 dishes that make up the South African MeerKAT radio telescope.

A large elliptical galaxy sitting in the middle of the ring is probably its source, the astronomers argue, but what happened there is still open for debate.

There are two likely prospects: First, it's possible that that the central galaxy underwent a starburst: The birth (and death) of some 20 billion Suns' worth of stars could have powered a strong-enough galactic wind to set off the shock wave that now expands far beyond the galaxy.

Another possibility, which Norris hopes to explore in the future, is that the supermassive black hole at the galaxy's core underwent a collision, which also could have sent out shock waves.

Both scenarios are consistent with the MeerKAT observations. A third possibility, that we are staring down the barrel of a black hole's jet, appears less likely, Norris says. But, he adds, "my colleagues and I continue to debate this."

Whatever set off the shock wave, it passed out of the galaxy and into intergalactic space, becoming a thin, spherical shell. Charged particles carried outward with the expanding shell emit radio waves as they wind their way around magnetic fields. We only see a circle for the same reason that it's easier to see the edges of a soap bubble, because that's where there's more material along our line of sight.

From the shell's size, Norris's team estimates that the originating event occurred some 100 million years ago.

"The authors have been creative and thorough in coming up with possible scenarios," says George Heald (CSIRO, Australia), who wasn't involved in the study. Heald is particularly intrigued by the ordered magnetic structure that the MeerKAT data reveal, which he speculates might play a role in determining ORCs' origins.

While faint and rare ORCs escaped previous detection, ASKAP has only just begun full science operations and may yet discover more of them.

■ MONICA YOUNG

SOLAR SYSTEM

Venus History in Air, Rock, and Water

SOME 30 YEARS AGO, NASA's Magellan mission "closed the book" on Venus. Now, a new generation of astronomers is reconsidering the hellish world as a mystery begging to be solved (*S&T:* Oct. 2021, p. 18). A special session at this year's Lunar and Planetary Science Conference (LPSC) homed in on the planet's shrouded history.

Though Venus is inhospitable now, some models of the planet's evolution have suggested that it might have been habitable as recently as 700 million years ago. However, the Venusian atmosphere appears to contradict those models. As oceans evaporated, hydrogen would have escaped Venus, leaving heavier oxygen behind. Yet there are only trace amounts of oxygen in the atmosphere today.

At LPSC, Sasha Warren (University of Chicago) and colleagues provide a way out of this conundrum by

MARS

Mission Update from the Red Planet

TEAMS PRESENTING AT the Lunar and Planetary Science Conference (LPSC) in March provided updates on multiple missions at Mars.

As of the meeting, NASA's **Perseverance** rover had driven nearly 5 kilometers (3 miles) through Jezero Crater, doubling back on a V-shaped path. Before the rover's arrival, scientists thought formations on the crater floor might be made of igneous or sedimentary rocks. Observations have now shown that they're igneous rocks that cooled slowly. It's still unclear whether the formations are volcanic in origin, though; they might be impact melt instead.

Baptiste Chide (Los Alamos National Lab) and team used one of the rover's two microphones to suggesting that the planet might have hidden its oxygen among the basalts of volcanic ash and lava flows. Their model of Venus's atmospheric history opens up the possibility that surface water once existed there.

Another study, however, suggests that Venus never had much water at all. Cedric Gillman (Rice University) and colleagues built a simulation to trace when and how much water was delivered to the surface and where it all went. They consider several paths for water's arrival on the planet, such as volcanic outgassing and delivery via comets, as well as multiple ways for water to escape the atmosphere. Their calculations suggest that Venus hosted at most only a tenth the amount of water in Earth's oceans today.

▲ The desolate surface of Venus, as radar-mapped by NASA's Magellan and Pioneer Venus orbiters

Another focus of renewed interest is a type of Venusian terrain known as *tesserae*. Some have suggested that these regions of deformed, folded rock represent the oldest preserved crust on Venus. As such, they might shed light on whatever global catastrophe(s) Venus endured in its past.

But a new study, led by Paul Byrne (Washington University in St. Louis), describes evidence that some tesserae formed geologically recently — and their formation could even be ongoing.

The studies presented at the LPSC make clear that even the most basic questions about Venus's history remain wide open. Future missions to our sister planet (*S&T:* May 2022, p. 12) will help provide answers.

■ ARWEN RIMMER

---

measure the speed of sound on Mars: 240 meters per second (540 mph), which is slower than on Earth (where it's 342 m/s). Sounds with frequencies higher than 240 Hz travel faster, which means high-pitched sounds arrive slightly earlier than bass.

Meanwhile the **Ingenuity** helicopter, the Little Technology Demonstration That Could, continues to accompany Perseverance and scout out its drives. Even after nearly a year and a regional dust storm, Ingenuity shows no signs of wear, said Matthew Golombek (JPL), and NASA has extended flight operations through September.

Elsewhere on Mars, the **Zhurong** rover that arrived as part of China's Tianwen 1 mission has been driving since May 2021 in Utopia Planitia, a large, flat plain in the planet's northern hemisphere. Using the rover's six scientific payloads, the team is investigating wind-shaped ridges, pitted cones, giant troughs, and craters along the way.

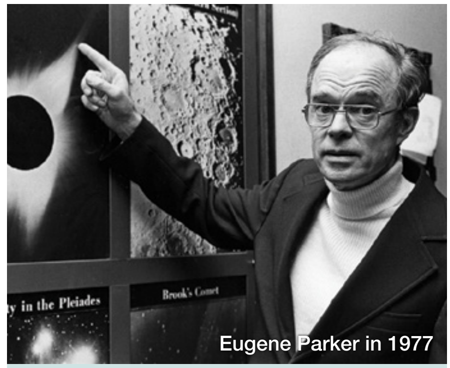
The **Insight** lander's Seismic Experiment for Interior Structure (SEIS) continues to collect seismic data, having logged 1,300 marsquakes and counting. Four recent ones were strong enough, with magnitudes greater than 4, to inform models of the Martian core.

Finally, the United Arab Emirates' **Hope Probe**, on a wide orbit around Mars, is providing continuous global analysis of the Martian atmosphere, including the most complete images yet of the planet's unique aurorae. It has detected a type of aurora known as *discrete* in two-thirds of its observations. Hope also monitors daily surface changes and seasonal variability.

Meanwhile, the European Space Agency has canceled this year's launch of its **ExoMars** mission because of the Russia-Ukraine war.

■ CAMILLE M. CARLISLE, MONICA YOUNG & DAVID DICKINSON

VENUS: NASA / JPL-CALTECH; PARKER: UNIVERSITY OF CHICAGO



Eugene Parker in 1977

OBITUARY

Eugene Parker (1927–2022)

Scientific pioneer and namesake of NASA's Parker Solar Probe Eugene Parker has passed away, having forever altered the way we view the Sun and its interaction with the solar system.

Born in Houghton, Michigan, Parker completed his undergraduate degree in physics from Michigan State University in 1948 and his PhD from Caltech in 1951. He taught at the University of Utah and married his wife, Niesje, before accepting a position in 1955 at the University of Chicago. He remained there for the rest of his career and continued to publish long after he retired in 1995.

In 1957, at 30 years old, Parker proposed the concept of the *solar wind*, the charged particles that stream outward from the Sun. He realized that if the plasma in the solar corona was so hot, it wouldn't stay tied down by gravity but would rather flow outward along open magnetic field lines.

Though two reviewers rejected his conclusion, Parker's colleague and editor of the journal in question, Subrahmanyan Chandrasekhar, overruled them and allowed the paper to be published. Spacecraft observations provided definitive evidence of the solar wind just a few years later. The swirling magnetic field flowing out with these particles was later named the Parker Spiral, and his name now graces several other astrophysical phenomena.

"It is only fitting," says Angela Olinto (University of Chicago), "that Gene's name is quite literally written in our star, the Sun, and in the physics that describes stars."

■ THE EDITORS OF *S&T*

BLACK HOLES

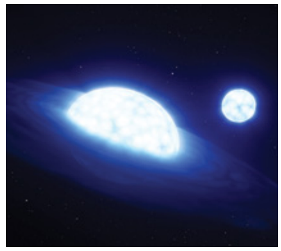
"Closest Black Hole" Doesn't Exist After All

A CONTESTED CANDIDATE for the closest black hole to the solar system has proven to be a mirage, a team of astronomers has concluded.

The putative black hole lay in the binary HR 6819, some 1,000 light-years away in Telescopium. HR 6819 appears to be a single, bright star, but its spectrum reveals two: a rapidly spinning *Be* star that's bright blue and skirted by a disk of hot gas, and a second, also bluish but fainter *B*-type star.

In 2020, Thomas Rivinius (European Southern Observatory, Chile) and colleagues teased apart the binary's spectrum to discover that the *B*-type star was moving through a 40-day orbit. The *Be* star showed no clear signs of movement, so the team proposed a third, invisible companion — perhaps a black hole.

But as we reported at the time (*S&T:* Aug. 2020, p. 8), other astronomers were skeptical. To settle the debate, Rivinius's team and some of the skeptics joined forces. Using imaging and spectroscopic instruments at the Very Large Telescope in Chile, the team was able to split the stars apart and confirm that they lie only 0.3 astronomical unit from each other, not at the much wider separation that would require a close-in, third object to explain the 40-day orbit. Abigail Frost (KU Leuven, Belgium) heads up the team's report in the March *Astronomy & Astrophysics*.



◀ New data show that HR 6819, previously suspected to be a triple system with a black hole, is in fact a system of two stars and no black hole, as shown here in an artist's illustration.

Instead of containing a black hole, the astronomers explain, HR 6819 is actually a unique type of stellar system, in which the *Be* star has sucked the atmosphere off its companion. It has spun itself up and vested itself in gas in the process. The system provides a rare chance to study this kind of "stellar vampirism" in action.

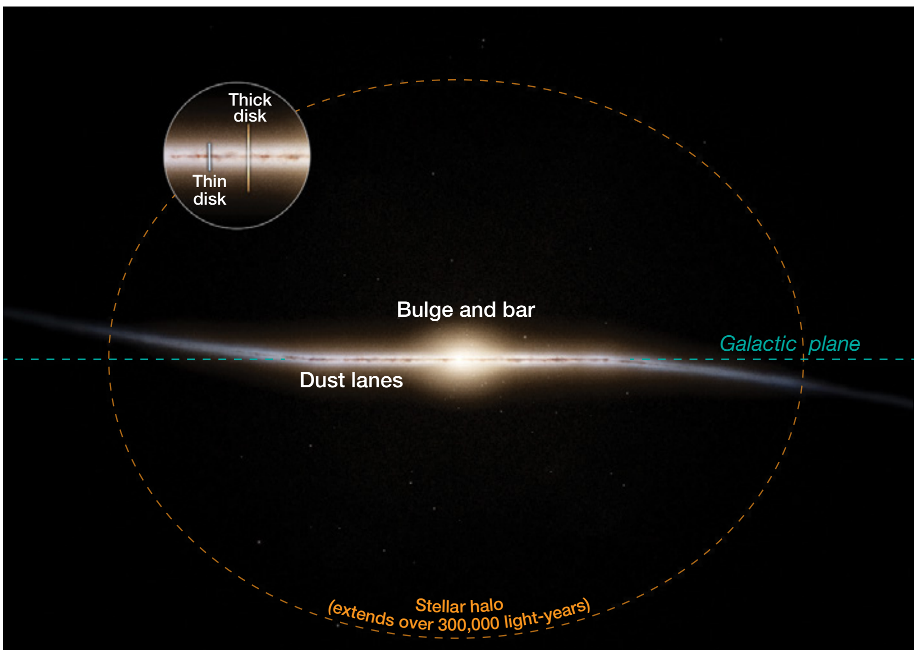
■ CAMILLE M. CARLISLE

MILKY WAY

Multitudes of Stars Reveal Our Galaxy's Early Years

HUNDREDS OF THOUSANDS of subgiant stars in our galaxy have provided a window into the Milky Way's history.

Maosheng Xiang and Hans-Walter Rix (both at Max Planck Institute for Astronomy, Germany) constructed a sort of population pyramid of some 250,000 subgiants in the Milky Way. Subgiant stars still fuse hydrogen in a thick shell around their helium cores, and previous research has established a relationship between their luminosity and age. The European Gaia mission provided the stars' positions, distances, and motions, while the Large Sky Area Multi-Object Fiber Spectroscopic Telescope in China gave the stars' temperatures and chemical composition.



This illustration shows the basic structures of the Milky Way Galaxy.

In the March 24th issue of *Nature*, Xiang and Rix used this population census to put together a timeline of the major events in our galaxy's early history. The analysis sheds light on the origin of the Milky Way's *thick disk*, the fluffier pancake of older stars that's some 6,000 light-years thick. (Newer stars populate the *thin disk*, which is only about 1,000 light-years thick).

From their data, Xiang and Rix conclude that the thick disk of stars started forming around 13 billion years ago, 800 million years after the Big Bang.

Star formation in the thick disk peaked 11 billion years ago, likely a direct result of the merger between our budding galaxy and a smaller intruder nicknamed Gaia Enceladus. In addition to contributing most of the Milky Way's halo stars, the incoming galaxy also caused new stars to form. The stellar baby boom halted 3 billion years later, though starbirth continued at a more moderate pace in the galaxy's thin disk.

Future Gaia data releases may enable an even more detailed reconstruction of the Milky Way's history.

■ GOVERT SCHILLING

TWO STARS: ESO / L. CALÇADA; MILKY WAY: © STEFAN PAYNE-WARDENAAR / MPIA

PROTOPLANETS

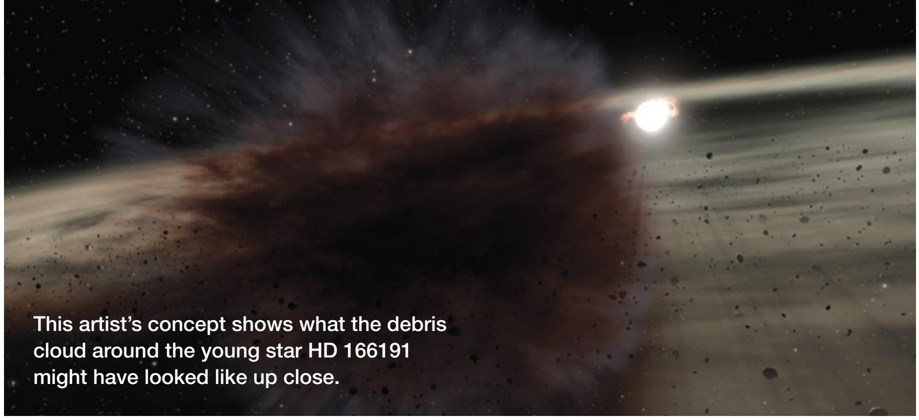
Dusty Debris Transits Star

ASTRONOMERS HAVE WATCHED protoplanetary rubble transit across the face of a star, giving us our best view yet of planetary formation in action.

For years, a group led by Kate Su (University of Arizona) observed young stars with NASA's Spitzer Space Telescope, looking for the warm, infrared signature of planet formation.

Debris disks around two young stars showed signs of past planetesimal collisions. But serendipity struck when they witnessed a large cloud of rubble form, then cross in front of the 10 million-year-old star HD 166191, 329 light-years away in Sagittarius.

Su and colleagues reported in the March 10th *Astrophysical Journal* that the system's infrared emission started brightening in early 2018, and it had doubled by early 2020.



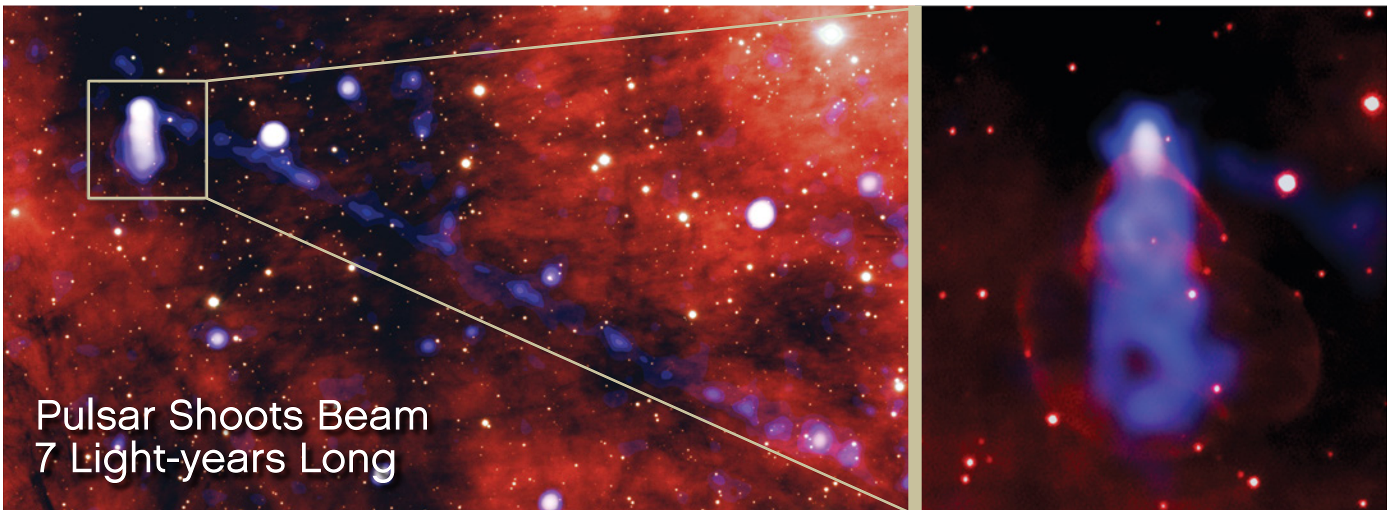
This artist's concept shows what the debris cloud around the young star HD 166191 might have looked like up close.

During this overall brightening, the star's light (visible and infrared) twice plunged steeply before returning to previous levels. The group concluded that two bodies the size of the asteroid Vesta had collided, producing a giant debris cloud that passed twice in front of the star. The second pass was 142 days after the first, corresponding to a distance from the star of 0.62 astronomical unit, or slightly smaller than Venus's orbit around the Sun.

On the first pass, the debris covered an area up to hundreds of times larger than that of the star. The cloud appeared to expand further between the two transits.

"[The researchers] have strong evidence for ongoing collisions of the kind thought to occur during the giant impact epoch," says Scott Kenyon (Center for Astrophysics, Harvard & Smithsonian), who was not involved in the study. The observations thus provide a sanity check on computer simulations describing the violent early years of planet formation.

■ JEFF HECHT



Pulsar Shoots Beam 7 Light-years Long

This image tells the story of a pulsar as it speeds through space via a combination of visible light (red, brown, and black), collected by the Gemini telescope through a hydrogen-alpha filter, and high-energy photons detected by the Chandra X-ray Observatory (blue).

PSR J2030+4415 is a city-size stellar core that whirls around three times every second, 1,630 light-years away in Cygnus. When Martijn de Vries and Roger Romani (both at Stanford University) first observed its X-ray emission, they saw not only the pulsar and the glow of energetic particles trapped within its magnetic field, but also a thin, straight beam that trailed off the edge of the discovery image like a celestial version of Harold's purple crayon. So de Vries and Romani asked for additional observations (more pages for Harold) to determine the beam's true extent: 15 arcminutes across the sky, or 7 light-years long. The results will appear in the *Astrophysical Journal*.

The beam formed a couple decades ago, when the pulsar punched through the bow shock that preceded its journey through space. The breakthrough briefly aligned the pulsar's own magnetic field lines with those of the galaxy, allowing a thin thread of electrons and positrons to escape.

Events such as this one might help astronomers explain how energetic particles, including antimatter, spread throughout the galaxy.

■ MONICA YOUNG

See more images and details at https://is.gd/phaserpulsar.

DEBRIS CLOUD: NASA / JPL-CALTECH; PULSAR: X-RAY: NASA / CXC / STANFORD UNIV. / M. DE VRIES; OPTICAL: NSF / AURA / GEMINI CONSORTIUM

Searching for Intelligence on Earth

Space exploration can serve as an antidote to war. And vice versa.

IN OCTOBER 2007 I attended celebrations in Moscow for the 50th anniversary of Sputnik 1. Space Age ironies were on full display. The festivities highlighted both the militaristic motivations that launched us off Earth, and the belief in an enlightened, unified human future that drove, and still drives, many involved in space exploration. Post-Soviet Russia, though experiencing upheavals, seemed plausibly on a path toward a peaceful, open society.

Several Russian scientists shared with me in private the traumas they'd lived through. Following the Soviet collapse, their research programs had been stretched thin, but they'd had, at least on paper, plans for bold new planetary missions. And in 2007 we made plans, at least on paper, to work together in exploring our common solar system.

Now, along with the cities of Ukraine, all that lies in ruins.

Among the many reasons I was drawn to space exploration was that it seemed to transcend earthly conflicts and to promise a future when, as seen from a distance, our planet would seem so obviously small and interconnected that a mature humanity would never return to deadly fights for perceived power over tiny patches of it. Yet here we are, watching wanton, cruel destruction unfold amid the renewed specter of nuclear annihilation.

From a cosmic perspective, geopolitics can seem pathetic and shortsighted. Even during the height of the Cold War, space scientists from both sides found ways to cooperate and assist each other's missions.

In one example, Russian astrophysicist Iosif Shklovsky and American Carl Sagan (both of Ukrainian Jewish background) reached across the Iron Curtain to collaborate on the landmark 1966 book *Intelligent Life in the Universe*, which anticipated much contemporary thought in astrobiology and SETI. They acknowledged that high-tech war could be the reason why our galaxy isn't full of chatter. Yet they also pictured civilizations maturing beyond our current "technological adolescence," surmising that truly advanced societies would have long ago left behind such primitive, self-destructive practices.

As of this writing, Vladimir Putin's army is committing unspeakable crimes, attacking cities and bombing hospitals and schools. These atrocities are unforgiveable. There will be no more talk of shared missions to the planets — not with this version of Russia. I fear for my Russian colleagues, good people caught up in a bad system.

As long as this MADness, this threat of mutual assured destruction, persists, I have to ask: Doesn't that describe us all — good people caught up in a bad system? Why didn't we get rid of our Dr. Strangelove machines during the post-Cold War thaw? Anyone who thinks it's unrealistic to dispose of nuclear weapons entirely has to ask how realistic it is to think we could go on not using them ever again. If we are to survive to become the kind of galaxy-spanning civilization Shklovsky and Sagan dreamed of, we'll have to find other ways to resolve our differences, and ways to keep sociopathic demagogues out of power.

I do think that humanity has a chance to live long and prosper, to seed a truly sustainable society that could eventually sprout throughout the galaxy. But right now, any ETs exploring our solar system, seeking new prospects for their galactic club of wise civilizations, would probably take a quick scan of Earth and keep on searching.

▲ **DARKNESS REIGNS** A 2011 crew on the International Space Station that included American and Russian astronauts took this oblique view of Ukraine (Kyiv, top center). Today, future cooperation in space between Russia and the West now remains deeply uncertain.

NASA

■ Contributing Editor **DAVID GRINSPOON** is author, among other books, of *Earth in Human Hands: Shaping Our Planet's Future.*

 by Christopher Crockett

The Elusive Planet X

CALTECH / R. HURT (IPAC)

IS THERE A WORLD OUT THERE?
Artist's concept of a distant mini-Neptune, looking back on the Sun. If Planet X exists, its average distance from the Sun is perhaps 10 times larger than Neptune's is.

Some astronomers suspect that a ninth planet lurks in the most distant reaches of the solar system. *Does it really exist?*

Of everything we know about our solar system, the number of planets orbiting the Sun might seem like one thing that we should have nailed down.

And yet, there have been rumors of another world, lurking beyond Neptune. This is no dwarf planet like Ceres or Pluto, but a world with some heft, possibly five to 10 times as massive as Earth. The primary hints of its existence come from a paltry number of diminutive icy objects whose orbits all appear to be bunched up in one quadrant of the solar system (*S&T:* Oct. 2017, p. 16).

For the past six or so years, Konstantin Batygin (Caltech) has been at the forefront of the hunt for this elusive world, dubbed by some as Planet X, by others as Planet Nine (sorry, Pluto).

"Here's the update," he says. "We haven't found it yet."

That's not for lack of trying. Planet sleuths have been hunting in various ways — searching through old telescope images for a possible glimpse of this phantom planet; looking for more of those tiny objects, to see if they're bunched up as well; poring over data on the small bodies we do know about, to see what other secrets they hold; and running computer simulations to better understand how an extra planet might interfere with the motions of things that orbit far from the Sun.

Despite all that effort, we're no closer to a clear answer. Some say the evidence is shaky. Some say it's a slam dunk. Everyone says we need more data, with a lot of hope pinned on the upcoming Vera C. Rubin Observatory, which could settle the debate once and for all.

"It is the way science works," says Scott Sheppard (Carnegie Institution for Science), one half of the duo who first proposed that this planet might exist. "At some point, the data reach a tipping point where the hypothesis is either ruled out or it becomes much, much stronger. And we just haven't reached that yet."

Hypothesis Testing

Astronomers have been predicting the existence of additional planets for more than 170 years. Irregularities in the orbit of Uranus led to the discovery of Neptune in 1846. Further apparent orbital oddities in those planets and in some comets sparked many suggestions of additional planets throughout the late 19th and early 20th centuries. One of those proposals triggered the search that, by chance, found Pluto.

So, when Sheppard and Chad Trujillo (now at Northern Arizona University) suggested in 2014 that there may be a planet hiding far from the Sun, they became part of a long legacy. The pair had been surveying the sky for small icy bodies beyond Neptune and the ring of frozen relics in the main Kuiper Belt. They noticed that all objects beyond a certain distance from the Sun made their closest approach to our star near where their orbits crossed the *ecliptic*, or the midplane of the solar system.

That was odd, because subtle yet persistent tugs from the known giant planets should make those orbits drift. Over the age of the solar system, they should have slowly arranged themselves in random orientations — unless something was corralling them. And these orbits didn't appear to be strongly influenced by the known giant planets. Perhaps, Sheppard and Trujillo suggested, there was another planet out there, holding these orbits in place.

Two years later, Batygin and Mike Brown (Caltech) took a closer look. Zeroing in on a handful of "extreme" objects — those that are far enough from the Sun to keep well clear of Neptune — they not only confirmed what Sheppard and Trujillo saw but also reported that the orbits were physically aligned, all stretching out roughly in the same direction away from the Sun. They agreed that the probable culprit was a planet, roughly 10 times as massive as Earth, with an average distance from the Sun of several hundred astronomical units (a.u.) — about 10 to 30 times farther out than Neptune.

In the years since, this possibility has kept some planetary scientists busy examining and reexamining the evidence. "There've been three themes through which the Planet Nine hypothesis has progressed," Batygin says. "Data analysis, theory, and actual observations."

Analysis of available data has produced the most controversy. "There are a lot of observational biases in discoveries of the outer solar system," says Samantha Lawler (University of Regina, Canada). If those biases aren't accounted for, she adds, "you can find some really weird things, like it looks like there's clustering when there's not."

In the case of Planet X, there appear to a bunch of objects whose perihelia are near the ecliptic. But observers are biased toward finding things when they are near perihelion — because that's when they're closest to the Sun and therefore brightest — and they tend to search along the ecliptic, because that's where most solar system stuff resides.

There are more subtle biases as well, Lawler notes. Seasonal weather patterns in Hawai'i and Chile — where many planetary surveys are conducted — mean certain parts of the sky have better telescope coverage than others, which could make it look like some extreme Kuiper Belt objects are crowding up on one side of the solar system.

Accounting for these biases is tricky. It requires knowing everything about the observations, including where the telescope pointed (including where it didn't find anything) and how faint an object it could have seen. Unfortunately, for many Kuiper Belt finds, much of that info is lost.

"What the community has been trying to do for a few years now is not only try to find objects but try to understand what objects a given survey can find," says Pedro Bernardinelli (University of Washington). This type of work involves limiting analyses to just the Kuiper Belt objects found by a single survey — one which has a good grasp of all its biases — and seeing if the orbital clustering shows up there in some statistically meaningful way.

These analyses keep saying there's no evidence for an extra planet.

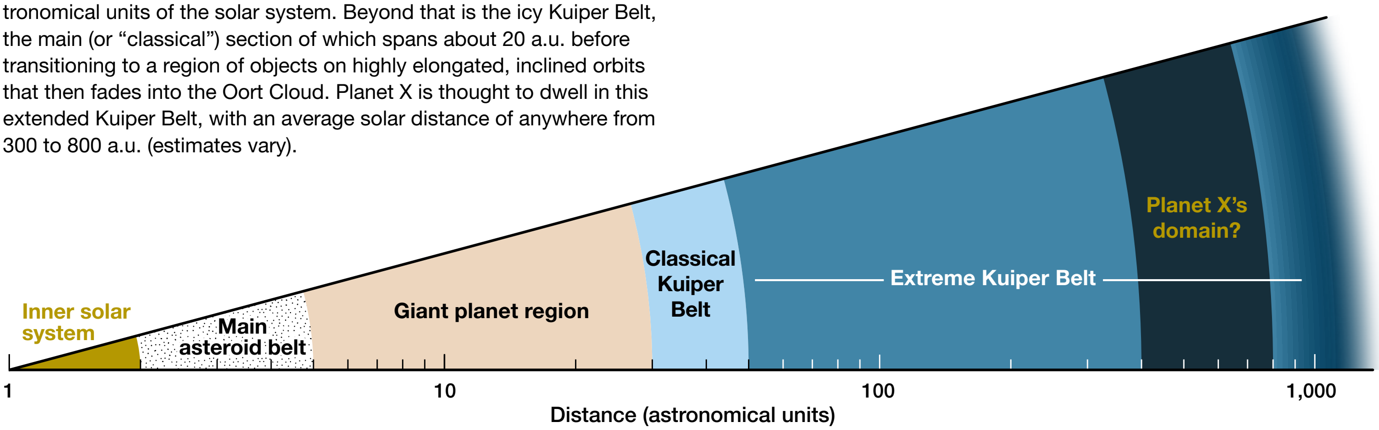
The Outer Solar System Origins Survey, or OSSOS, spent four years focusing on two regions of sky near the ecliptic. During that time, the project tallied more than 830 new Kuiper Belt objects, four to eight of which fit some definition of "extreme" — that is, some combo of perihelion distance and orbit size that keeps them mostly detached from the gravitational sway of Neptune. Based on computer simulations of what OSSOS could find, these extreme objects could be part of a larger, unseen population spread uniformly around the Sun, the team reported in 2017.

"We can't say Planet Nine doesn't exist," Lawler says. "But we don't have evidence in favor of the reason for it existing."

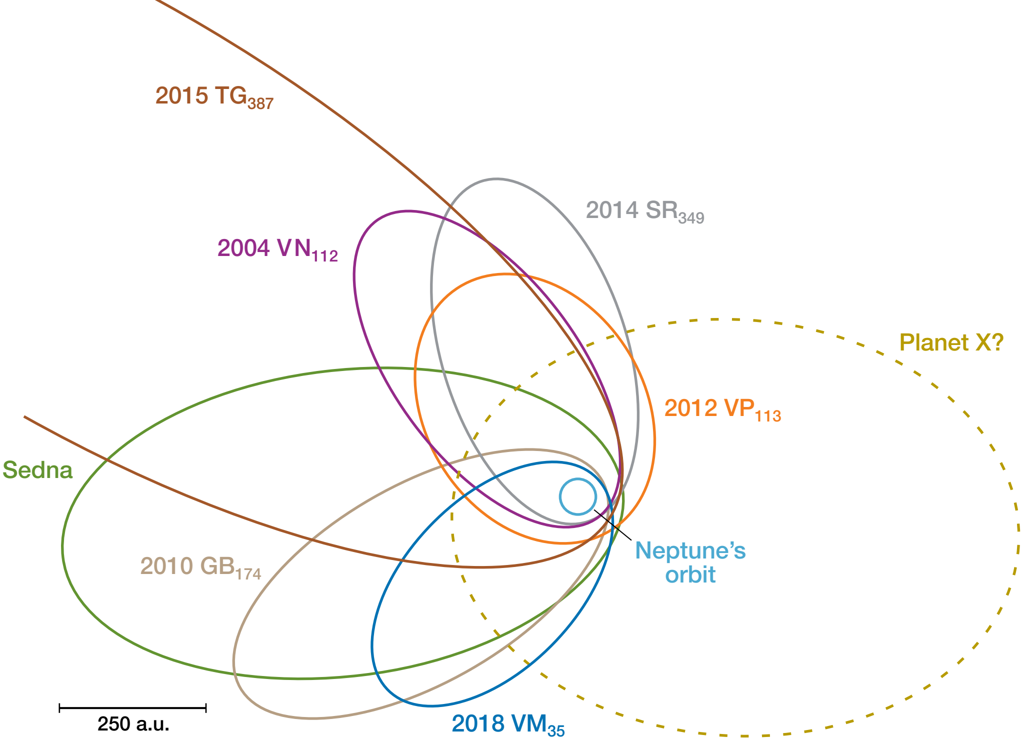
Recently, two other teams came to similar conclusions.

The Dark Energy Survey (DES) wasn't designed to look for things in the solar system. It spent six years scanning

▼ **DISTANT NEIGHBOR?** The known planets inhabit the inner 30 astronomical units of the solar system. Beyond that is the icy Kuiper Belt, the main (or "classical") section of which spans about 20 a.u. before transitioning to a region of objects on highly elongated, inclined orbits that then fades into the Oort Cloud. Planet X is thought to dwell in this extended Kuiper Belt, with an average solar distance of anywhere from 300 to 800 a.u. (estimates vary).



GREGG DINDERMAN / S&T



STRANGE CLUSTERING Several objects in the extreme regions of the Kuiper Belt follow stable orbits that are notably aligned, suggesting the presence of a shepherding planet. Astronomers have found additional objects on unstable orbits in these regions that show weaker signs of clustering behavior, but they're omitted here for clarity.

GREGG DINDERMAN / *S&T*, SOURCE: WORLDWIDE TELESCOPE AND K. BATYGIN & M. E. BROWN / *ASTROPHYSICAL JOURNAL LETTERS* 2021

a wide swath of southern sky for supernovae and patterns in large-scale cosmic structure. But plenty of locals have photobombed the survey, including 812 small bodies beyond Neptune, 458 of which had never been seen before.

Of the nine most extreme objects they saw — those which should be most sensitive to the proposed planet — they didn't find evidence of orbital clustering, the team reported in February 2022. "We can't really differentiate between a clustering effect caused by Planet Nine . . . and just having things everywhere," says Bernardinelli, a DES team member. "In other words, we're finding things where we're looking for things."

Going further, a team led by Kevin Napier (University of Michigan) combined data from OSSOS, DES, and an ongoing survey led by Sheppard and Trujillo. Those data also show no clear evidence of clustering, the team reported in April 2021.

All of this might seem like bad news for Planet Nine. But the pro–Planet Nine crew thinks these analyses, while well done, also miss the mark. Each survey on its own has found relatively few of these extreme objects, Batygin says, and small numbers can lead to wonky statistics.

These surveys also aren't great for testing the Planet Nine hypothesis, Sheppard says. The Dark Energy Survey overlapped with only one stretch of the ecliptic, while OSSOS focused on two relatively small patches. "It's hard to . . . get rid of observational biases if you haven't looked in other places," he says. Scanning along the whole ecliptic, for example, could clarify whether extreme objects are actually hanging out in one part of the sky, or if it just appears that way because that's where astronomers keep looking.

To maximize the number of objects, Batygin and Brown have repeatedly turned to the Minor Planet Center (MPC), a database that records when and where every Kuiper Belt object, or KBO, was discovered. "The full census of KBOs that are discovered on the night sky provides you with a map of where people have looked," Batygin explains. (Others counter, however, that the MPC doesn't record where past teams have looked and not found anything worth reporting.)

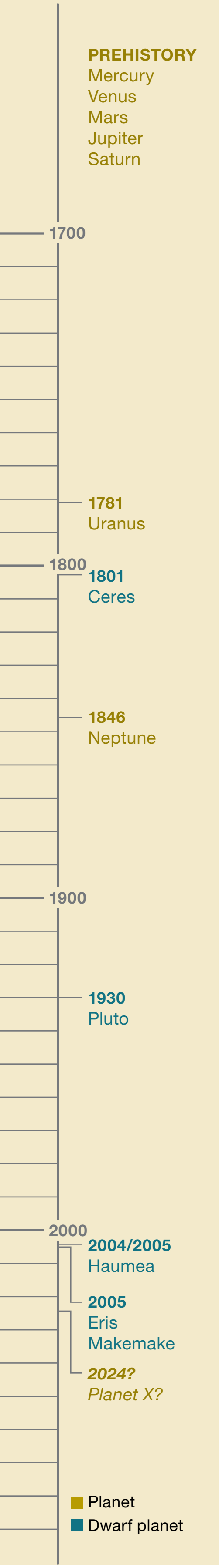
By using the orbits and brightnesses of known KBOs, Batygin and Brown simulated a "synthetic" population whose elliptical orbits are orientated uniformly around the Sun. For each known KBO, they calculated which members of this synthetic population should have been spotted in the same patch of sky, if they existed. Using that info, Batygin and Brown estimated which orbit orientations have historically been more likely to be seen than others.

And, of course, past observations *are* biased. But not in a way that is likely to produce the observed clustering patterns, Brown reported in 2017 and, with Batygin, again in 2019. They calculate that the odds that all the clustering is just a coincidence is about 0.2%. "I'm not a gambling man, but that's pretty good," Batygin says.

Part of the trouble in reconciling all these results is that every group has focused on a different cache of objects in the extended part of the Kuiper Belt. "No one agrees on the definition of 'extreme,'" Bernardinelli says.

And muddled definitions lead to muddled results. "The question 'Is the population overall clustered?' is not the right question," Batygin says. "The right question is whether the *stable* Kuiper Belt objects in the distant solar system are clustered." Here, stable refers to bodies that — in the absence of an extra planet — are never sharply redirected by the gravity of Neptune.

But the bigger issue may be that both sides of the debate are trying to wring a definitive story out of too few characters. "I



◀ **DISCOVERY TIMELINE** Excluding Earth, astronomers currently know of seven major planets and at least five dwarf planets in the solar system. (There are six additional dwarf planet contenders in the Kuiper Belt awaiting official approval, with the prospect of dozens more.) Could there be another planet lurking out there somewhere — and will we soon find it?

talk to certain groups, they say, 'This planet doesn't exist, it's not possible, almost zero percent,'" Sheppard says. "You talk to other groups, and they're saying it's 100 percent. Both of those groups, I would say, have rose-colored goggles on." He puts himself more in the middle. "I would say it's more likely than not that there's a planet out there . . . but we're just not using that many objects."

Getting a Better Picture

One way to settle the debate would be to see the planet directly. "Lots of predictions of Planet X are that it's pretty bright," says David Trilling (Northern Arizona University). By "bright," he means roughly magnitude 24; Pluto is 10,000 times brighter right now, at magnitude 14. "You just need to be looking in the right place."

And that's the rub. The solar system is big, and telescopes see only a sliver of it at a time. Planet Nine's proposed orbit is rife with uncertainty. And even if it were better constrained, there is zero intel about where along that orbit the planet might be.

That hasn't stopped people from trying. Over the past several years, many researchers have combed through archival images from telescopes in space and on the ground, in visible and infrared light, to see if the planet ever wandered into some past survey's field of view. Even a group studying the cosmic microwave background got into the game, looking through seven years of data from the Atacama Cosmology Telescope for possible thermal emissions from a remote planet. If Planet Nine is out there, it has eluded our gaze so far.

Better odds lie with building up a larger census of these extreme KBOs.

One way forward might be to find more *high-inclination objects*. One prediction is that Planet Nine's gravity could lift some extreme KBOs into orbits that are highly tilted relative to the rest of the solar system. In 2018, Juliette Becker (now Caltech) and colleagues reported finding the first of such a cohort. "In the known solar system, you really can't produce an object like this," Becker says. Locating a few more could clarify whether this one was just an oddball or part of a larger, undiscovered family.

Others are trying to figure out if the orbits of the extreme bodies are truly bunched up. Partly to that end, Sheppard and Trujillo, along with David Tholen (University of Hawai'i), have been continuing their survey of the outer solar system, ongoing since 2012. "The main goal of our survey is to make sure we get rid of those observational biases or make them pretty much minimal," Sheppard says. "To do that, you need to observe very uniformly."

Using the Subaru telescope in Hawai'i and the Víctor M. Blanco telescope in Chile, the team has been observing a wide band straddling the entire ecliptic at all times of year, sweeping the gaze of these two telescopes in a full circle around the Sun to tally up extreme KBOs in all quadrants of the solar system, not just the one whether they seem to show up. The hope is to triple the number of known objects on these distant orbits.

However, they've been coming up a bit short. "We're finding fewer of them than we thought we'd find," Sheppard says.

To Sheppard, that suggests that the orbital clustering might be real. The spot on the sky where these objects bunch together was covered early on in their survey. If the distant KBOs truly are hanging out in one quadrant of the solar system, then observing elsewhere won't turn up many more.

"Right now, the statistics are still borderline," Sheppard says. "The stats are a little better than or similar to what we saw a few years ago."

Another survey, the DECam Ecliptic Exploration Project (DEEP), is using a large camera on the Blanco telescope to scan four patches of sky along the ecliptic, going wider and fainter than other similar projects. Entering its third year, the survey will hopefully find between 5,000 and 10,000 new objects beyond Neptune, says project lead Trilling, substantially increasing the known census.

In particular, the survey could find more of these very distant objects that have been at the heart of the Planet Nine debate, Trilling says. Though it's not yet clear, he cautions, if the calculated orbits will be refined enough to put better constraints on the planet's trajectory.

But what most in the community are waiting for is the Vera Rubin Observatory.

Scheduled to start science operations in 2024, the Rubin Observatory in northern Chile will spend at least 10 years sweeping all the sky it can see every few days, providing an unprecedented view of anything that changes — including the motions of tiny things in the outer solar system.

Researchers expect the tally of objects seen orbiting past Neptune to increase by about a factor of 10. "Today we know of only about 4,000," says Megan Schwamb (Queen's University Belfast), cochair of the project's Solar System Science Collaboration. After Rubin, "it's going to be about 40,000."

Crucially, astronomers will have a good handle on Rubin's observing biases. For the Planet Nine hypothesis, "I feel like

TERRI DUBÉ / *S&T*

that's going to say the answer: yes or no," Schwamb says. "We're going to find so many Kuiper Belt objects, if there's any influence of a distant planet on that disk [of objects], we might start seeing that in more subtle ways."

What's more, Rubin has a good shot at directly seeing the planet. Based on available estimates about the planet's orbit and size, the world might be bright enough to show up in the observatory's camera and could be seen along much of its orbit, Trilling and colleagues calculated in 2018.

"It will not reach all of the necessary parts of the sky to have the final word on Planet Nine," Batygin says. "But if Vera Rubin doesn't discover Planet Nine, at least it should discover these stable, long-period Kuiper Belt objects."

Even Rubin's persistent gaze may not be enough to settle the debate, though, as the project may not be optimized to see lots of objects distant enough to be swayed by an extra planet, Sheppard cautions. "It will definitely find more of these. . . . The question is, how many more?"

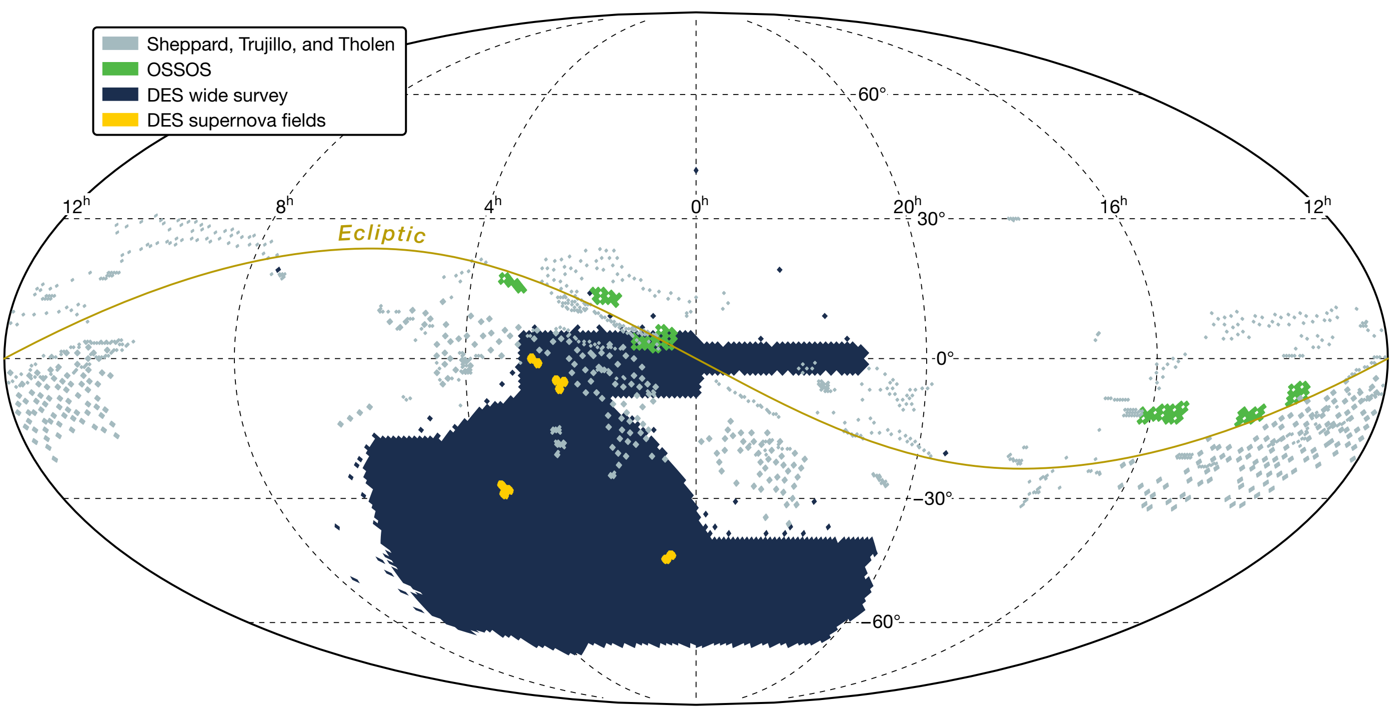
If it turns out Planet Nine doesn't exist, that doesn't mean the search was in vain. "This whole Planet Nine debate has basically made people care a lot more about the outer solar system," Bernardinelli says. "If we find Planet Nine, that will be amazing. If not, then we have a lot of explaining to do. But in the end, it only matters that we've learned things either way."

Planet Nine, if nothing else, has helped sharpen focus on the tiny, remote, frozen residents of our solar system. Far removed from the gravitational influence of the known giant planets, the motions of these icy denizens preserve a tale about how the planets formed and jockeyed for position, and about the neighborhood in which our Sun was born some 4.6 billion years ago.

"The solar system has been mapped out pretty well out to Pluto. But it has not been mapped out well beyond that," Sheppard says. "And we don't know what's out there."

▲ **UNDER CONSTRUCTION** The Vera C. Rubin Observatory, seen here at twilight on Chile's Cerro Pachón in April 2021, will discover many thousands of distant Kuiper Belt objects. Science operations will begin no sooner than December 2023.

■ **CHRISTOPHER CROCKETT** has a PhD in astronomy and is now an award-winning science journalist based in Arlington, Virginia. He looks forward to the next Planet Nine update, whenever that may be.



▲ **NOT ALL SURVEYS ARE THE SAME** Shown here are the coverage maps for the three major sky surveys of the region beyond Neptune: the Dark Energy Survey, the Outer Solar System Origins Survey, and the ongoing survey by Sheppard and company. The latter two follow the ecliptic, where solar system objects tend to lie. DES has a notably different footprint because it's a cosmological survey.

RUBIN OBSERVATORY: RUBIN OBSERVATORY / NSF / AURA; MAP: K. J. NAPIER ET AL. / *PLANETARY SCIENCE JOURNAL* 2021 by Ted Forte

NGC Globulars for

Go beyond the Messiers and explore a collection of lesser-known clusters.

Globular clusters are impressively dense, spherical collections of stars typically found in the halos of spiral galaxies. We inherit the term from William Herschel's paper "On the Construction of the Heavens," published in 1785 in the *Philosophical Transactions of the Royal Society of London*, in which he described a group of objects that "form themselves into a cluster of stars of almost a globular figure."

Of the roughly 190 globular clusters associated with our galaxy, about 40% are found in the richest parts of the summer Milky Way. In 1918, the American astronomer Harlow Shapley mapped the distribution of globular clusters to determine the Sun's position within the galaxy. He correctly deduced the location of the galactic center — pinpointing it in Sagittarius — based on the high concentration of globular clusters found in that direction. He also demonstrated that our Sun isn't located at the galaxy's core as star surveys implied at the time, but instead is in the disk some 27,000 light-years from the center. This was a significant milestone in our understanding of the cosmos.

It's no surprise, then, that more than half the globular clusters listed in the Messier catalog lie in Sagittarius, Ophiuchus, and Scorpius. Many of the 16 Messier globulars are well-known telescopic favorites. The *New General Catalogue of Nebulae and Clusters of Stars* records a similar proportion of globulars in the same area of the sky. In this celestial tour, we'll explore some of the more interesting globular clusters in the summer Milky Way that didn't make Messier's list.

With only a few exceptions, I viewed the objects included in this tour with my 18-inch Dobsonian at 197×, but all of them *should* be visible in a 10-inch or smaller scope from a reasonably dark sky. However, detecting a globular cluster is

ESA / HUBBLE / NASA

Summer Nights

not the same as *resolving* it, which refers to how well you can distinguish individual stars within the cluster. The ability to resolve a cluster is determined by several factors, including the size of your telescope, the magnifications employed, the angular size of the object, the brightness of the stars within the cluster, and by how concentrated or compact the cluster appears. When we can see stars as separate, deep into the core of a globular, we say it is *well resolved*; at the other extreme, when we can't separate stars within the main body of the cluster, we say it's *unresolved*.

Messiers Lead the Way

Several of the targets on our tour reside near Messier globulars, which provide convenient starting points for star-hopping. **NGC 6144** in Scorpius lies less than 1° northeast of M4 and just 38′ from Antares. To better see the 9th-magnitude globular, keep the 1st-magnitude star out of the field.

▲ **DECORATED BY A JEWEL** NGC 6401, adorned with a 12th-magnitude star, lies 26,000 light-years away in southeastern Ophiuchus. Note that north is to the right in this Hubble Space Telescope image.

Sources give various distance estimates for NGC 6144, with some putting it at least three times and others as many as five times farther away than M4, the closest globular to Earth at around 6,000 light-years. NGC 6144 is small, faint, and unresolved in smaller telescopes, but I can distinguish about a dozen stars in my 18-inch.

NGC 6284 and **NGC 6293** are both short hops from M19 in Ophiuchus. Herschel discovered these two globulars on successive sweeps two nights apart in May 1784 and in his notes compared them to M19. He included all three clusters in his object sample for a paper published in 1818 in the *Philosophical Transactions* in which he argued that the *profundity* (distance) of star clusters might be deduced from the brightness of their stars. NGC 6284 lies about 1.5° north-northeast of M19 and is small with a fairly dense core and just a hint of resolvability. Next, slide 1.7° east-southeast from M19 to find NGC 6293, which Herschel described as a miniature version of the larger Messier. My 18-inch scope shows it to be small and bright with a dense core, while the outer halo resolves into about a dozen or more stars.

From NGC 6293 it's a 2.1° hop southeast to **NGC 6316**. While only moderately bright and unresolved, detecting this cluster isn't very difficult — a 4-inch telescope at 100× should do. An 11th-magnitude star lies southeast of the core, while a 12th-magnitude star is just west of it. Herschel found NGC 6316 in the same sweep as NGC 6293 and noted it to be bright, round, and resolvable; but even in an 18-inch scope, at best I see it as only mottled and granular.

NGC 6304 appears a little brighter than NGC 6316 but is also unresolved — its core is a bit elongated with a flattened edge. Look for it some 1.4° south-southwest of NGC 6316 and about 3° east-northeast of M62. This object is special to me as it was the final one that I logged for the Astronomical League's Herschel 400 Observing Program, concluding a decade-long endeavor. Herschel discovered all but two of the objects on this tour, and they're included in either the Herschel 400 or Herschel II Observing Programs; nearly all are also listed in the League's Globular Cluster Observing Program. (Go to **astroleague.org** for more on these and other observing programs.)

Head back to NGC 6284 and then continue about 2° north to arrive at **NGC 6287**, the brightest exemplar of the Shapley–Sawyer concentration Class VII, which places it approximately in the middle of the scale. Through the eyepiece it does indeed present a rather intermediate degree of central concentration and a partially resolved outer halo.

Slew about 2.8° west-northwest of NGC 6287 to find **NGC 6235**, which is set within a triangle of 11th- and 12th-magnitude stars. This small globular has an irregularly shaped core that's unresolved in a 10-inch at 200× and a rather ragged-edged halo.

NGC 6355 is about 4.75° east of M19 in a portion of the sky relatively devoid of stars. About its discovery, Herschel commented: "It was preceded by many vacant fields and I had

Shapley–Sawyer Concentration Classes

In the 1920s, Harlow Shapley and American-Canadian astronomer Helen Sawyer Hogg developed a widely used scale to categorize globulars by how concentrated they appear. The scale runs from Class I for the most highly concentrated clusters through Class XII for those displaying almost no concentration toward their centers.

BERNHARD HUBL

▼ **BY THE HEART OF THE SCORPION** Two globular clusters lie by Antares, the smoldering red supergiant in Scorpius. The cluster almost due right of Antares is M4, while the one upper right of the star is NGC 6144. The wisps that envelop Antares and NGC 6144 are part of the nebulosity associated with the Rho Ophiuchi cloud complex. The star at the far upper right of the image is 2.9-magnitude Sigma (σ) Scorpii.

just been saying that I was upon nebulous ground." You can pinpoint it by extending an imaginary line that runs from Eta (η) Ophiuchi to Theta (θ) Ophiuchi another 1.4° to the south-southeast. This small, faint cluster has an unresolved, elongated core.

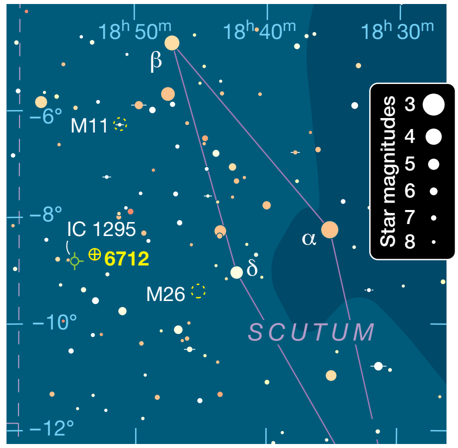
Now head over to M9 and look 1.3° northeast to find **NGC 6356**. While Herschel described it as a miniature M9, it's actually considerably more concentrated than its larger, brighter neighbor. I see it as having a bright, compact core with a fairly resolved periphery.

Slew a little more than 1° south-southeast of M9 to spot small and faint **NGC 6342**. My 8-inch Schmidt-Cassegrain Telescope at 100× shows it as a weakly concentrated patch of nebulosity. A 10-inch scope at 133× reveals a sparkly pattern that hints at resolution. It's pretty in the 18-inch (at 197×). A faint stream of nebulosity trails away to the southwest, terminating at a 12th-magnitude star.

Next, let's shift south from Ophiuchus and over the border into Sagittarius where we find **NGC 6642**, which lies a little more than 1° west-northwest of M22. This small, bright globular has a core that looks lopsided. I can resolve a few stars in the 18-inch, and I note a conspicuous arc of three stars of about 12th magnitude north of the core.

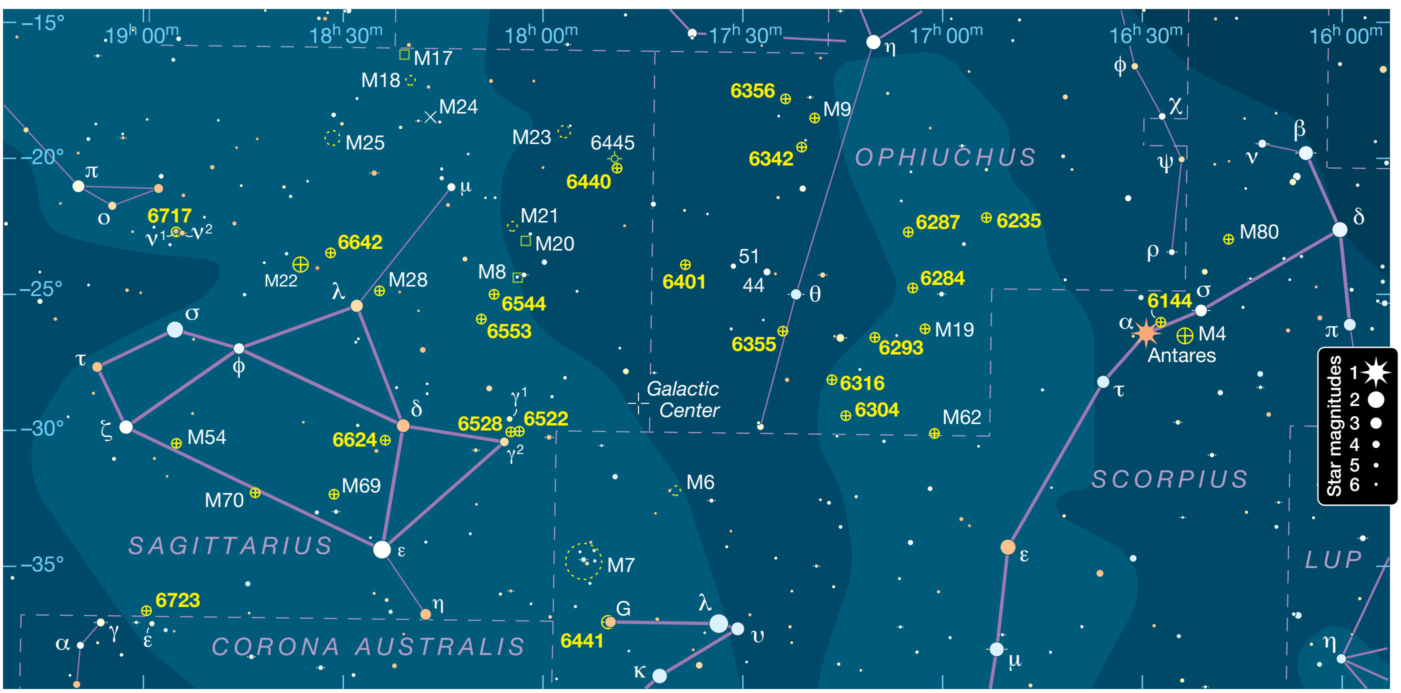
Just off the spout of the Teapot in Sagittarius is a fine globular twofer. **NGC 6522** and **NGC 6528** lie a mere 16′ apart, with NGC 6522 only 4° south-southeast of the galactic center. While NGC 6522 is considerably larger than NGC 6528, both present as small, relatively faint, and mostly unresolved. Herschel discovered the pair on June 24, 1784, and in that same sweep, he also detected **NGC 6624**, ¾° southeast of Delta (δ) Sagittarii, also known as Kaus Media (Middle Bow). The cluster is fairly bright with a rather uniform, circular core, which looks granulated, surrounded by a partially resolved halo. A conspicuous pair of stars of magnitudes 11.4 and 13.5 stand out southwest of the core.

▶ IN THE SHIELD Stop by Scutum to see the pretty pairing of NGC 6712 and a planetary.



Of Planetaries and Nebulosities

Let's go for a little detour into Scutum, the Shield, where we find **NGC 6712**. My notes describe it as "peppery, with stars that almost resolve," and reminiscent in appearance to M107. It lies in a very pretty star field that it shares with the planetary nebula IC 1295. A dark lane sets off a somewhat detached section of the globular's core to the southeast. While it's a little north of our target area, the contrast of globular and planetary makes it well worth the detour. Pop in an O III filter to see the planetary to best effect and remove it to enjoy the globular.



▲ **HEART OF THE MATTER** The bulk of the globular clusters discussed here lie on or near the summer Milky Way. While you're hopping between targets, remember to spend some time enjoying the journey, too.

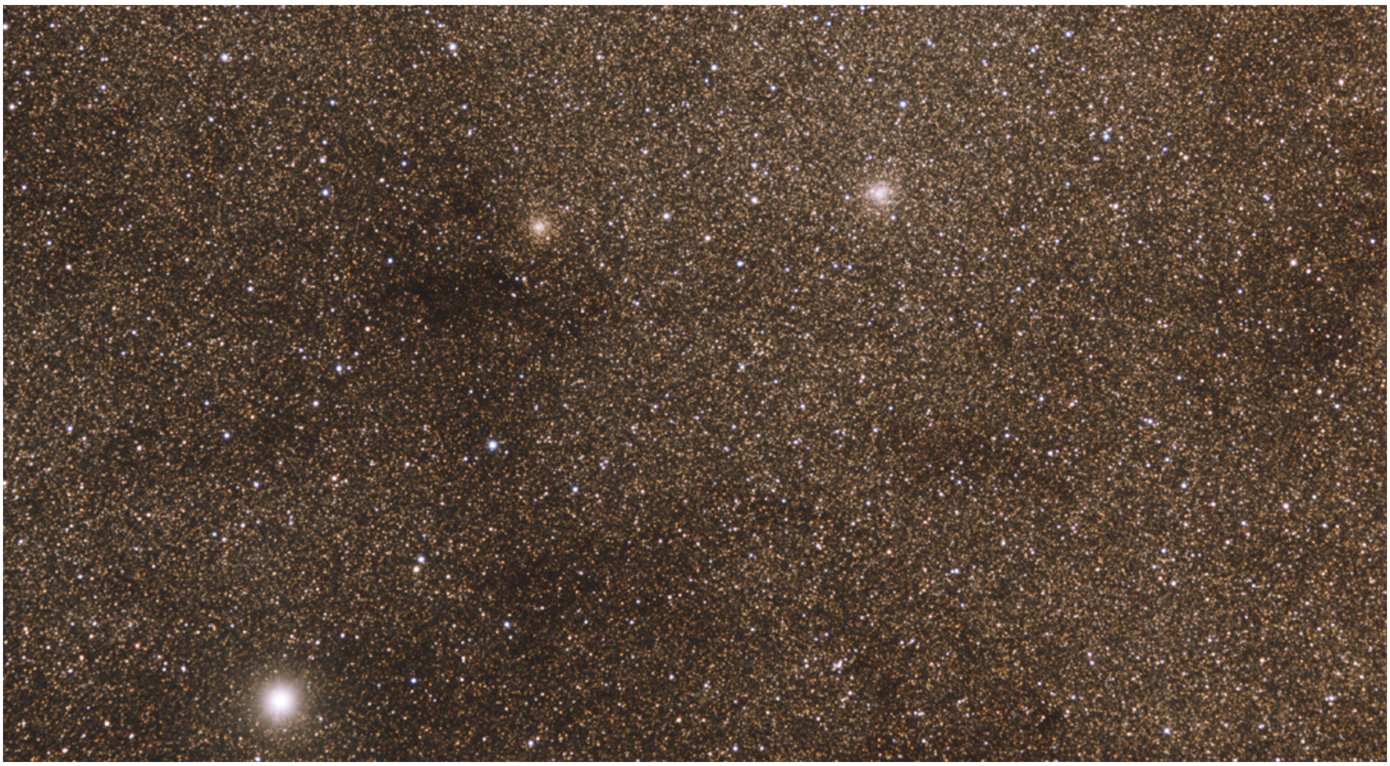
Another very nice globular-planetary pair resides in Sagittarius a bit less than 2.5° west-southwest of the open cluster M23. **NGC 6440** fits in the same low-power field of view as the wonderful bipolar planetary nebula NGC 6445. My favorite sight is in the 18-inch Dob at 88×. The two objects are 22′ apart and appear about equal in brightness though the globular is larger. The cluster contains a moderately bright, unresolved core surrounded by a diffuse halo that appears mottled on the edges.

NGC 6717 is of interest, in part, because of its multiple identities. Herschel first discovered the cluster on August 7, 1784, and logged it as three small stars with nebulosity, even as he was uncertain of its character. It's sometimes conflated with IC 4802 (discovered by Guillaume Bigourdan in 1884), but that object more correctly refers to a nebulous patch on the northeastern edge of the globular. Swedish astronomer Per Collinder was the first to establish the object as a globular cluster in 1931, but then George Abell "discovered" it again in 1952 while examining photographic plates of the first *National Geographic Society — Palomar Observatory Sky Survey*, bestowing it the designation Palomar 9. It's generally considered the easiest of the 15 Palomar globulars to observe visually. The center of NGC 6717 lies about 2′ south of the 5th-magnitude star Nu^2 (ν^2) Sagittarii. I see the object as an unresolved amorphous disk with several stars superimposed on it.

Globular clusters typically comprise very old stars identified, in part, by their low metallicity. **NGC 6723** is therefore unusual for containing a large fraction of younger stars with enhanced metallicity and is an important natural laboratory for the study of these objects. It's located on the Sagittarius-Corona Australis border about 30′ northeast of the 5th-magnitude star Epsilon (ε) Coronae Australis. NGC 6723 shares a low-power eyepiece field of view with a number of reflection nebulae, including NGC 6729, the bright fan-shaped glow surrounding the star R Coronae Australis. The nebula is part of the larger Corona Australis Molecular Cloud, one of the closest star-forming regions at a distance of about 420 light-years. This exceptional globular is large, bright, and fairly easy to resolve. Scottish astronomer James Dunlop discovered NGC 6723 in June of 1826, while surveying the southern skies from Australia.

Planetary *in* a Globular

Dunlop also discovered **NGC 6441** in Scorpius. The globular sits just 4.3′ east of the 3.2-magnitude star G Scorpii. The star tends to overwhelm the cluster but makes an interesting contrast with the dense, unresolved globular. Also a little lost in the glare of the star is the planetary nebula mimic Haro 2-36 (PN G353.5-04.9). This small object is easily overlooked, but it's apparent through an O III filter. Haro 2-36 is a symbiotic star, a binary system usually comprising a red giant

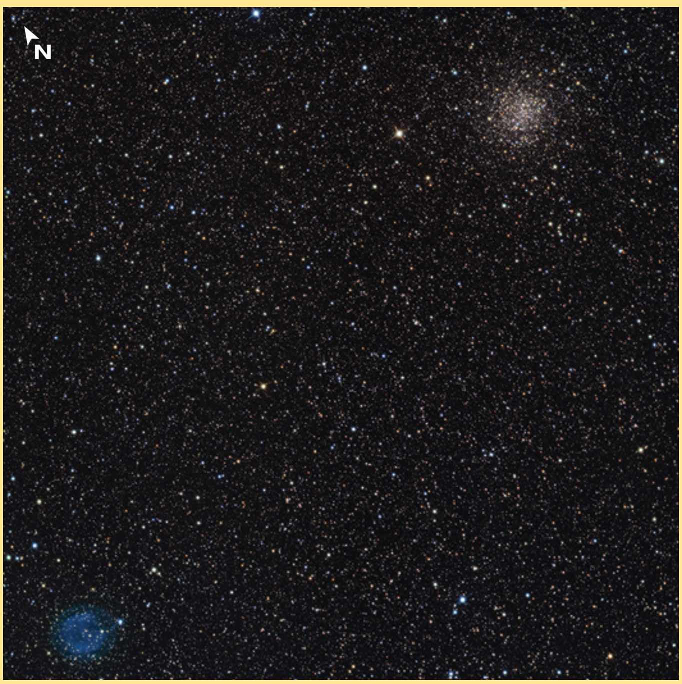


TEAM CHAMELEON / WOLFGANG PAECH / FRANZ HOFMANN

▲ **ABOVE THE TEAPOT'S SPOUT** NGC 6522 (at right) and NGC 6528 are at a similar distance (around 24,000 and 25,500 light-years, respectively) from Earth. With only 16′ separating the pair, that also means they're physically fairly close to each other in space. The clusters are located in Baade's Window, a relatively dust-free region along the line of sight toward the center of the galaxy. The star at the bottom of the frame is 3rd-magnitude Gamma^2 Sagittarii, also known as Alnasl, and lies 25′ from NGC 6528.

▲ **WORTH A VISIT** Fellow Contributing Editor Alan Whitman notes that since neighboring M22 (just 1° away) is so spectacular, NGC 6642 often gets overlooked. But the fainter globular is worth taking a peek. You can always feast your eyes upon a Hubble Space Telescope image such as the one above.

▲ **A GEM AND A GLOB** The northwestern reaches of Sagittarius hold an attractive globular cluster-planetary nebula pairing. Here, the planetary NGC 6445, which also goes by the name Little Gem or Box Nebula, lies 22′ north-northeast of NGC 6440. The cluster is some 27,000 light-years away, while the planetary enthralls us from much closer, at a distance of 4,500 light-years.



▲ **NOT ONLY A CLUSTER** NGC 6712 in Scutum, the Shield, presents a pleasant surprise in the form of the planetary nebula IC 1295 floating ethereally less than ½° to the east-southeast.

▲ **SPARKLY FIELD** Shimmering just below Nu^2 Sagittarii, NGC 6717 lies around 25,000 light-years from Earth. Along with Nu^1 Sagittarii and other field stars, this collection of sparkles makes for a very pretty view.

NGC 6642: ESA / HUBBLE / NASA; NGC 6440: GARY IMM; NGC 6712: JOSEF PÖPSEL / STEFAN BINNEWIES / CAPELLA OBSERVATORY; NGC 6717: DAN CROWSON and a white dwarf (here, the red giant is a Mira variable). The spectra of symbiotic stars resemble those of planetary nebulae, hence these systems are often misclassified as such.

If you want to seek a *true* planetary nebula associated with a globular, aim your scope at NGC 6441 — it's one of only four globular clusters confirmed to contain a planetary. That any globular cluster contains a planetary at all is a bit of a problem for stellar evolution models. Globular clusters are old — almost as old as the universe itself. Their most massive stars evolved off the main sequence long ago. Hertzsprung-Russell diagrams of globular clusters show a very distinct feature in which stars "turn off" the main sequence. As the cluster ages, the turn-off mass decreases. Today the main sequence in most globulars ends just below 0.8 solar masses — planetary nebulae don't form from stars of such low mass.

A couple of scenarios propose how a planetary might form in a globular cluster. First, it may be the evolutionary result of a *blue straggler*, which is a rejuvenated star created either by the collision of two older stars or through mass transfer from one companion to the other. A planetary might also form from the interaction of a binary system where two stars once shared a common envelope.

In 1997, astronomers George Jacoby (then at Kitt Peak National Observatory) and Kellar Fullton (Space Telescope Science Institute) discovered the planetary JaFu 2 in NGC 6441. The 18.6-magnitude object is only about 4.9″ across and lies

▲ **HIDDEN TREASURE** While Haro 2-36 is the blue dot northwest of the star G Scorpii, the globular NGC 6441 conceals the much-tougher-to-detect planetary nebula JaFu 2 (not readily visible in the image).

37″ southwest of the core. I'm unaware of any successful amateur attempts to observe it — if you have, please let me know.

Field Stars Decorate

To finish up, let's visit three globulars that have extra jewels that make them even more attractive. The most striking feature of **NGC 6401** (see page 21) is a 12th-magnitude star southeast of the core. This unresolved cluster appears round with a bright central region. It's located about 4° northeast of 3.3-magnitude Theta Ophiuchi. From Theta, make two jumps of a little more than 1° to the northeast, first to 4.2-magni-

REFLECTIONS The globular NGC 6723, which lies some 27,000 light-years from Earth, skirts the southern border of Sagittarius, while a superb collection of reflection nebulae glow just south in Corona Australis. The dark patch is part of the Corona Australis Molecular Cloud. The pre-main sequence star R Coronae Australis sits left of NGC 6726, the larger of the bright patches left of the globular.

NGC 6441: TEAM CHAMELEON / WOLFGANG PAECH / FRANZ HOFMANN; NGC 6723: RON BRECHER tude 44 Ophiuchi and then east to 4.8-magnitude 51 Ophiuchi. Follow that arc another 1.5° or so to put the globular in your eyepiece. Herschel discovered NGC 6401 on May 21, 1784, the last object he recorded for the sweep of that night.

A field star also marks **NGC 6544**. An 11th-magnitude sparkle lies in the halo about 1.5′ southwest of the core. The periphery of the cluster is seemingly resolved, but it's likely foreground field stars that give that false impression. NGC 6544 appears rather bright and somewhat elongated in the northwest-southeast direction, with an irregular outline. It lies about 1° southeast of the center of the Lagoon Nebula (M8). Another degree southeast of NGC 6544 is **NGC 6553**, which is more open and so appears larger. An 11.8-magnitude star sits 45″ northwest of the core. The globular has a pleasing appearance: It's mostly unresolved yet with considerable speckling. Herschel discovered both objects on May 22, 1784.

Observers who enjoy seeking out globular clusters will find the starry realm of the summer Milky Way a satisfying hunting ground. More than 60 globular clusters sparkle within 20° of the galactic center. It's instructive to recognize, however, that this is a two-dimensional perspective effect. In three dimensions, these objects lie quite far apart. The most distant object on our tour, NGC 6356, at a distance of around 50,000 light-years, is about six times farther than NGC 6544, which is the nearest. Near or far, however, they're some of the most spectacular objects in the night sky. There's hardly a better use for a summer evening than to spend it collecting these celestial jewels in your eyepiece.

■ Contributing Editor **TED FORTE** enjoys observing the deep sky from his home observatory in southeastern Arizona. Have you detected the planetary nebula JaFu 2 in NGC 6441? If yes, please email him at **tedforte511@gmail.com**.

FURTHER READING Several websites aggregate the histories of these and other NGC objects. Among them are: **https://is.gd/steve_gottlieb_ngc**; **http://haroldcorwin.net/ngcic/**; and **https://is.gd/wolfgang_steinicke_ngc**.

Summertime Globulars

Object	Const.	Mag(v)	B * Mag(v)	HB * Mag(v)	Size/Sep	Class	RA	Dec.
NGC 6144	Sco	9.0	13.4	16.5	7.4′	XI	16^h 27.2^m	–26° 01′
NGC 6284	Oph	8.9	—	16.6	6.2′	IX	17^h 04.5^m	–24° 46′
NGC 6293	Oph	8.3	14.3	16.5	8.2′	IV	17^h 10.2^m	–26° 35′
NGC 6316	Oph	8.1	15.0	17.8	5.4′	III	17^h 16.6^m	–28° 08′
NGC 6304	Oph	8.3	14.5	16.2	8.0′	VI	17^h 14.5^m	–29° 28′
NGC 6287	Oph	9.3	14.5	17.1	4.8′	VII	17^h 05.2^m	–22° 42′
NGC 6235	Oph	8.9	14.0	16.7	5.0′	X	16^h 53.4^m	–22° 11′
NGC 6355	Oph	8.6	—	17.2	4.2′	—	17^h 24.0^m	–26° 21′
NGC 6356	Oph	8.2	15.1	17.7	10.0′	II	17^h 23.6^m	–17° 49′
NGC 6342	Oph	9.5	15.0	16.9	4.4′	IV	17^h 21.2^m	–19° 35′
NGC 6642	Sgr	8.9	—	16.3	5.8′	—	18^h 31.9^m	–23° 29′
NGC 6522	Sgr	9.9	14.1	16.9	9.4′	VI	18^h 03.6^m	–30° 02′
NGC 6528	Sgr	9.6	15.5	17.1	5.0′	V	18^h 04.8^m	–30° 03′
NGC 6624	Sgr	7.6	14.0	16.1	8.8′	VI	18^h 23.7^m	–30° 22′
NGC 6712	Sct	8.1	13.3	16.3	9.8′	IX	18^h 53.1^m	–08° 42′
NGC 6440	Sgr	9.3	16.7	18.7	4.4′	V	17^h 48.9^m	–20° 22′
NGC 6717	Sgr	8.4	14.0	15.6	5.4′	VIII	18^h 55.1^m	–22° 42′
NGC 6723	Sgr	6.8	12.8	15.5	13.0′	VII	18^h 59.6^m	–36° 38′
NGC 6441	Sco	7.2	15.4	17.1	9.6′	III	17^h 50.2^m	–37° 03′
NGC 6401	Oph	7.4	15.5	18.0	4.8′	VIII	17^h 38.6^m	–23° 55′
NGC 6544	Sgr	7.5	12.8	14.9	9.2′	V	18^h 07.3^m	–25° 00′
NGC 6553	Sgr	8.3	15.3	16.9	9.2′	XI	18^h 09.3^m	–25° 54′

Angular sizes, as well as B * Mag(v) and HB * Mag(v) values, 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. B * Mag(v) is the estimated brightness of the brightest stars — your telescope must reach this magnitude to partially resolve the cluster. HB * Mag(v) is the estimated magnitude of the horizontal branch — if your telescope reaches this magnitude, you'll see a well-resolved cluster. Class refers to the Shapley–Sawyer scale.

 by Douglas MacDougal

Charles Greeley Abbot

and the Epic Hunt for the Solar Constant

Unlocking the Sun's secrets is an ongoing challenge that got its start in the 19th century.

With satellite missions continuously streaming solar data from space, it's hard to imagine a time when it took years of effort to wring out even the smallest bits of dependable information about the Sun. Yet, despite all the progress, basic questions a century old remain unresolved. How much total power does the Sun produce, and is it truly constant? Answers remain elusive. Understanding how our nearest star works now has renewed importance since a firm value for the solar output (*total solar irradiance*, or TSI) is a vital component in climate modeling and global energy balance calculations.

For most of the 19th century, almost nothing was known about how the Sun worked. No one knew the causes of sunspots, faculae, prominences, or anything about the Sun's interior. Even the most obvious questions were hair-pulling puzzles. How was the Sun's heat generated and sustained? Is it stable or variable? How long will it last? And most obvious of all, how hot is it? In 1876, the Paris Academy of Sciences offered a prize to anyone who could determine the Sun's surface temperature. Up for grabs were thousands of francs and international prestige. The game was afoot.

Getting Warmer

An early, promising approach was to simply focus the rays of the Sun on a container of water (or other liquid) and time how long it took to heat up. A hot Sun would warm the liquid more quickly than a cool Sun. English astronomer John Herschel tested the concept in 1837 while at the Cape of Good Hope in South Africa. Then, in that same year, experiments by physicist Claude Pouillet showed that 1.76 grams of water under the French Sun warmed 1°C in one minute. (This can also be expressed as 1.76 calories per square centimeter per minute.) He named this value the *solar constant*.

It was a beginning, but data only make sense in context. Only repeated experiments over long periods would reveal if the solar constant were truly a *constant*. But there were two immediate problems. The first is Earth's atmosphere. We humans exist at the bottom of a moving ocean of atmospheric gases. How did that affect the results? And what about different parts of the world, altitudes, weather conditions, and times — how would they influence the outcomes? A second major problem was that, until the late 19th century, there was no way to mathematically relate Earthly measurements of heat to a reliable value for the Sun's surface temperature.

Tackling even the first of these problems was a steep challenge. Early investigators assumed that the task was simply to determine the degree to which sunlight was diminished before it reached their detectors. Estimates of total atmospheric absorption ranged wildly from about 30% to more than twice that, leading to estimates of the Sun's surface temperature that were all over the map. Something was plainly wrong.

The key turned out to be in the Sun's rainbow of colors. As early as 1814, German lens maker and physicist Joseph von Fraunhofer had been examining sunlight using the spectroscope he'd invented, but at the time no one knew how (or even *if*) spectroscopic information could reveal the temperature of the Sun.

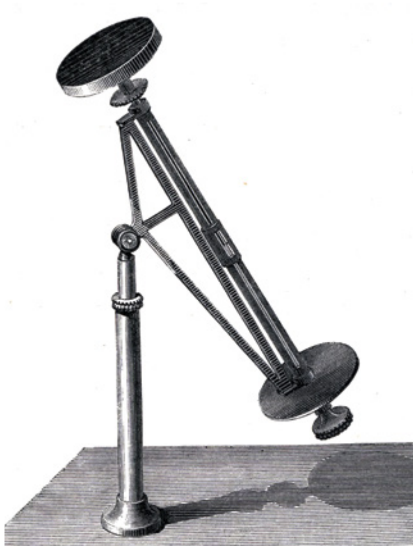
Fraunhofer's solar spectrum presents an intriguing forest of dark lines of unequal intensity. As shown on page 32 (lefthand graph), plotting intensity against wavelength results in a rounded curve interrupted by occasional sharp dips. When sunlight passes through Earth's atmosphere, absorption features (the so-called *telluric lines*) appear superimposed upon the spectrum, most prominently from the presence of atmospheric water vapor, carbon dioxide, oxygen, and ozone. Revealing the solar constant meant being able to distinguish the telluric lines from those inherent in the Sun's atmosphere. To do this, a transmission coefficient for Earth's atmosphere had to be calculated at each wavelength. It was a daunting task. Yet the timing was fortuitous for the future of solar research — the problem was perfectly teed-up for two pioneering solar scientists at the Smithsonian Astrophysical Observatory (SAO) to have a crack at it.

◀ **RISING STAR** Although the Sun is relatively close to Earth, a basic understanding of our star eluded astronomers for most of the 19th century. Even obvious features, like the sunspots shown in this striking sunrise photo, defied explanation. Despite advances in technology, the Sun continues to hold on to many of its secrets.

▲ **SOLAR PIONEER** Charles Greeley Abbot appears here sometime between 1913 and 1917 with his silver-disk pyrheliometer, a device used to measure solar irradiance. In contrast to the bolometer, which measures radiation intensities at different wavelengths, the pyrheliometer measures the total amount of solar radiation.

SUN: JORDI L. COY; SOLAR SPECTRUM: N. A. SHARP, NOAO / NSO / KITT PEAK FTS / AURA / NSF; ABBOTT: HARRIS & EWING COLLECTION - LIBRARY OF CONGRESS / PUBLIC DOMAIN

Kindred Spirits



◀ **A MEASURE OF THE SUN** French astronomer Claude Pouillet used a pyrheliometer in an early attempt to measure the solar constant. The device consisted of a dark plate (aimed sunward) that heated a small volume of water, which was measured by an internal thermometer.

SAO founder, visionary scientist, and aviation enthusiast Samuel Pierpont Langley had always been drawn to solar studies. Determining the degree to which our planet's atmosphere intercepts solar rays would become Langley's first great contribution to astronomy. In 1881, he invented a device called a *bolometer* to measure the Sun's heat at different wavelengths. This was a crucial innovation because, as plainly as the sky is blue and sunsets are red, atmospheric absorption and scattering vary greatly with wavelength. Measuring sunlight through the high air of Mount Whitney in California, Langley created a solar radiation curve based on 12 selected wavelengths and derived a solar constant of 2.54 calories per square centimeter per minute — higher than Pouillet's value of 1.76. Langley's findings were rough, but his purpose was to establish a proof of concept and demonstrate that his wavelength-by-wavelength approach to atmospheric transmission was a viable way to calculate the solar constant.

What Langley most needed next was a capable collaborator to help take his work to the next level. It was his good fortune to then meet an exceptionally talented New Englander with unique skills for the task. Their paths converged in a basement lab at Massachusetts Institute of Technology (MIT).

It's hard to imagine two more outwardly unlike people than the urbane, immaculately dressed Samuel Pierpont Langley and the rough-hewn farm boy Charles Greeley Abbot. Born in 1872 in Wilton, New Hampshire, Abbot grew up in a farmhouse where all the rooms were freezing cold except in the kitchen and the sitting room, which was warmed by a great fireplace. Upstairs was a library of books left by his great uncle, who was an inventor. On Saturdays, it was Abbot's delight to "steal away to the arctic upstairs room" and pore over dusty books about the workings of clocks, watches, and the double-acting condensing steam engine of James Watt. "To trace out the operation of such things I was willing to shiver with cold for hours," he later wrote. Perhaps it's no surprise that heat later became his life's work. An inquisitive tinkerer, Abbot when he was little used the kitchen stove as a torch to solder pans for the household, and at age 13 he built a forge to fix farm implements.

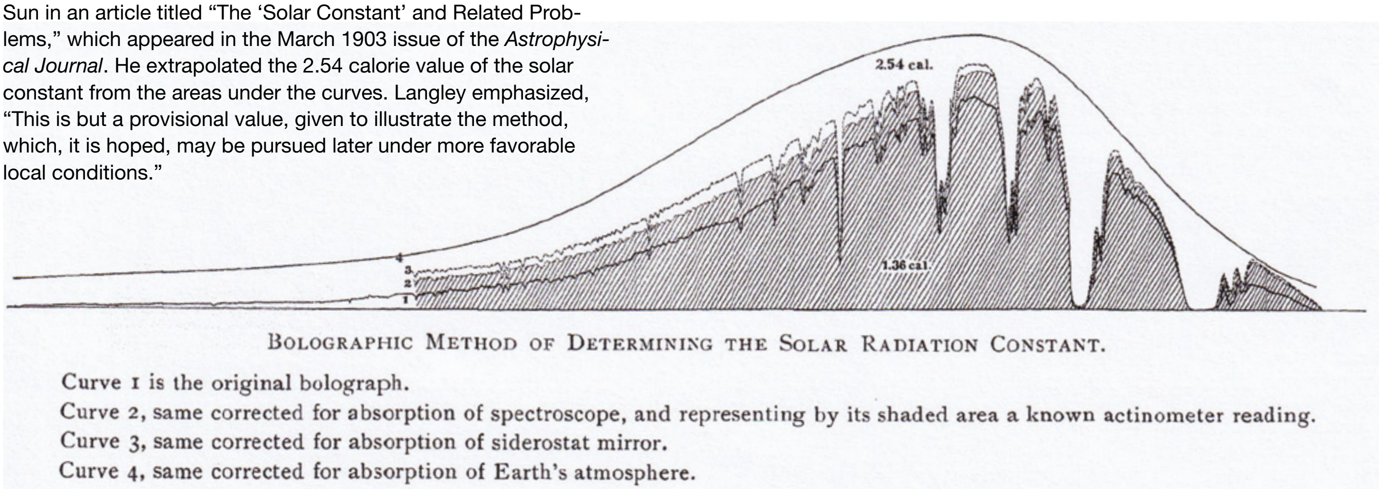
Abbot's future calling was partly shaped by chance. One day, some of his classmates at Phillips Academy in Andover, Massachusetts, decided to go to Boston to take the entrance examination for MIT. Abbot went along for the train ride, and not wanting to wander alone in the city, decided on a whim to take the examinations himself. He passed them easily, enrolled, and graduated with high honors in physics.

It was during a postgraduate year at MIT that Abbot met the dapper Langley, who happened to drop by the Institute in search of an assistant. "Wouldn't you like to see my experiment?" Abbot asked. "I should like it extremely," replied Langley.

They chatted briefly, and no doubt sensing a kindred spirit, Langley hired the amiable inventor. The boy, who not long before was building bicycles and water mills, would soon be making scientific instruments of great sensitivity.

Arriving at the SAO in 1895, Abbot's first task was to help Langley map the Fraunhofer lines in the Sun's infrared spectrum. Langley quickly recognized the young man's talent for working with delicate instruments and soon engaged him as

MAPPING SUNLIGHT Langley published his first bolograph of the Sun in an article titled "The 'Solar Constant' and Related Problems," which appeared in the March 1903 issue of the *Astrophysical Journal*. He extrapolated the 2.54 calorie value of the solar constant from the areas under the curves. Langley emphasized, "This is but a provisional value, given to illustrate the method, which, it is hoped, may be pursued later under more favorable local conditions."



POUILLET'S PYRHELIOMETER: WORLD HISTORY ARCHIVE / ALAMY STOCK PHOTO; BOLOGRAPH: THE ASTROPHYSICAL JOURNAL a collaborator in the important effort to measure the intensity of solar radiation. Over time, Langley's interests would drift to the nascent field of aviation, leaving Abbot in charge of solar work.

Abbot built two instruments for probing the Sun's heat. The first, a pyrheliometer of the type used by Pouillet, was an odd sort of thermometer with a blackened silver disk that was aimed at the Sun. Tracking the Sun across the sky, the device measured changes in solar radiation as sunlight passed through different thicknesses of Earth's atmosphere. The second instrument was an improved version of Langley's bolometer, which was essentially a wire whose electrical resistance would change as radiation of a particular wavelength was directed at it by a prism. By passing the whole solar spectrum across the wire, he could create a radiation curve of the Sun's output (a *bolograph*) by plotting intensity versus wavelength.

Abbot collected data on solar radiation and atmospheric transmission at 44 different wavelengths over multiple zenith angles, then mathematically extrapolated this information to determine what the radiation values should be outside Earth's atmosphere. Analyzing his data in 1908, Abbot found a mean value for the solar constant of 2.01 calories, equivalent to about 1,403 watts per square meter. By 1915, with accumulating observations and improved methodology, Abbot refined this number to 1.93 calories — close to the current value of 1.95, or 1,361 watts per square meter.

Sadly, Abbot's great mentor, Samuel Langley, died in 1906 and wasn't able to enjoy the results of his partner's efforts. Although Langley's early accomplishments in solar physics were pivotal, he's better remembered for his great contributions to early aviation. Several important facilities bear his name, including Langley Air Force Base and NASA's Langley Research Center, in Virginia.

A Voyage to the Sun

What's the Sun's surface temperature? To solve this second question Abbot would need to determine the solar constant at

▲ **SUMMIT SHELTER** This stone-and-steel structure 14,502 feet above sea level atop Mount Whitney in California was one of the locations where Abbot collected data in search of a solar constant. Built in 1909, the building still exists today and is frequently used by hikers seeking shelter.

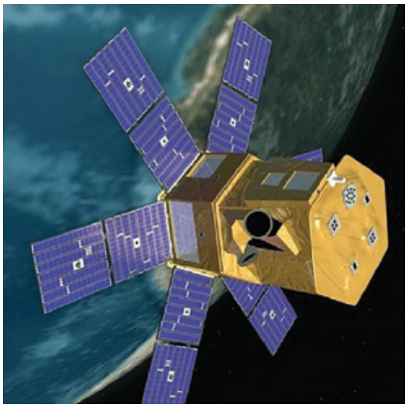
the Sun's surface. But how? Math helps. As with gravitational force, radiation from the Sun varies inversely with the square of the distance. To illustrate, imagine two enormous spheres each having the Sun at their center. The first has a radius of almost 700,000 kilometers (435,000 miles) — big enough to encompass the *photosphere*, the visible surface of the Sun. The other, vastly larger sphere extends about 150 million km to Earth's orbit. A space probe traveling from the outer sphere to the inner one would record a steady increase in the solar constant. At the halfway point, the energy recorded will have increased fourfold. When it reaches the photosphere, the solar constant will be 46,000 times greater. Multiplying this by the solar constant measured at the distance of Earth, we can calculate the solar radiation emitted from each square meter at the Sun's surface (the *solar flux*).

Using the modern value of 1,361 watts per square meter (equivalent to a solar constant of 1.95) for the solar radiation received outside of Earth's atmosphere, we find a solar flux

▶ **FLYING TO THE SUN** Samuel Pierpont Langley was a visionary solar scientist and passionate enthusiast of early aviation who wrote that "the observation of the amount of heat the Sun sends the earth is among the most important and difficult in astronomical physics."

▶▶ **SPLENDID SPOT** While serving as the first director of the Allegheny Observatory in Pennsylvania, Langley used the facility's 13-inch Fitz-Clark refractor to make this detailed drawing of a "typical" sunspot that crossed the Sun's face in December 1873.

at the Sun's photosphere to be about 63 million watts per square meter. That's a difficult number to grasp! It's the equivalent of a million 60-watt bulbs crammed into a one-meter-square frame.



◀ **WORKHORSE INSTRUMENT** The Solar Radiation and Climate Experiment (SORCE) was a satellite mission designed to measure incoming X-ray, ultraviolet, visible, near-infrared, and total solar radiation. Its mission ended in 2020 but overlapping data collection continues with the Total and Spectral Solar Irradiance Sensor (TSIS-1) instrument aboard the International Space Station and with TSIS-2 set for launch in 2024.

Taking the Sun's Temperature

After calculating the total energy output at the Sun's surface, Abbot next had to convert the solar flux into temperature. This required understanding the relationship between thermal radiation and temperature. In other words, if we record the heat from a candle at a distance of one foot, how do we determine the temperature of the candle?

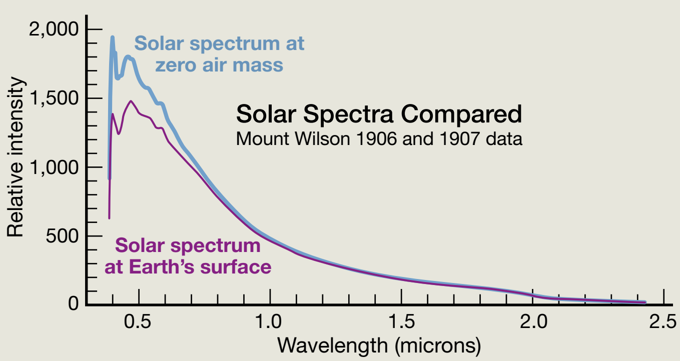
For much of the 19th century, the relationship between heat and temperature was unknown. Fortunately, in 1879 Slovenian physicist (and poet) Jožef Štefan showed that for an ideal *blackbody radiator* — one that emits and absorbs radiation in equal amounts in perfect equilibrium — *radiation* is proportional to the fourth power of the *temperature*. We know this today as the Stefan-Boltzmann law.

However, the solar spectrum has areas of absorption where the Sun's radiation curve deviates from the ideal blackbody, especially at shorter wavelengths. Abbot was concerned about this effect and about the uneven transmissivity of the Sun's photosphere. Today, though, we know that for the wavelength range Abbot was working with (ignoring the bites taken out of it by the absorption lines), the Sun's smoothed spectrum approximates a blackbody radiation curve corresponding to an effective temperature of 5,700 kelvin. Abbot used his 1908 value for the solar constant and found the Sun's effective temperature to be 5,962K. At the time, this was the closest match to the currently accepted value of 5,772K.

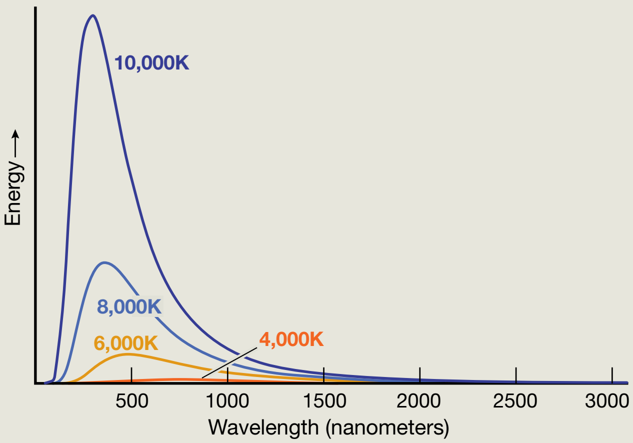
Abbot also tried to compute the Sun's surface temperature using Wien's Law, named after German physicist Wilhelm Wien. The idea is simple: The temperature of a blackbody radiator is betrayed by its color. Each radiator has a unique radiation curve (described by fellow German physicist Max Planck and called the *Planck curve*) that's strictly determined by its temperature. It's the peak radiation intensity that chiefly determines the colors of stars (and other hot objects) as they appear to us. A hot star will peak in the blue end of the spectrum, while cooler ones peak more toward the red — just as red charcoals are cooler than the blue flame of a welder's torch. The Wien relation between the peak wavelength (λ_{max}, in microns) of the curve and temperature (T) of a blackbody radiator is given by a simple relation:

$$T = 2{,}898/\lambda_{max}$$

This may be one of the simplest equations in physics, so savor it! What it says is that if you can identify the wave-



▲ **SOLAR CURVES** Abbot's Mount Wilson 1906–1907 data show solar radiation intensity versus wavelength. The purple curve depicts measured intensities from Mount Wilson in California, while the blue line extrapolates the data to zero air mass, outside the Earth's atmosphere. The pronounced gap between the two graphs at the shorter wavelengths is due to increased atmospheric absorption at those wavelengths. The sharp dips are due to so-called telluric absorption lines of molecules in Earth's atmosphere.



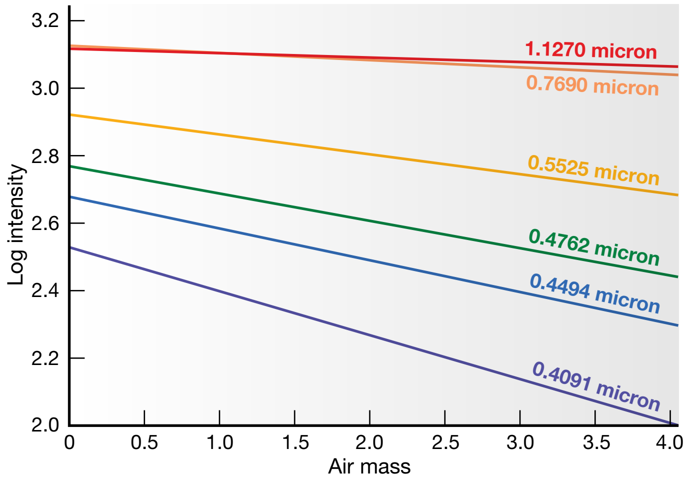
▲ **READING THE CURVES** The four curves in this diagram show blackbody radiation at different temperatures. By measuring a star's peak spectral output, astronomers can determine its temperature. The peak of the curve shifts to shorter wavelengths at higher temperatures, while the area under the curve is proportional to the total amount of energy radiated.

SORCE SATELLITE: NASA; GRAPHS: GREGG DINDERMAN / S&T; SOURCE: DOUGLAS MACDOUGAL (2) length of a star's peak intensity, you can approximate its temperature. However, locating the peak isn't always easy, as a glance at Abbot's solar curve (page 32, bottom right) demonstrates. Nonetheless, Abbot confirmed that the Sun's spectrum is similar in shape to a blackbody at around 6,000K.

Later Life

Despite Abbot's growing trove of data, whether or not the Sun's output was constant remained a mystery. He took thousands of measurements to address that question. From 1903 to 1914 Abbot collected data from various locations, including Washington, D.C., a balloon over Algeria, and Mount Wilson and Mount Whitney in California. And he kept at it. By 1922 he and his colleagues had amassed 1,244 observations. Studies of the constancy of the total solar irradiance continue even today, though now the observations are made with instruments of incredible precision aboard satellites and the International Space Station. A definitive answer about the long-term constancy of TSI remains elusive.

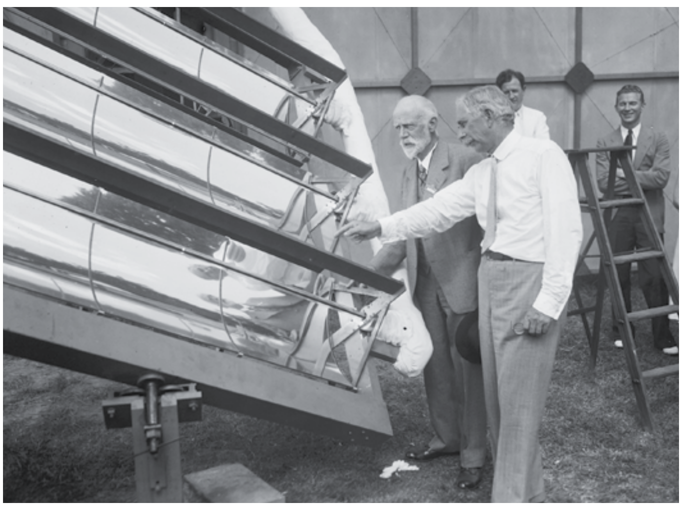
Abbot took up directorship of the SAO after Langley's death, and in 1928 he became Secretary of the Smithsonian Institution, leading it during the Depression and war years. A passionate advocate for solar energy, Abbot never stopped inventing. He constructed a solar oven for Mount Wilson Observatory, a solar boiler for generating power in arid places, and a solar still for extracting freshwater from the sea. In 1932, at age 60, he authored a volume in the *Smithsonian's Scientific Series* — a collection he himself initiated. His book was, appropriately enough, entitled *Great Inventions*. It's a lucid tour de force explaining the most important electrical and mechanical inventions of the 19th and 20th centuries. Abbot was a vibrant, engaged man to the very end of his life. His last patent was issued in 1972, the year of his 100th birthday.



▲ **WHY SUNSETS ARE RED** Curves of atmospheric transmission at selected wavelengths from Abbot's Mt. Wilson 1906–1907 data. Through the course of a day, the Sun's light passes through varying thicknesses of atmosphere, or air masses (1 air mass = the zenith), which affect individual wavelengths differently. As shown by its relatively level line, red light penetrates dense air more easily than blue light does, which is why sunsets appear red. At left is the extrapolation of these curves to zero air mass, outside Earth's atmosphere.

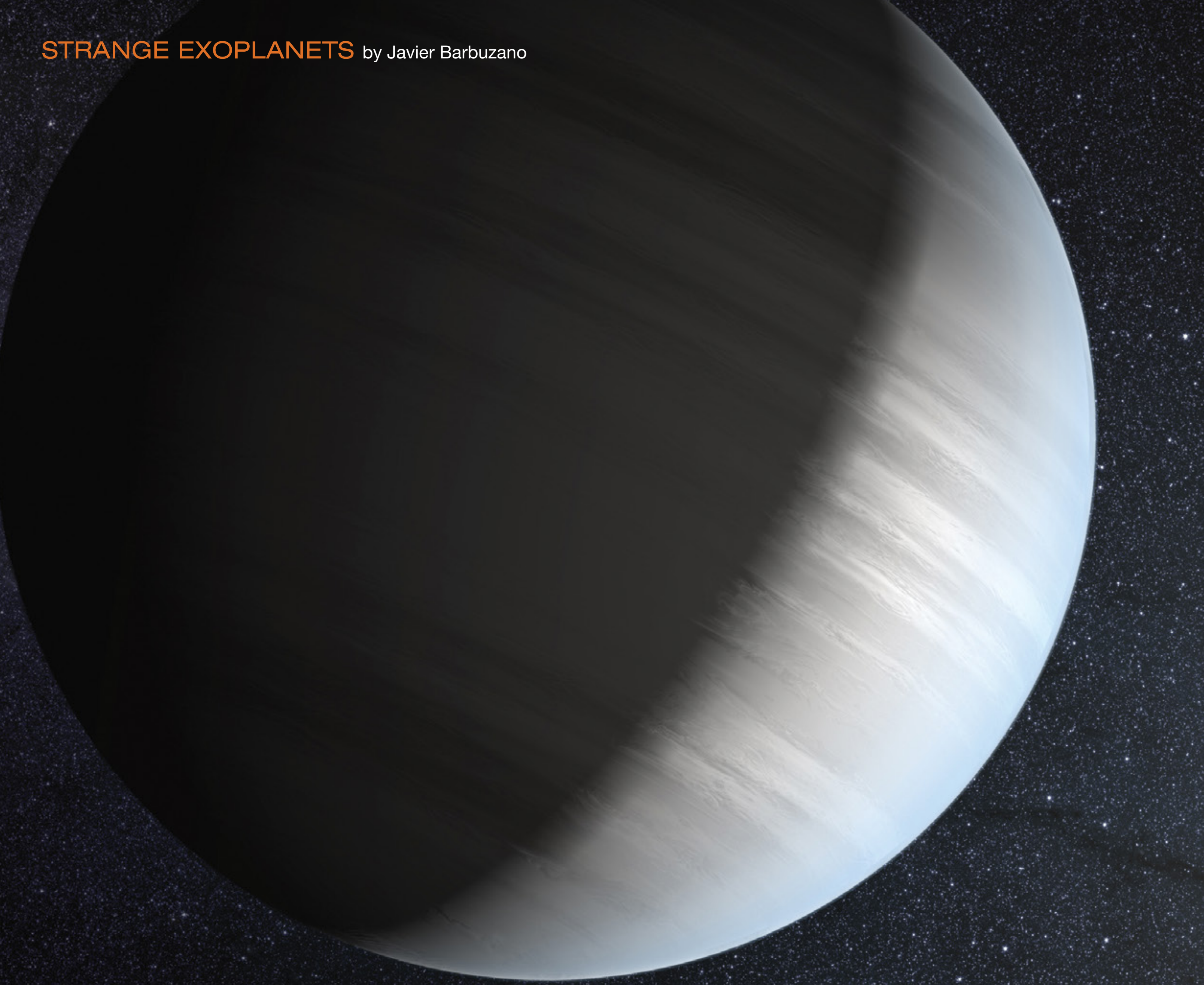
Meanwhile, Abbot's quest continues. NASA's Total and Spectral Solar Irradiance Sensor – 2 is scheduled to launch in 2024. Its sensitive instruments will begin adding to the many decades of continuous measurements of solar irradiance that began with the dedicated efforts of a curious and talented farm boy.

■ **DOUGLAS MACDOUGAL** is the author of *Newton's Gravity: An Introductory Guide to the Mechanics of the Universe* (Springer, 2012). You can visit his website and blog at **www.douglasmacdougal.com**.



▲ **POWERED BY THE SUN** Abbot points at one of his solar-powered boilers in this 1936 photo. This was just one of the many solar devices he experimented with throughout his life. Steam generated by this device could power an engine.

▲ **A LENGTHY CAREER** Abbot is pictured here in the Smithsonian Institution Building in 1930. He remained active throughout his life and passed away in December 1973 at the age of 101. A 10-km-diameter lunar crater south of Mare Crisium is named in his honor.



The Real Tatooines

Astronomers now know of more than 200 alien worlds orbiting one or both stars in a binary system.

On October 6, 1995, exoplanet science went from an obscure research topic to making headlines. That was the day astronomers announced the discovery of 51 Pegasi b, the first exoplanet orbiting a star like the Sun.

The discoverers, Michel Mayor and Didier Queloz (both University of Geneva, Switzerland), measured how the star 51 Pegasi wobbled back and forth under the gravitational pull of the planet. This method, known as the *radial velocity* technique, enables observers to estimate an exoplanet's mass. It took them only about two weeks of telescope time to spot 51 Pegasi b, because it turned out to be a peculiar planet of a type previously unknown: a gas giant lying extremely close to its host star, so close that it completed an orbit in four days. These planets are now called hot Jupiters, and the discovery earned the two scientists the 2019 Nobel Prize in Physics.

Several years earlier, though, in 1987, Canadian astronomers Bruce Campbell (then University of Victoria), Gordon Walker, and Stephenson Yang (both then University of British Columbia) had announced another discovery — a Jupiter-sized planet around the primary star of a binary system called Gamma Cephei. They had also used the radial velocity technique, but their planet was more challenging to detect because it needed 2.7 years to complete an orbit. They had monitored the star for six years to pick up its periodic signal.

That year, the three scientists announced their preliminary results at a press conference at the summer meeting of the American Astronomical Society in Vancouver. They hit a wall of skepticism.

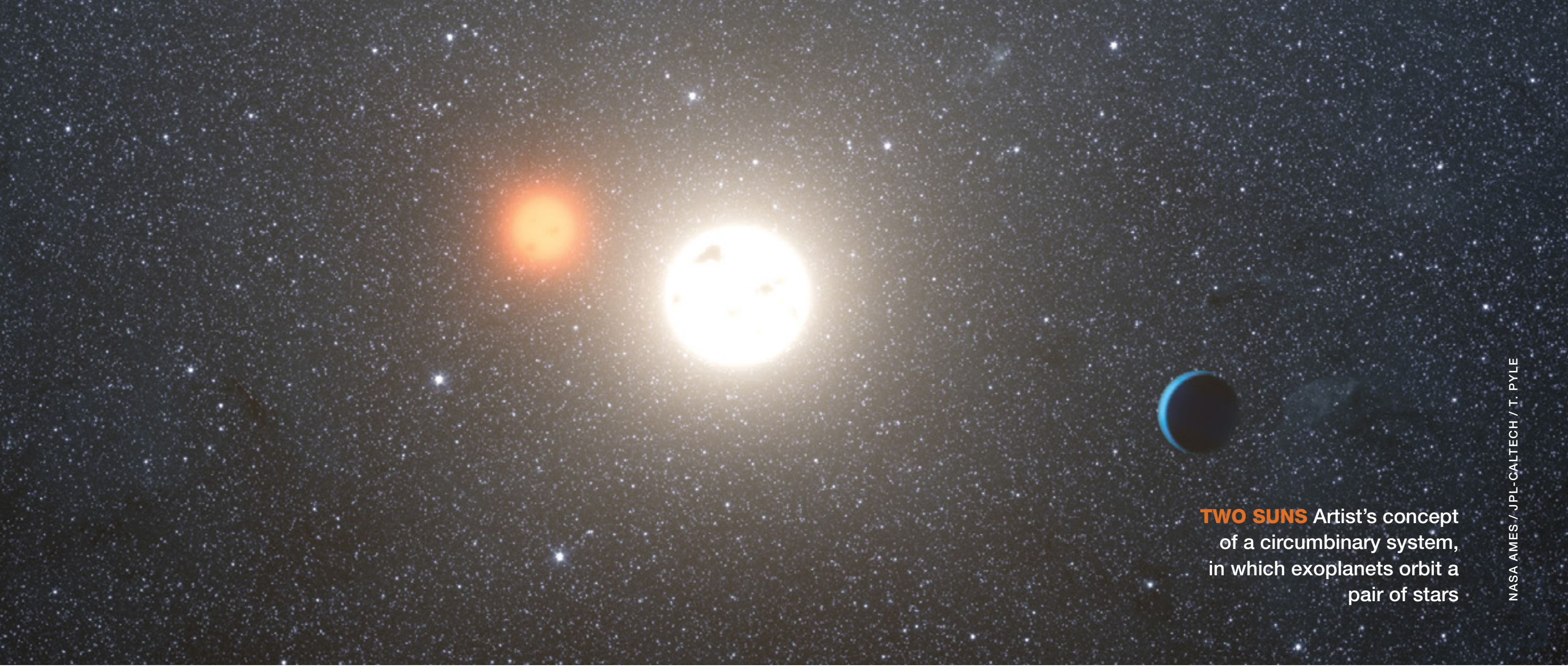
At that time, most scientists saw exoplanets as a matter of science fiction rather than a legitimate field of research. If any planets could be found around other stars, they were expected to resemble those in our own solar system. Hence, the discovery of a planet in a binary system, where the stars are as close as the Sun is to Uranus, was a hard sell. It seemed unlikely that a planet could form and survive in the narrow space between the stars.

In 1992, doubtful of their own findings, Walker and Yang joined with colleagues to retract their claim to the discovery of the first exoplanet. They chalked the wobble they'd picked up to the intrinsic variability of the primary star, which was misclassified as a giant at the time and therefore expected to suffer surface variations that could mimic the presence of a planet. The third member of the team, Bruce Campbell, had already quit astronomy in frustration when he couldn't find a permanent position in the field.

But years later, in 2003, updated observations of Gamma Cephei showed beyond doubt that Gamma Cephei Ab is real. The star is actually a less active subgiant and does not produce a planet-mimicking signal. Its exoplanet is a gas giant at least 1.4 times more massive than Jupiter and has an orbital period of 2.5 years, almost identical to the orbit originally calculated by Campbell, Walker, and Yang. Had they stuck to their guns, they might have been the ones shaking hands with the King of Sweden.

Seeing Double: How Many Planets Are There?

Around half of all Sun-like stars in our galaxy are in binary or multiple systems — groups of gravitationally bound stars that orbit a common center of mass. Binaries are the most common, but there are also cases in which two binaries are bound to each other to form a quadruple system. Even three binaries can join to create a sextuple system, like the recently discovered TYC 7037-89-1.



TWO SUNS Artist's concept of a circumbinary system, in which exoplanets orbit a pair of stars

NASA AMES / JPL-CALTECH / T. PYLE

Our closest stellar neighbor, Alpha Centauri, is a triple system. It includes a binary — made of two Sun-like stars orbiting each other at an average of 24 astronomical units (a.u.) — that is bound to Proxima Centauri, a planet-hosting red dwarf that orbits the pair at about 13,000 a.u. (*S&T:* Apr. 2019, p. 34).

Planets in multi-star systems can either orbit just one of the stars of the group (in which case they are called satellite-type or S-type planets) or they can orbit the whole system at once. The latter are known as circumbinary, P-type, or planet-type, depending on which research paper you're reading. These are the planets with two suns so often pictured in science fiction, including Luke Skywalker's home planet, Tatooine, in *Star Wars*. So far, astronomers have only found circumbinary planets around binary stars, but there are two cases where planets might be forming in gas disks surrounding triple systems.

Around half of all the Sun-like stars in our galaxy are in binary or multiple systems.

Both types of worlds are rare: Researchers have found compelling evidence for about 400 worlds in binary systems, with 217 so far fully confirmed around main-sequence stars. That's a small fraction of the roughly 5,000 exoplanets identified so far. This discrepancy is at least partly due to *observational bias*. Oftentimes, binaries are excluded from surveys because they introduce a series of technical challenges, such as interfering with radial-velocity measurements. Also, astronomers have incorrectly labeled many known exoplanet host stars as single stars, mostly because there's no way to tell if a star has a partner without (and sometimes even with) detailed follow-up studies. According to recent analyses, planets in multiple systems could be as common as around single stars.

Double Stars, Double Trouble

How planets form and live around one of the stars of a binary system boils down to the distance between the stars. If the stars are far apart, then the perturbing effect from the stellar companion is too weak to affect the formation and dynamical evolution of S-type planets.

Things become trickier when the stars get closer. "The question is, how close can they come so planets can still form around either of them?" says Nader Haghighipour (Planetary Science Institute), who has been searching for exoplanets in binary systems since the 2000s. "We've found that there is a gray area once [the stars] get closer than about 100 a.u."

To build planets, stars need to keep a *protoplanetary disk* around themselves early in their lives. This disk of gas and dust provides the raw material for planet-building. But in close binaries, the interactions between one star and the circumstellar disk around the other could deplete the disks of usable material before planets can form.

These interactions also limit the growth of *planetesimals* — the building blocks of planets — by increasing their relative velocities, resulting in high-speed collisions that can erode or destroy objects before they grow larger.

"I like to call planets in binaries *hyperdynamophiles*," says Roman Rafikov (University of Cambridge, UK), making a play on *extremophiles*, organisms that live in inhospitable environments. "They really like extreme dynamics, and somehow they managed to form and survive in this environment."

Rafikov, along with his colleague Kedron Silsbee (Max Planck Institute for Extraterrestrial Physics, Germany), has developed complex computer simulations to determine how planets can form in such close quarters. The simulations track planetesimals as they move through the protoplanetary disk and collide with other planetesimals of different sizes and speeds. "So far nobody ever has done this for binary stars, simply because people probably did not well understand what the physical inputs are," Rafikov says.

According to the team's calculations, the companion star's influence impedes the formation of S-type planets. But two forces counteract its disturbing effect. One is the disk's own gravity, which tends to bind its material together in a circular orbit. The other is gas drag, which slows planetesimals down as they move through the disk, like a bicyclist facing a headwind. "There is this tug of war and, at some point, at some locations in the disk, there is a quiet location where planetesimals simply don't feel any perturbing gravity — they stay in circular orbits, and when they collide they can actually grow very efficiently," Rafikov explains.

Trojan Planets?

Theoretically, there's a third option for a planet to survive in a stellar binary: hovering at the fourth or fifth Lagrangian points. In the solar system, Trojan asteroids share the orbits of several planets this way, traveling about 60° ahead of and behind the planet in regions where centripetal and gravitational forces due to the Sun and the planet cancel each other out (*S&T:* Feb. 2022, p. 12). The same gravitationally quiet zones could occur in binaries and could harbor planets, which would be called libration- or L-type. But astronomers think it's very unlikely that planets could form or find their way to these locations.

Of the 131 S-type exoplanet systems known, astronomers have only found about 20 around a star that's less than 50 a.u. from its companion, confirming that S-type planets exist around close binaries but are less common than they are in wide binaries. It seems that when the stars in a binary get too close, nature prefers a different solution: circumbinary planets.

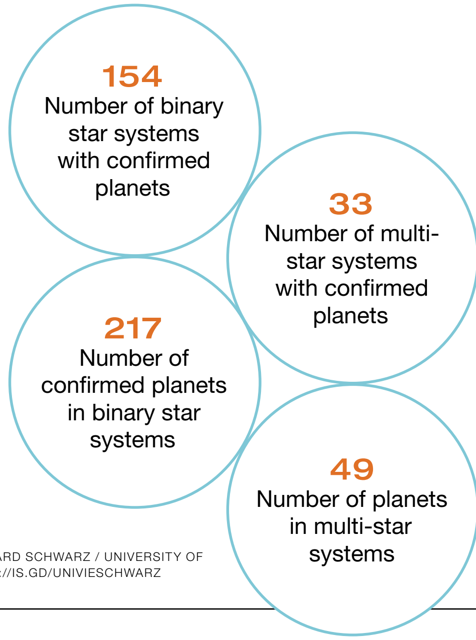
Two Suns in the Sky

When NASA's Kepler mission started operations in May 2009, astronomers knew it would find hundreds of eclipsing binaries. The same sensitivity that enabled the space telescope to detect small dips in starlight as planets crossed in front of stars also revealed stars passing in front of each other. After four years of operation, it had detected 2,878 of them.

Kepler scientists were interested in eclipsing binaries because if the stars' orbital plane was aligned with our line of sight, then it was likely that any planets the binary harbored would be in the same plane. But astronomers were expecting S-type planets in binaries with large separations.

"What happened with Kepler was that it was looking into eclipsing binaries and then, entirely by accident, Kepler-16 was discovered," Haghighipour says. Kepler-16 contains two low-mass, main-sequence stars in a 41-day orbit, only 0.22 a.u. apart — less than Mercury's distance from the Sun. A planet travels in a nearly circular orbit around the pair at 0.7 a.u., completing an orbit every 229 days.

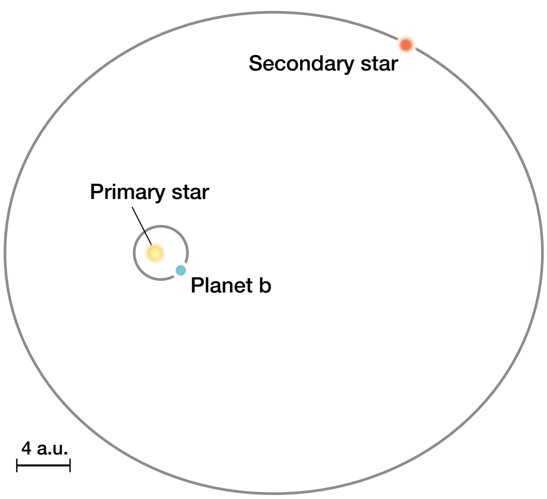
"Once we found the first one, then we were able to find other ones," says Haghighipour. By the end of its mission, Kepler had discovered a total of 12 circumbinary planets in 10 systems. One of them, Kepler-47, is the only multiple-planet circumbinary system found to date. It has three, roughly Neptune-size planets in 49.5-, 187-, and 303-day orbits around a tight binary. With a density similar to that of Saturn, none of them seems to have a rocky surface. The whole system could fit inside Earth's orbit around the Sun.



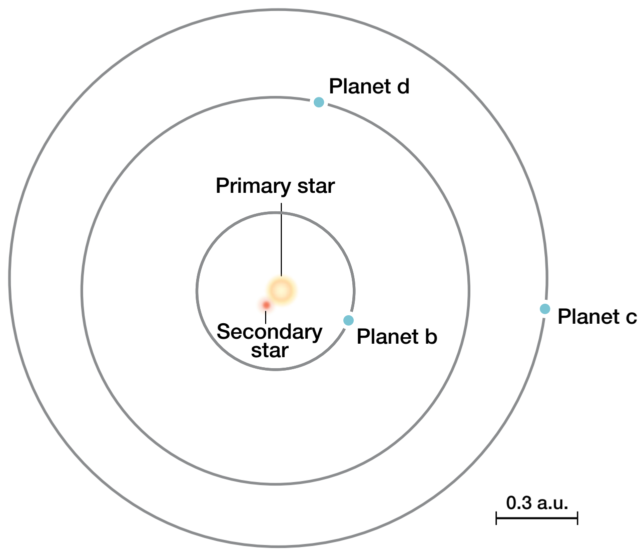
SOURCE: RICHARD SCHWARZ / UNIVERSITY OF VIENNA, HTTPS://IS.GD/UNIVIESCHWARZ

The fact that every circumbinary planet found so far is a gas giant might confirm predictions made by Haghighipour and others, even before these planets were found. They predicted that in circumbinary systems, planets could only form at distances greater than 5 a.u. from the stellar pair, where they wouldn't feel its disrupting gravitational wobble. Out there, in the vast expanse of chilly gas, the most likely worlds to form would be giants.

Other scientists also predicted that, once formed, circumbinary planets would migrate in towards the stars, where



▲ **GAMMA CEPHEI** Long disputed, the gas giant around Gamma Cephei A is an S-type planet: It orbits only one of the stars in a binary system, with the second, cooler star much farther away.



▲ **KEPLER-47** The three gas giants in the Kepler-47 system orbit a pair of stars — one a near-twin to the Sun in size and temperature, the other a much cooler red dwarf.

S-TYPE PLANET: GREGG DINDERMAN / *S&T*, SOURCE: MCDONALD OBSERVATORY; P-TYPE SYSTEM: GREGG DINDERMAN / *S&T*, SOURCE: NASA / JPL CALTECH / T. PYLE the central binary's effects prevent planets from coalescing. Interactions between the planet and the protoplanetary disk drive this migration, so when the planet arrives at the inner edge of the disk, there's less gas to drag on the planet and the migration halts.

The migration tends to stop close to the system's *inner stability limit*. This limit is the distance from the binary at which planets become unstable due to three-body interactions. The location of this limit varies with the size of the binary and the masses of its stars, but as a rule of thumb it's about three times the stars' average separation.

"There are 14 circumbinary planets we have discovered both with Kepler and with TESS and, as we predicted, they are all big, Neptune-size or larger, and they all have migrated," Haghighipour says. This migration, he adds, enabled their discovery in the first place, because their orbital periods had shrunk. Otherwise, astronomers would have taken many more years to pick up multiple transits of the same planet.

This process could also mean that smaller, rocky planets might not have a chance to form in circumbinary orbits: The inner zones in the protoplanetary disk where terrestrial planets would form are too unstable.

"What I would like to see is a terrestrial-class circumbinary planet, Earth-size or a small super-Earth," Haghighipour says. "I'm predicting that these types of planets do not exist."

Circumbinary Brainteaser

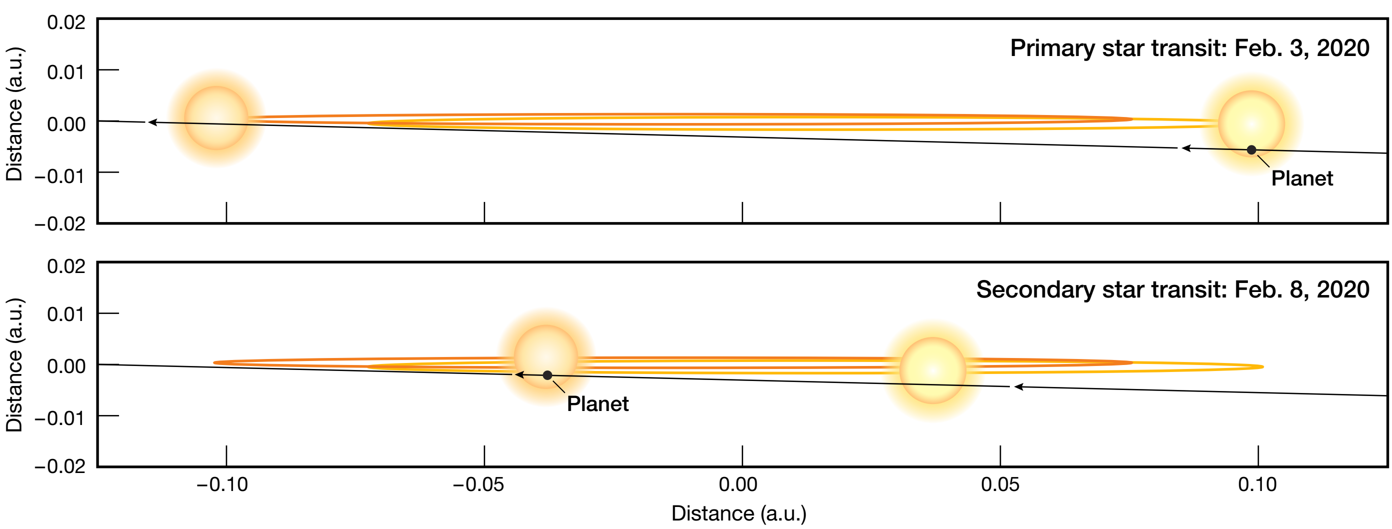
Circumbinary planets are difficult to detect. One challenge comes from the stellar eclipses, which are frequent and deep, and which can hide the fainter planetary transits. The planetary transits themselves are also hard to spot because they happen at irregular intervals, caused by the relative motion of the stars as they orbit each other. The transit duration also varies depending on the relative direction the stars are moving from the observer's point of view. If the planet moves in the same direction as the stars, the transits are longer. If they move in opposite directions, they are shorter.

"It's a brainteaser," says Veselin Kostov (NASA Goddard), who has led the discovery of several circumbinary planets over the last ten years. "The orbits of the planets are not closed, meaning that the planet never comes back to the same spot after one period. The orbital parameters are constantly changing — the separation from the stars, the eccentricity, the inclination . . . everything is moving in there."

As a result, the orbital period of a circumbinary planet isn't fixed. At the end of its year, the planet might be early or late by several (terrestrial) days. This creates a lot of trouble for automated detection algorithms, which can easily pick out the regular signals of exoplanets around single stars but become confused by the irregular dips of circumbinary planets. All the circumbinary planets discovered so far have therefore been spotted by eye. "For the moment nothing beats the eye, believe it or not," Kostov says.

Kostov has discovered circumbinary planets using data from two different spacecraft: Kepler and the Transiting Exoplanet Survey Satellite (TESS). Kepler spent its primary mission observing the same patch of sky continuously over four years. TESS, however, is surveying the entire sky, monitoring tens of millions of stars. To do so, it needs to switch its field of view every 27 days.

To find circumbinary planets in such a short window, Kostov and his colleagues tried a novel approach. Instead of waiting for a planet to complete a full orbit, they look for the planet to transit both of the binary's stars during the



LIGHT CURVE AND TRANSIT CARTOON: GREGG DINDERMAN / *S&T*, SOURCE: V. KOSTOV ET AL. / *ASTRONOMICAL JOURNAL* 2021

▲▶ **CATCHING A DOUBLE TRANSIT** Astronomers found a planet around the eclipsing binary TIC 172900988. *Above:* The planet's transit of both stars, just a few days apart, enabled the astronomers to confirm its existence. *Facing page:* Data from the TESS space telescope reveal the stars' mutual eclipses and the planet's transit across first the primary, then the secondary star. Note how small the drop in brightness is when the planet traverses, compared with when one of the stars blocks the other.

same orbit. From the timing of these transits and the stars' motions, they can work out the position of the stars in the binary and approximate the orbit and size of the planet with reasonable precision.

For most stars, chances are that ground-based observatories have observed them for decades before TESS. "So you go into the archive and look at what the binary is doing," says Kostov. "If you see a slight shift in the times of the stellar eclipses, this means that the planet is perturbing the orbit of the binary, and you can actually measure the orbit of the planet. You can even measure the mass of the planet because it's massive enough to perturb the binary star."

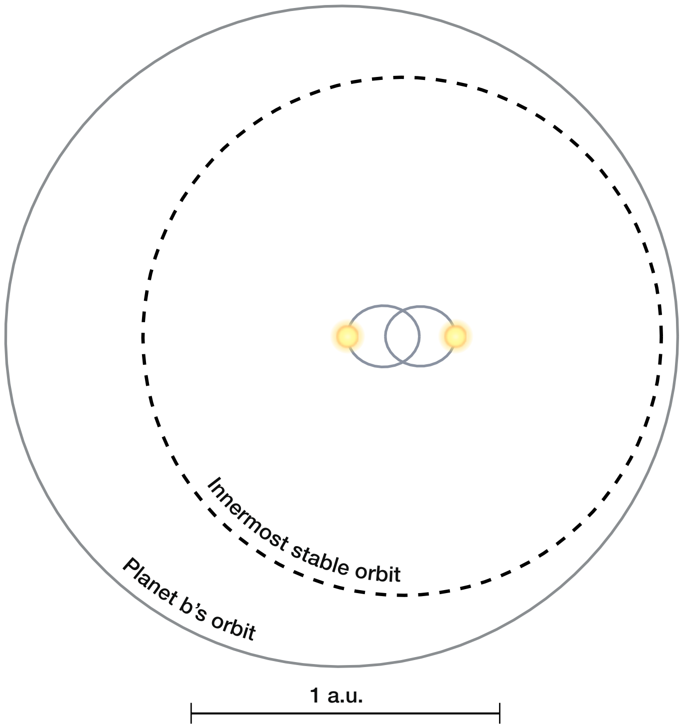
His team has already detected one planet using this method, a Jupiter-size gas giant called TIC 172900988b with an orbital period somewhere between 188 and 204 days.

Hiding Planets

Circumbinary planets hold a final surprise for planet hunters: Over time, transits disappear. This is because the exoplanet's orbital plane changes its orientation in response to the binary's gravitational influence, a movement known as *precession*. That cycle can last anywhere from decades to hundreds of years.

"There are several examples where, in the early part of the Kepler mission, we don't see any transits and in the later part we do," says Jerome Orosz (San Diego State University).

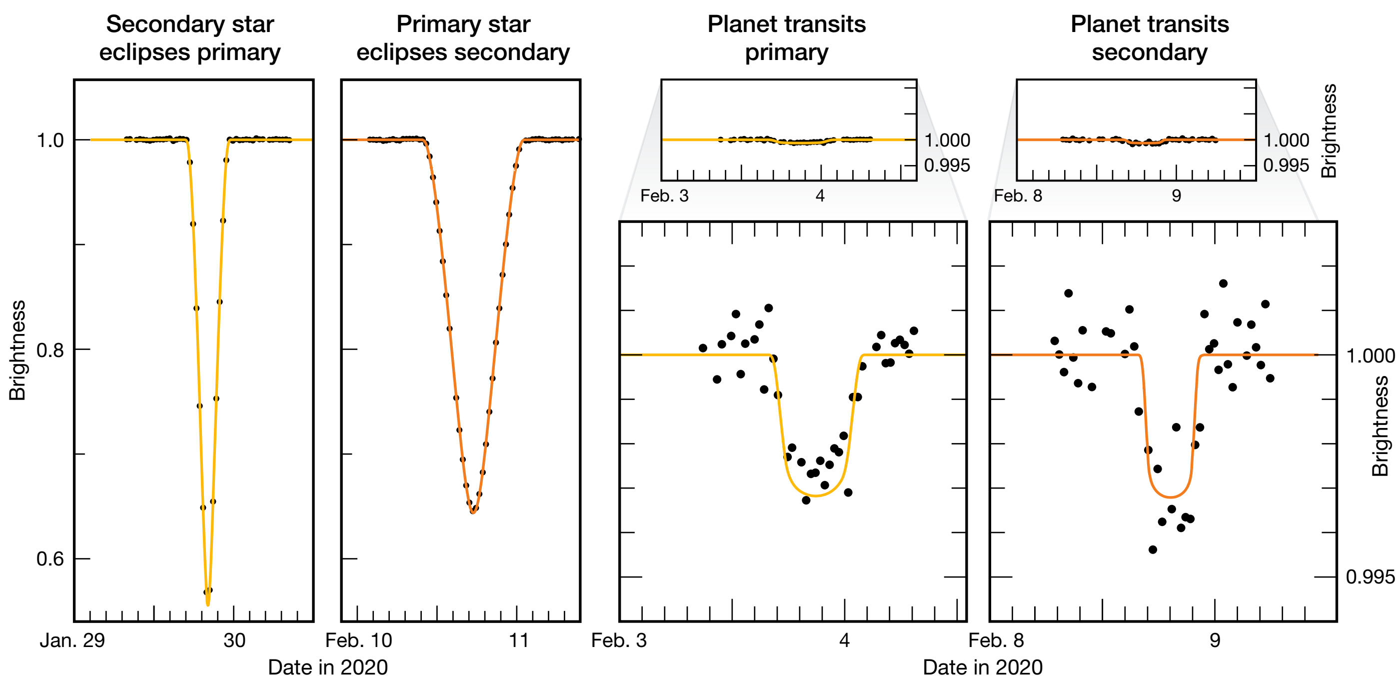
Kepler-413b pulled such a disappearing act. Kepler detected three transits with a period of 66 days at the beginning of the mission, then nothing for 800 days, then five more transits before the mission ended. The planet Kepler-453b, likewise, has a precession period of 103 years. Kepler detected three transits halfway through its mission, but the world isn't expected to cross our line of sight again until 2066.



▲ **KEPLER-34** The gas giant around the binary star system Kepler-34 lies about the same distance from its two suns as Earth does from our Sun. Its path takes it close to the innermost stable orbit around the stars.

Habitability

Astronomers define the habitable zone as the region around a star where a planet like Earth could have liquid water on its surface. We have to expand this concept for planets in binaries, for which there is more than one source of radiation.



KEPLER-34: GREGG DINDERMAN / S&T, SOURCE: TOBIAS MÜLLER (INST. FOR ASTRONOMY & ASTROPHYSICS, UNIVERSITY OF TÜBINGEN) / HTTP://ASTRO.TWAM.INFO/HZ-PTYPE

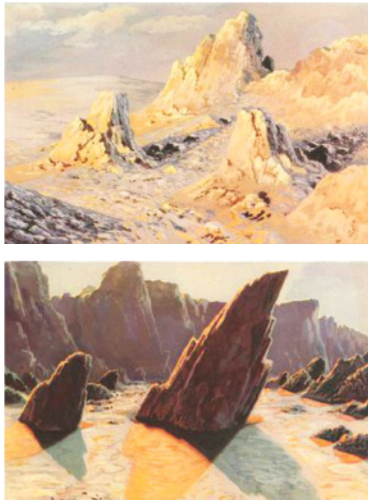
When you have a double star, both stars shine on the planet. But all photons are not created equal, Haghighipour explains. They likely come from two distinct types of stars, so they'll carry distinct energies. As a result, the planet's atmosphere responds differently to each star's photons. When the photons hit the molecules in the atmosphere, they produce different chemical reactions, warming the planet in different ways. Astronomers need to estimate how each source will contribute to global temperatures separately, then combine the effects.

For planets in S-type configurations, the presence of a companion star widens the habitable zone a little. Things are more complicated in circumbinary systems, where insolation changes dramatically over time and on several time scales.

First, stellar eclipses can reduce insolation by a few percent over a period of hours every few days. How much depends on which star is hidden from view and on the stars' luminosities, which in some cases can be very different from each other. Second, the stars change position relative to each other over the course of their mutual orbit, typically with a period of days or weeks.

Third, there's the planet's own orbit. If the exoplanet follows an elongated path around the stars, the insolation can be many times higher when the planet is closer to the stars than when it's farther away. This cycle can last from 50 to 1,000 days for known circumbinary planets. Last, there's precession, which moves the planet around on a cycle that lasts from tens to hundreds of years.

There's no doubt that the concept of seasons takes on a completely different meaning for circumbinary planets. Irregular seasons have implications for habitability, since any life forms would need a great tolerance for climate swings. These variations are not equally severe for all circumbinary planets, though. Some planets, like Kepler-453b, have nearly circular orbits and stay within the habitable zone of their stars throughout their year. Although life as we know it couldn't get a foothold on these gas giants, perhaps they have moons where organisms could eke out a living.



◀ **SHADOWSCAPE** French astronomer Lucien Rudaux (1874–1947) illustrated the shadow effects that might occur in the landscape of planets with two suns in his comprehensive 1938 book *Sur les Autres Mondes* (*About Other Worlds*).

Beyond Science Fiction

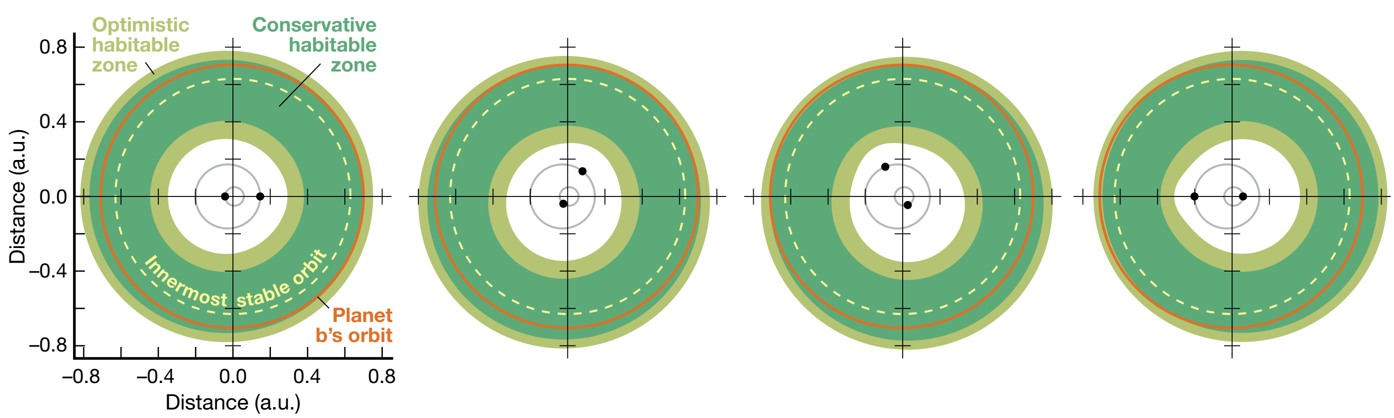
Over the past 100 years, several thinkers and artists have envisioned what a planet with two suns could look like. From George Lucas's Tatooine to the ocean planet in Stanisław Lem's 1961 novel *Solaris*, science fiction has readily embraced them. They also appear in paintings of landscapes where two suns cast shadows of different colors, created nearly a century ago by French astronomer Lucien Rudaux.

Now, such work has to contend with comparisons to real worlds in our galaxy.

Astronomers' picture of these worlds is still in sketch form. TESS and projects now in the works, like the European Space Agency's PLATO mission, will ensure more discoveries down the line. And if exoplanet discoveries have taught us anything so far, it's that anywhere planets can form, they do.

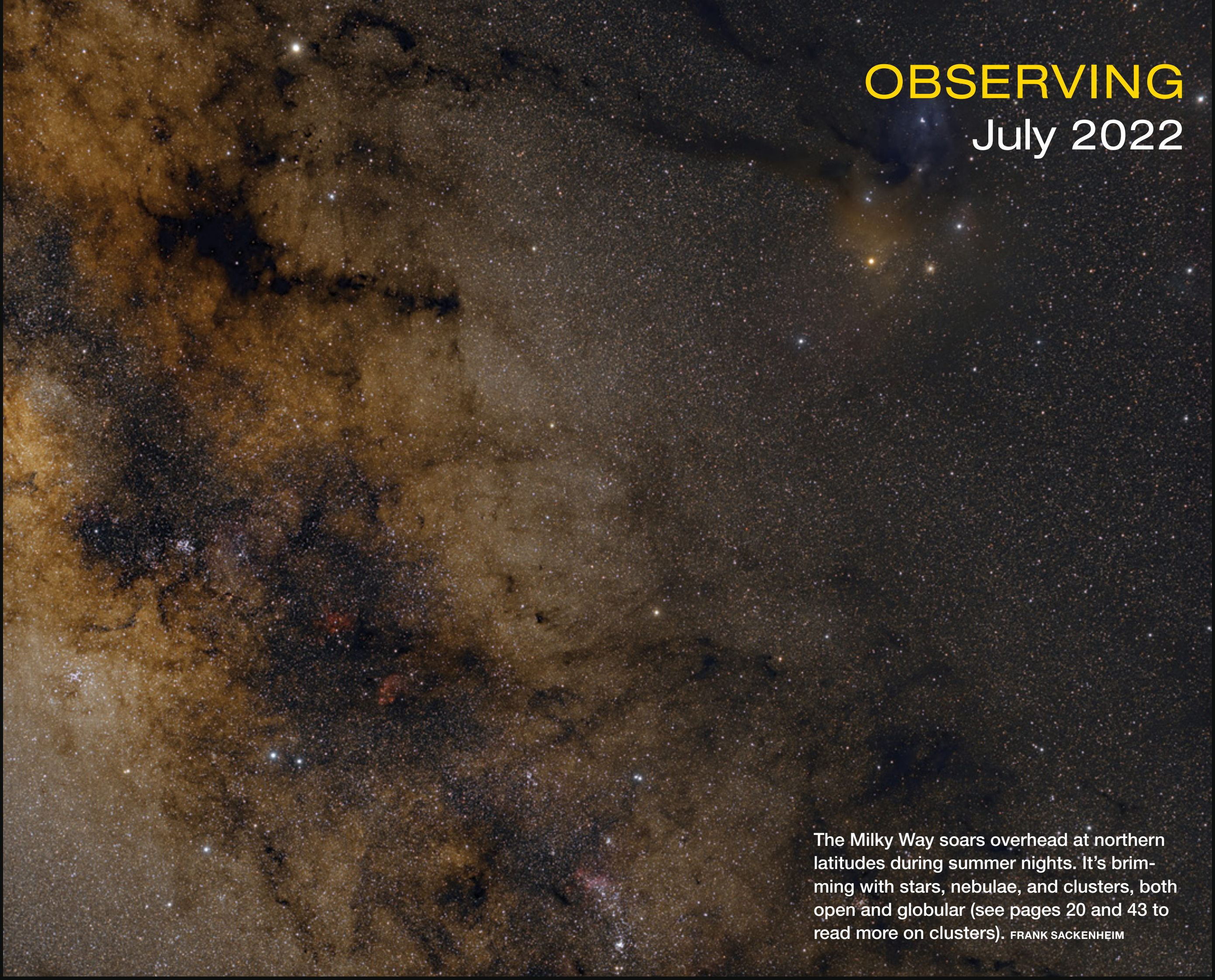
"The closest stellar system to us is a multiple stellar system, and it's known to have at least one planet," Rafikov says. "Half of the stars are in binaries." We must therefore try to understand what's happening around this half of the stellar population, long ignored by many exoplanet hunters. Maybe something there will be worth another Nobel Prize.

■ **JAVIER BARBUZANO** is a freelance writer in circumbinary orbit around his two little daughters, Clara and Sofia.



▲ **CHANGING SEASONS** As the stars in the binary Kepler-16 orbit each other, the habitable zone around them changes shape. Due to that shift, the planet's orbit moves in and out of the conservative habitable zone with time.

PAINTINGS: LUCIEN RUDAUX / *SUR LES AUTRES MONDES* 1938; HABITABLE ZONE: GREGG DINDERMAN / *S&T*, SOURCE: TOBIAS MÜLLER (INST. FOR ASTRONOMY & ASTROPHYSICS, UNIVERSITY OF TÜBINGEN) / HTTP://ASTRO.TWAM.INFO/HZ-PTYPE



OBSERVING
July 2022

The Milky Way soars overhead at northern latitudes during summer nights. It's brimming with stars, nebulae, and clusters, both open and globular (see pages 20 and 43 to read more on clusters). FRANK SACKENHEIM

2 **DUSK:** Look toward the west to see the waxing crescent Moon sitting 6½° right of Regulus, Leo's brightest star. Follow the pair as they sink toward the horizon in deepening twilight.

4 **EARTH** is at aphelion, farthest from the Sun for the year (around 3.4% farther than it was at perihelion in January).

7 **DUSK:** High in the south-southwest, the Moon, one day past first quarter, is in Virgo and gleams some 5° upper left of Spica.

10 **EVENING:** The waxing gibbous Moon visits Scorpius — look toward the south to see it a bit more than 2° upper left of smoldering Antares. (Turn to page 46 for more on this and other events listed here.)

15 **EVENING:** The waning gibbous Moon rises in the east-southeast. It trails Saturn by a little less than 6°.

17 **DAWN:** A lovely sight greets early risers as Venus, Aldebaran, Mars, Jupiter, the waning gibbous Moon, and Saturn adorn the horizon from the east-northeast to the south-southwest. Catch this sight before sunup.

19 **MORNING:** The Moon and Jupiter are high in the southeast; some 3° separates the pair.

21 **DAWN:** Keep looking high in the southeast to see the Moon (now one day past last quarter) and Mars about 2½° apart.

23 **DAWN:** In the east, the waning crescent Moon poses prettily between the Pleiades and the Hyades.

24 **DAWN:** A slightly different arrangement of solar system objects decorates the dawn sky, now with Venus, the Moon, Mars, Jupiter, and Saturn in a long line before sunrise.

26 **DAWN:** The thin lunar crescent and Venus are some 3½° apart in Gemini low in the east-northeast.

27 **DAWN:** The Moon, just one day before new, Castor, and Pollux form a right triangle above the east-northeastern horizon. Catch this view before it gets too light.

29–30 **ALL NIGHT:** If it's clear, try not to miss the Southern Delta Aquariid meteor shower — especially if you're at more southerly latitudes; the Moon, only a few days past new, won't interfere with viewing. See page 50 for details.
— DIANA HANNIKAINEN

JULY 2022 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

MOON PHASES

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

FIRST QUARTER
July 7
02:14 UT

FULL MOON
July 13
18:38 UT

LAST QUARTER
July 20
14:19 UT

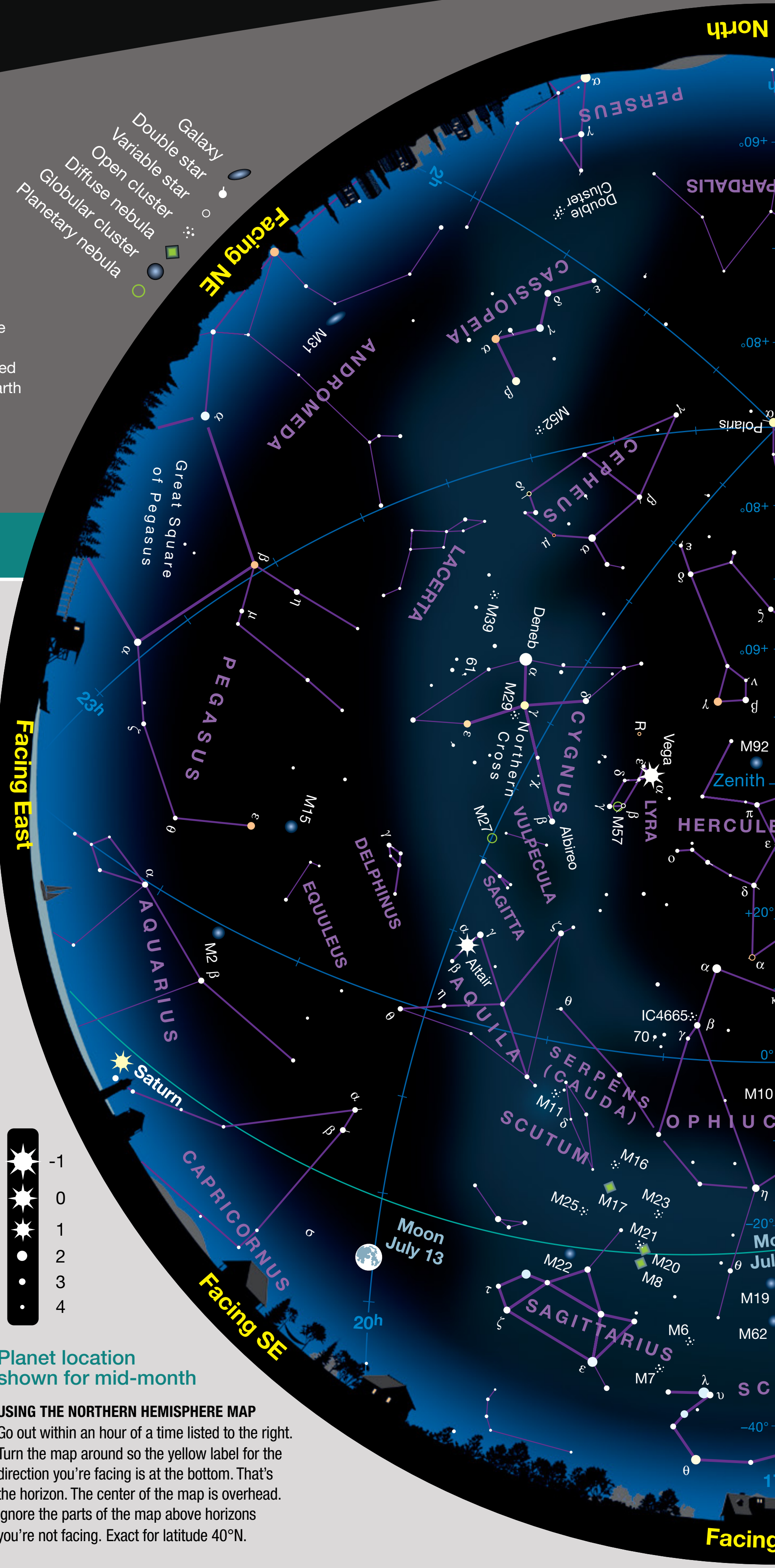
NEW MOON
July 28
17:55 UT

DISTANCES

Perigee	July 13, 09^h UT
357,266 km	Diameter 33′ 27″
Apogee	July 26, 10^h UT
406,273 km	Diameter 29′ 25″

FAVORABLE LIBRATIONS

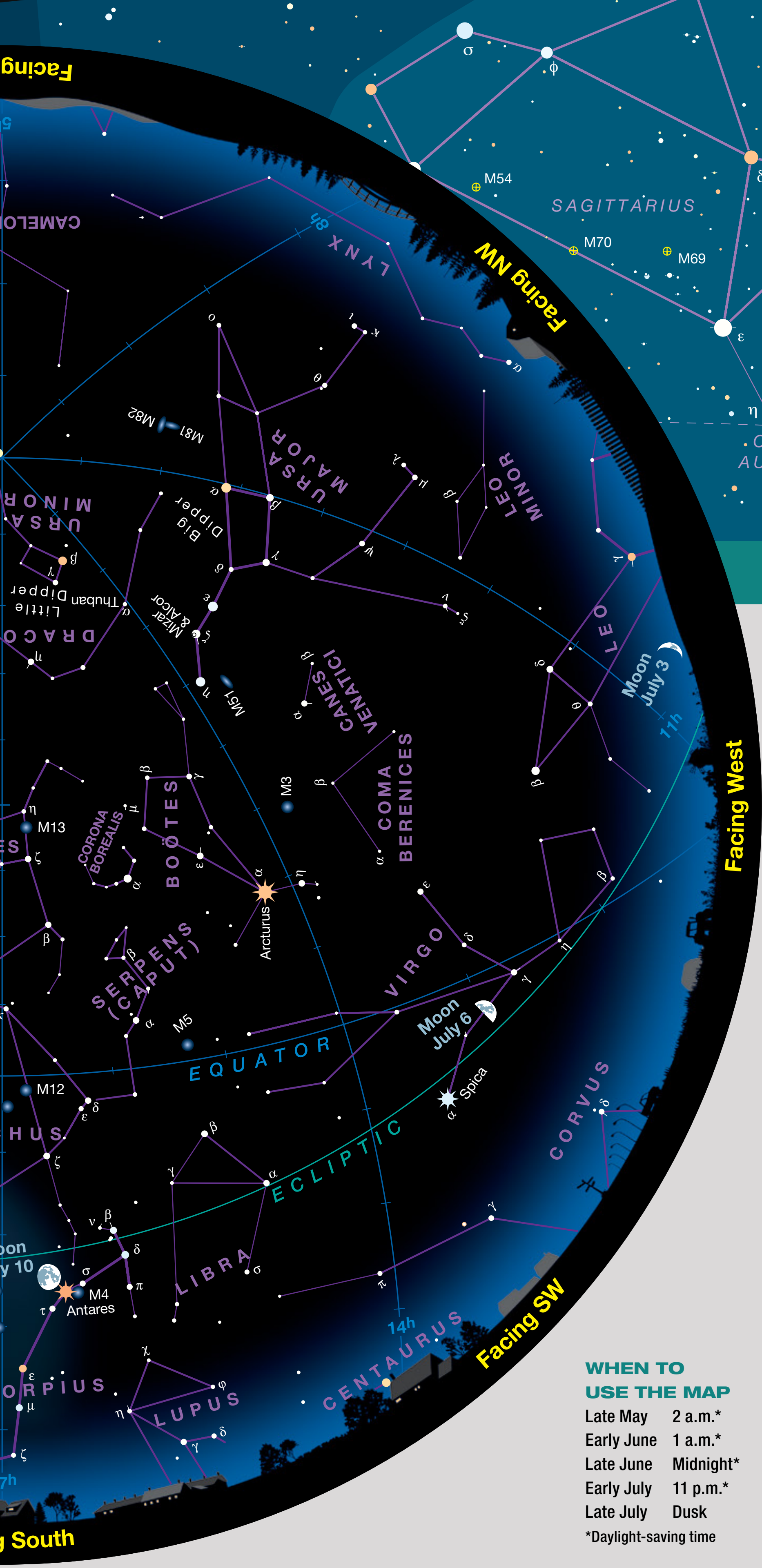
- Catena Sylvester — July 13
- Petermann Crater — July 14
- Hayn Crater — July 15

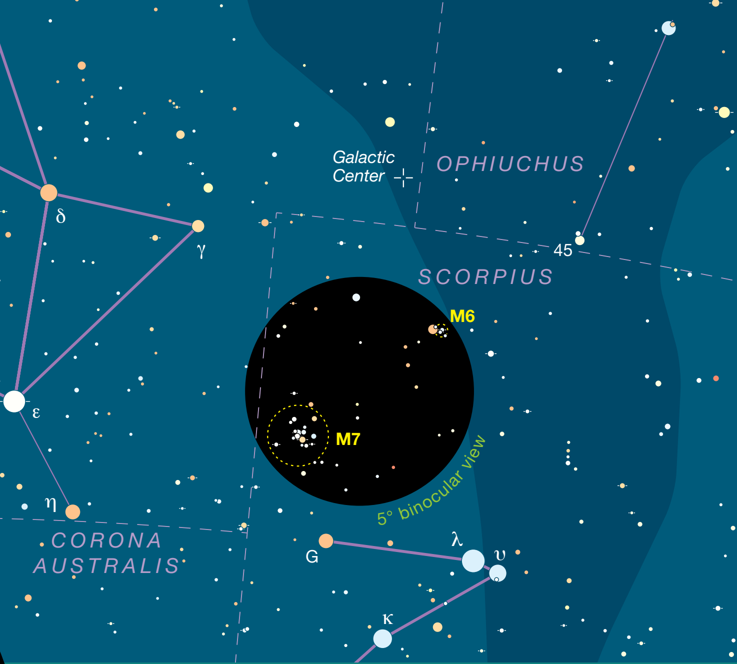


Planet location shown for mid-month

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

A Tail of Two Clusters

Our targets this month are the open clusters **M6** and **M7** in the tail region of the constellation Scorpius, the Scorpion. M6 is also called the Butterfly Cluster owing to its appearance, while M7 is known as Ptolemy's Cluster after Claudius Ptolemy, who first recorded it around AD 130.

To find the two objects, scan just north of the brightest star in the Scorpion's tail — magnitude-1.6 Lambda (λ) Scorpii — or west from Gamma (γ) and Epsilon (ε) Sagittarii in the spout of the Sagittarius Teapot. (Turn to page 20 to read about globular clusters in this region of the sky.) I like to imagine the bright stars of the Teapot and the tail of Scorpius as hands supporting a cat's cradle, with M7 firmly ensnared and M6 having made a narrow escape to the northwest. M7 is the bigger and brighter of the two clusters, but both are dead-easy in binoculars and are even naked-eye visible under good conditions.

As viewed from Earth, M6 and M7 lie pretty close to the galactic center, but that's a sort of visual pun. The two clusters are actually much closer to us, only about 1,500 and 1,000 light-years away, respectively. By contrast, the Lagoon Nebula (M8) and Trifid Nebula (M20), which also appear nearby in the sky, are much farther, more than 4,000 light-years distant. And the galactic center is another 23,000 light-years farther still. So, observing this stretch of the Milky Way gives us practice appreciating that space is, well, *space*: It has depth. If you plumb those depths with your binoculars, you'll have a better appreciation for the scale of the galaxy and our place in it, and I think that's a pretty good way to spend a summer evening.

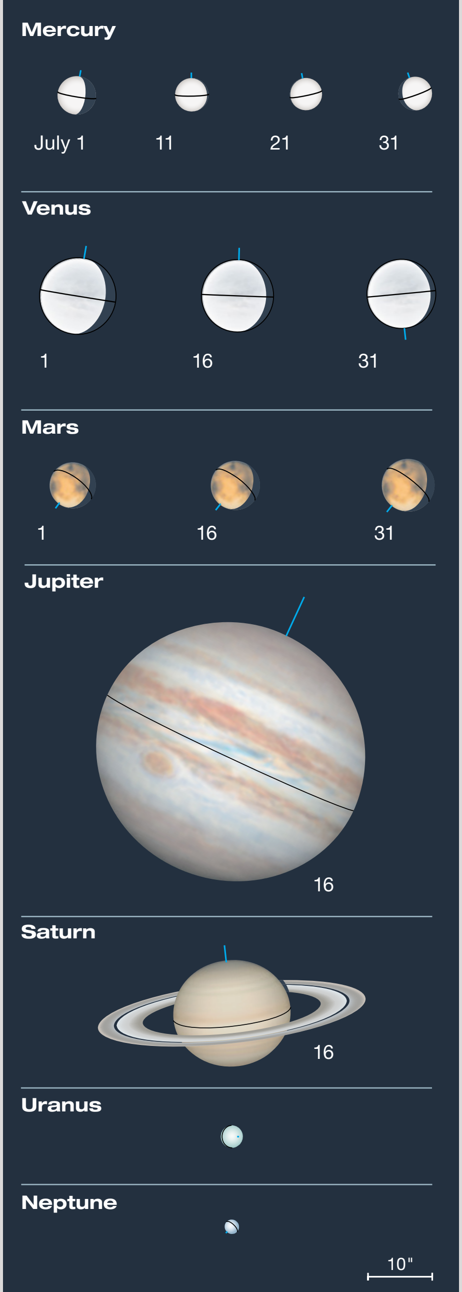
■ **MATT WEDEL** tries to really feel the three-dimensionality of the night sky when he looks out — not up — into it.

WHEN TO USE THE MAP

Late May	2 a.m.*
Early June	1 a.m.*
Late June	Midnight*
Early July	11 p.m.*
Late July	Dusk

*Daylight-saving time

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dawn until the 7th • **Venus** visible in the east-northeast at dawn all month • **Mars** and **Jupiter** visible at dawn all month • **Saturn** rises in the evening and is visible until dawn.



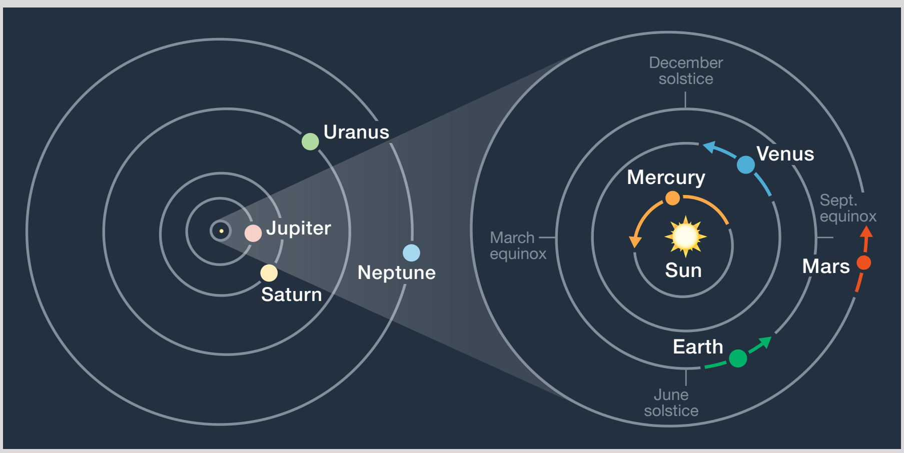
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

July Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	6^h 38.6^m	+23° 08′	—	–26.8	31′ 28″	—	1.017
	31	8^h 39.6^m	+18° 24′	—	–26.8	31′ 31″	—	1.015
Mercury	1	5^h 24.4^m	+22° 08′	17° Mo	–0.8	6.0″	72%	1.122
	11	6^h 50.1^m	+23° 46′	7° Mo	–1.7	5.2″	96%	1.291
	21	8^h 21.9^m	+21° 15′	5° Ev	–1.7	5.0″	98%	1.336
	31	9^h 40.3^m	+15° 33′	15° Ev	–0.7	5.3″	88%	1.277
Venus	1	4^h 31.0^m	+20° 28′	30° Mo	–3.9	11.9″	86%	1.404
	11	5^h 21.9^m	+22° 10′	27° Mo	–3.8	11.4″	88%	1.458
	21	6^h 14.1^m	+22° 51′	25° Mo	–3.8	11.1″	90%	1.507
	31	7^h 06.6^m	+22° 28′	22° Mo	–3.8	10.8″	92%	1.551
Mars	1	1^h 41.7^m	+8° 36′	72° Mo	+0.5	7.2″	86%	1.298
	16	2^h 21.5^m	+12° 12′	76° Mo	+0.3	7.7″	85%	1.218
	31	3^h 00.6^m	+15° 19′	80° Mo	+0.2	8.2″	85%	1.138
Jupiter	1	0^h 28.4^m	+1° 39′	92° Mo	–2.4	40.8″	99%	4.828
	31	0^h 33.1^m	+2° 00′	119° Mo	–2.7	44.9″	99%	4.386
Saturn	1	21^h 48.5^m	–14° 31′	134° Mo	+0.6	18.2″	100%	9.141
	31	21^h 41.8^m	–15° 10′	165° Mo	+0.4	18.7″	100%	8.890
Uranus	16	3^h 02.5^m	+16° 50′	65° Mo	+5.8	3.5″	100%	20.100
Neptune	16	23^h 43.7^m	–3° 04′	118° Mo	+7.9	2.3″	100%	29.424

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

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



The Dragon's Head

A fine summer asterism glides overhead.

▲ **SPOT THE DRAGON** Draco is an expansive constellation made up of mostly faint stars. Compare this image to our Northern Hemisphere map (pages 42 and 43) and see if you can trace the entire length of the Dragon's meandering form.

ALAN DYER

Of all the fantastical beasts, perhaps the most famous and fearsome is the dragon. Therefore, you might expect that the constellation Draco, the Dragon, would be bright and prominent. Instead, its stars shine meekly, and the figure's complicated curves are hard to follow. There is, however, one section that *is* conspicuous: the Dragon's head.

This part of Draco stands out because it's a compact, geometric asterism and located near Vega, the summer sky's brightest star. The head of the Dragon forms a large right triangle with Vega and Deneb, two of the three stars (along with Altair) comprising the Summer Triangle. Draco's head is also the northern point of a nearly equilateral triangle that includes Vega and another, less obvious summer asterism, the Keystone of Hercules.

On July evenings, observers at 40° north latitude watch Vega pass nearly overhead, but for those in southern Canada and England, it's Draco's head that arcs through the zenith. Indeed, Eltanin, the brightest star in the constellation, is a zenith star for the famous Greenwich Observatory in England.

Warm-hued Eltanin, Gamma (γ) Draconis, shines at magnitude 2.2 and is one of the mythical beast's glowing eyes. The star is 150 light-years away and slowly approaching our solar system. In one or two million years it'll pass at a distance of 28 light-years, at which point it will gleam near the celestial pole at magnitude –1.4.

For observers at mid-northern latitudes, Draco is a circumpolar constellation, like the better-known figures of the Big Dipper and Cassiopeia. Compared to the region near the south celestial pole, the stars in the northern sky are relatively faint — the circumpolar zone north of +50° declination lacks any stars of 1st-magnitude or brighter. What about 2nd-magnitude? There are only a dozen. The list includes five stars in the Big Dipper, Polaris and Kochab in the Little Dipper, three suns in Cassiopeia, Alpha Cephei, and Draco's Eltanin.

Remarkably, the head of Draco is composed of a tidy sequence of luminaries, with one each shining at 2nd, 3rd, 4th, and 5th magnitude. That's a handy range for determining the limiting magnitude of your sky — especially if you view under less-than-pristine conditions.

You can extend this scale at the bright end by including 1st-magnitude Deneb and zero-magnitude Vega. To go fainter, you can add 5.5-magnitude Mu (μ) Draconis (Alrakis), which is located just west of the constellation's head. Even fainter is a star right in the middle of the head, 5.8-magnitude HD 161693, sometimes called Al Ruba. Next time it's clear, try identifying which star in this collection is the faintest one you can see without optical aid.

Let's look a little more closely at the main stars delineating Draco's head. The other "eye," and the second brightest star in the asterism, is 2.8-magnitude Rastaban, Beta (β) Draconis. It's about 380 light-years way and a *G*2 star, like the Sun, but far more luminous with an absolute magnitude of –2.5.

The asterism's third-brightest star is magnitude-3.8 Grumium, Xi (ξ) Draconis. This orange sun lies at a distance of approximately 113 light-years. Grumium and Eltanin are aligned close to (and almost parallel with) the 18^h line of right ascension, with Eltanin being the star positioned nearest to Vega.

Finally, the faintest star in the Dragon's head is Kuma, Nu (ν) Draconis. Kuma is actually a pair of white, 4.9-magnitude stars. The apparent distance between the components is 62″, which makes Nu an easy and attractive equal-brightness binocular double.

I count no fewer than 13 stars in Draco that have proper names. But the star bearing the Greek-letter designation Alpha (α) — usually a constellation's brightest — actually ranks #8. Alpha Draconis is Thuban, a star in the dragon's tail famous for being the North Star when ancient Egypt's Great Pyramids were built on the Giza Plateau.

■ **FRED SCHAAF** began writing his first book, *Wonders of the Sky*, 42 Julys ago.

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

Lovely Lunar Link-ups

Bright stars and brighter planets greet the Moon.

FRIDAY, JULY 1

Last month's parade of planets has lost some of its luster since hitting its peak on June 24th, but there's still an impressive show going on at dawn. **Saturn** and **Mercury** still bracket the solar system array, but the span between those two outliers has increased from its minimum of 91° on June 4th to 118° this morning. Most of that spread is due to Mercury's eastward drift as it descends sunward while its current apparition draws to a close. Offsetting the planet's lower altitude is its increasing brightness — Mercury shines at magnitude –0.8 on this date. Even so, the innermost planet will be lost from naked-eye view in just one week. When it exits the dawn, the planetary parade essentially comes to an end.

The first of July is also notable because **Venus** is close to **Aldebaran**. The gleaming Morning Star has been creeping up to Taurus's leading light for days, and this morning it sits just a bit more than 4° from the star. In effect, Venus has become a temporary, honorary member of the Hyades, but you'll need your binoculars to really appreciate this scene since most of the cluster stars struggle to stand out against twilight's glow.

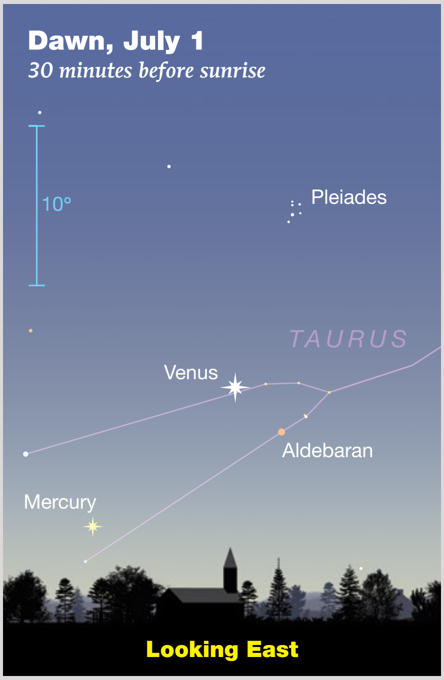
SUNDAY, JULY 10

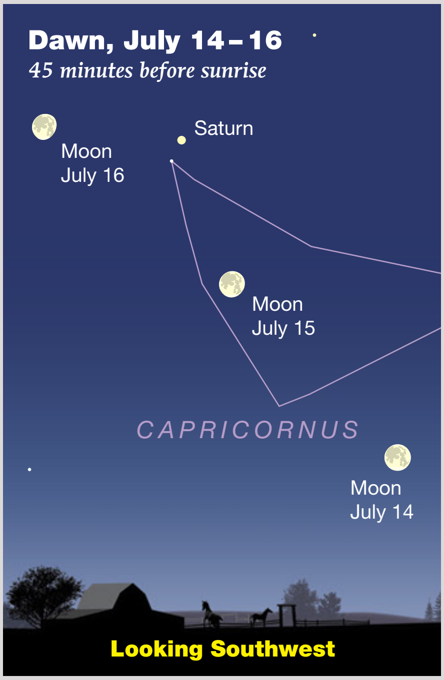
The **Moon** and **Antares** meet on a monthly basis, and these encounters are getting a little bit closer each time — as they will for a couple of years. Of course, given the Moon's rapid pace as it travels the ecliptic (it moves its own diameter in about an hour), the appearance of any given encounter depends a lot on when it's dark and whether the Moon's up where you are. This evening, look to the south-southeast as twilight fades to catch the waxing gibbous Moon (about 90% illuminated) sitting just a bit more than 2° above left of Antares. This is the closest link-up between the Moon and a bright star this month. You certainly don't need binoculars to enjoy this event, but I always find optical aid helps enhance the orangey hue of Antares.

TUESDAY, JULY 19

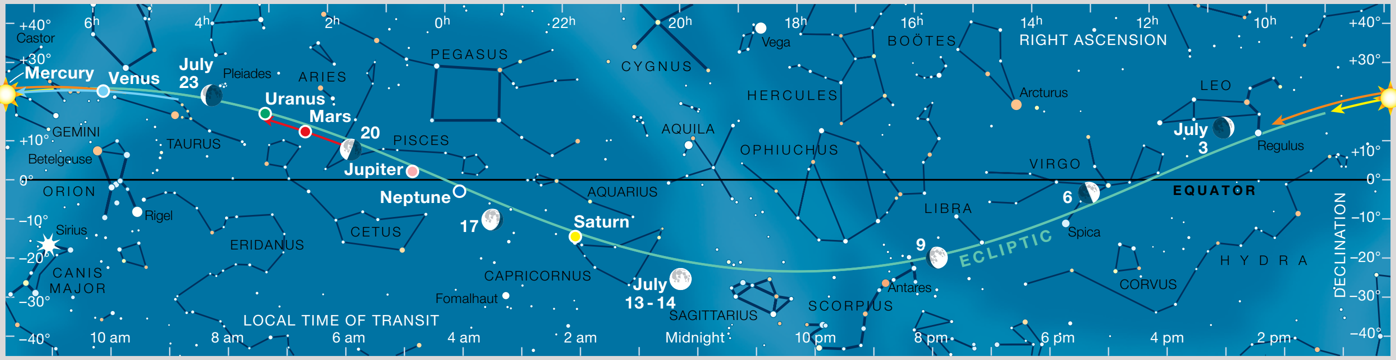
As the **Moon** tracks its way eastward along the ecliptic, it visits each of the planets currently strung out across the sky — some more closely than others. Late in the evening on the 15th, it rose roughly 6° apart from **Saturn**. And a few nights later, just after the calendar ticks over from the 18th to the 19th, the waning gibbous Moon ascends due east just 3° below mighty **Jupiter**. Here again, binoculars add something a little extra to the conjunction — and that "extra" is a Jovian moon or two.

The satellite you're mostly likely to catch is 6.2-magnitude **Callisto**, which is off to the planet's right. Jupiter's other three bright moons are likely too close to the planet's disk to be seen easily at binocular magnifications, but you can always try. The key to success is finding some way to hold your binoculars steady. You can prop them up on a fence or railing, or even mount them on a camera tripod with a special adapter. As always, you can identify which moon is which by turning to the diagram presented on





▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west).



▲ The Sun and planets are positioned for mid-July; 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.

page 51. As that graphic makes clear, it's Callisto that stays farthest from Jupiter's glare, which is why it's usually the easiest one to catch in binos.

THURSDAY, JULY 21

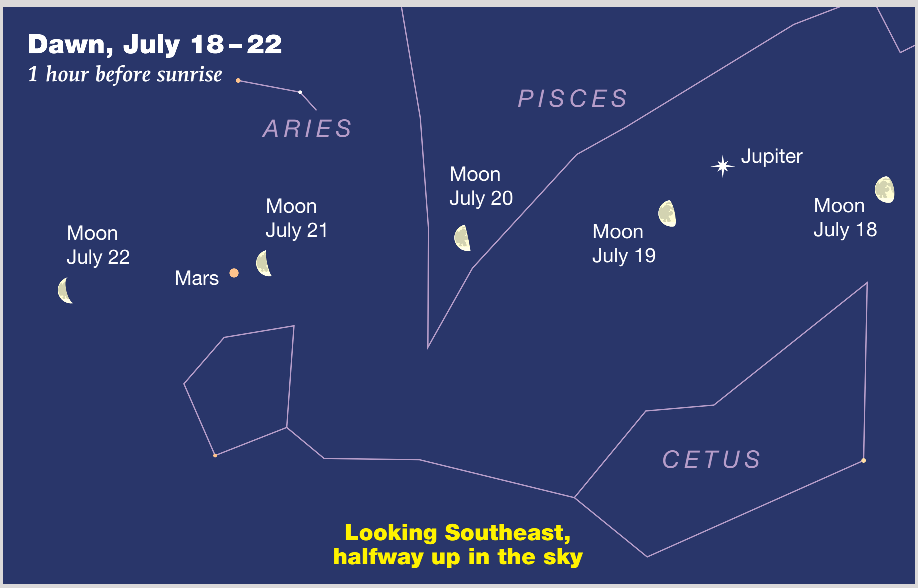
The next stop for the **Moon** is **Mars**. Since the Moon is catching up to the Red Planet, the later you look, the narrower the gap between them will be. For most observers in the Americas, you should be able to see them quite a bit less than 3° apart — the closest Moon-planet pairing this month. Indeed, from some locations in northern Japan and eastern Russia, the Moon not only catches up to Mars, it eclipses it.

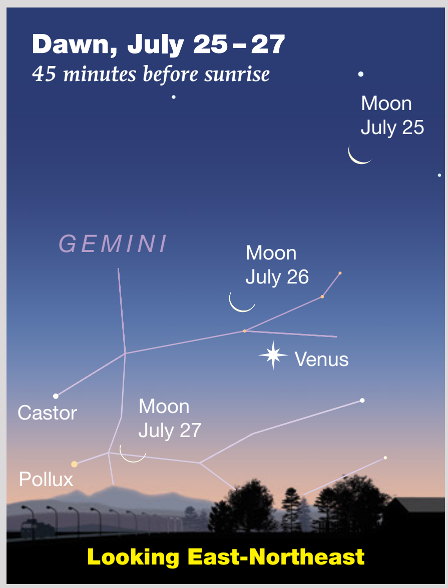
Slowly but surely, Mars is gaining brightness as it marches toward its December opposition. On this particular night it shines at magnitude +0.3, which is brighter than all but three of the stars it currently shares the predawn sky with. However, given that the planet is also positioned between the dueling beacons of Jupiter and Venus, Mars's luminosity is less impressive than it would be at other times. Still, its distinctive peachy color is something its silvery rivals can't match.

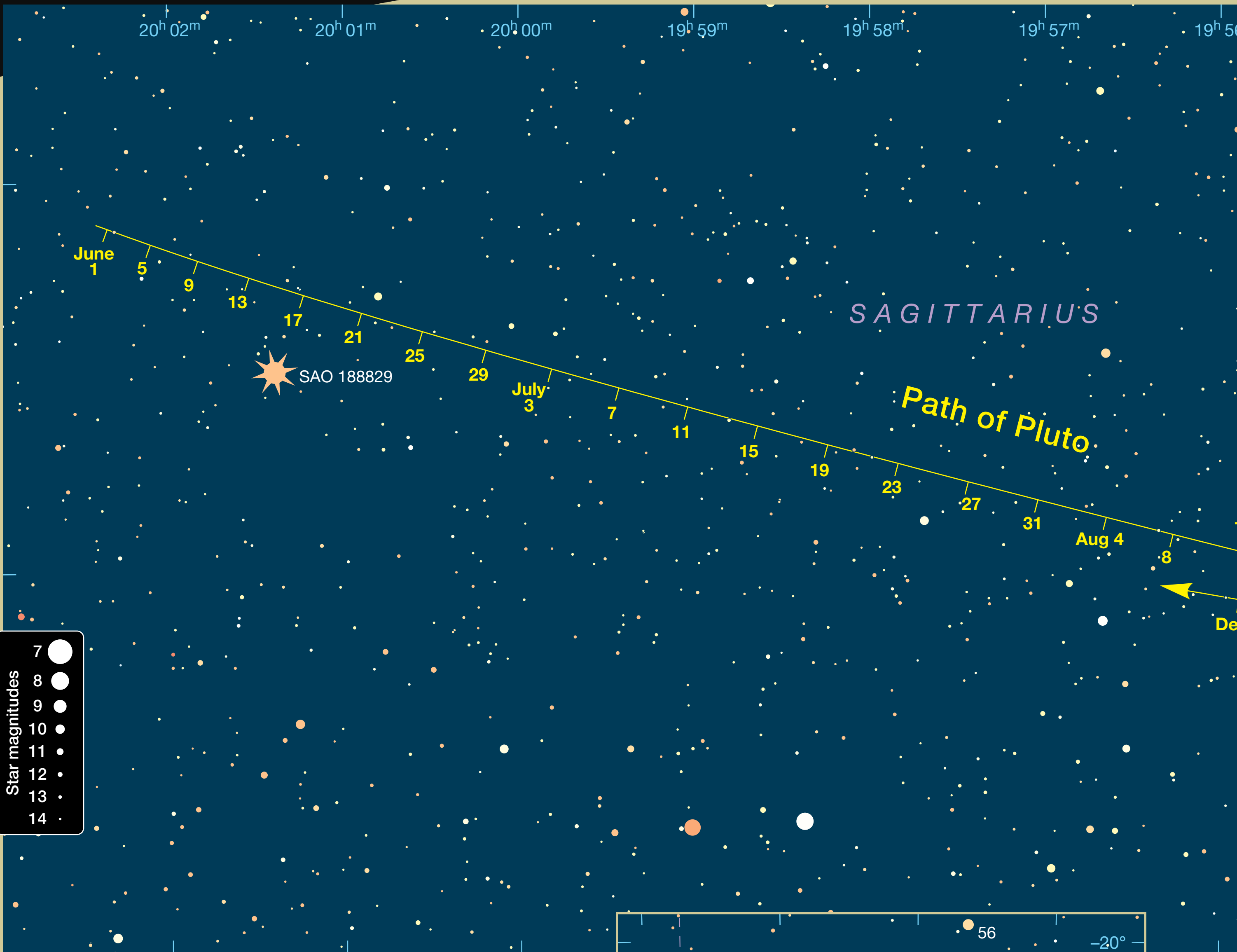
TUESDAY, JULY 26

Although the Moon's meet-up with Mars is the month's tightest lunar-planetary conjunction, there's no doubt the most eye-catching is this morning's with brilliant Venus. Exactly one month ago, the **Moon** and **Venus** had their closest encounter for 2022, when they were separated by just 2½°. Although they're one degree farther apart at dawn today, that's still good enough for second place on the list of 2022 Venus-Moon conjunctions for observers in North America. The other difference this time around is the lunar crescent is a touch thinner — 5% illuminated versus 6% in June. The twosome has also shifted one zodiacal constellation eastward, moving from Taurus into Gemini. So, if you were clouded out for last month's pairing, here's your redo. And even if you did catch it, who could tire of seeing the earthlit crescent sitting near the brightest object in the night sky?

■ Consulting Editor **GARY SERONIK** follows the Moon's journey along the ecliptic as closely as weather permits.



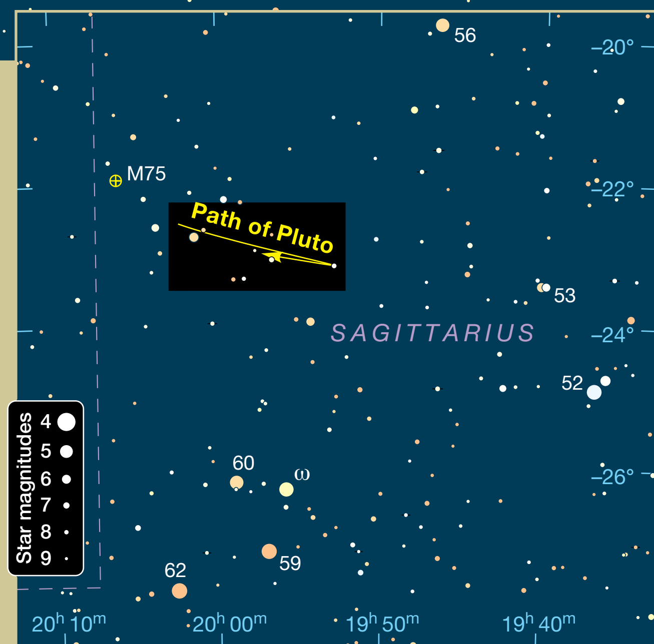


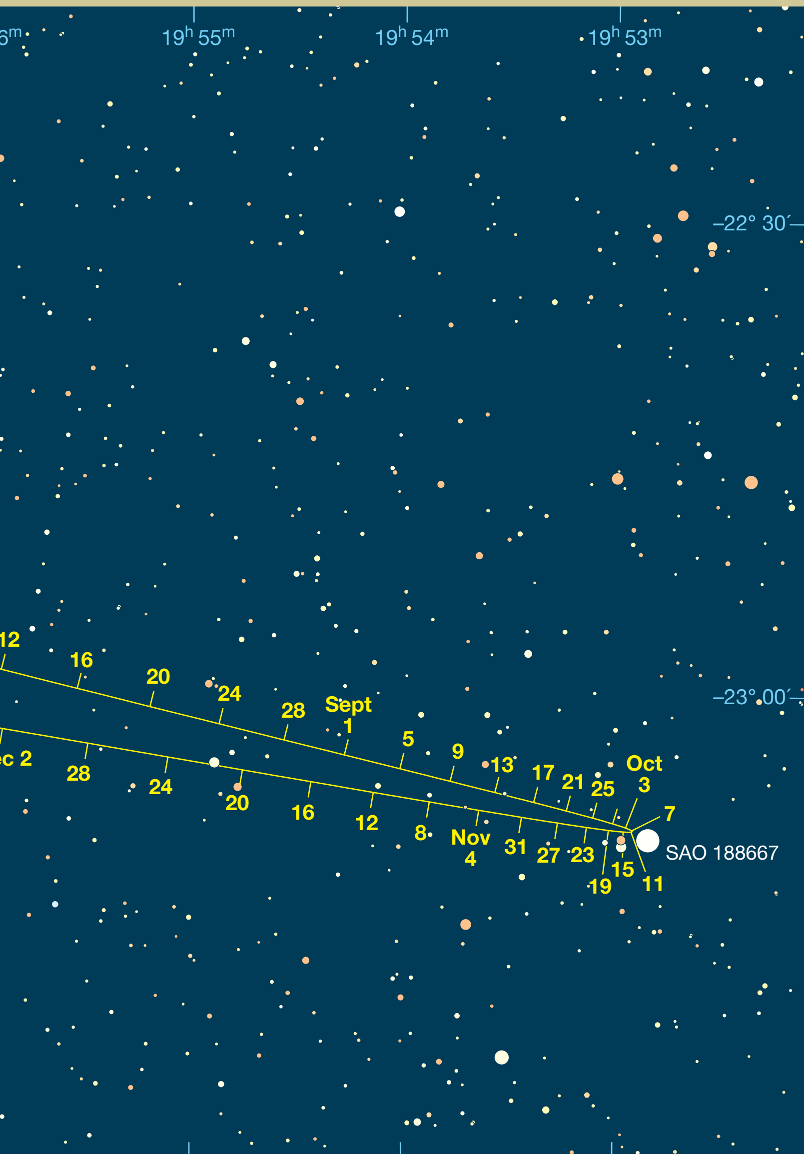


Pluto at Opposition

Scope the dwarf planet at its best for 2022.

Pluto comes to opposition on July 20th in eastern Sagittarius. You'll need at least an 8-inch (200-mm) telescope and dark skies to track down the 14.3-magnitude stellar blip. On opposition night, the dwarf planet is located about 2° southwest of 8.6-magnitude globular cluster M75. (Pluto's position is plotted in the chart above for 0h UT on the dates shown.)





Reliving a Famous Supernova

ON THE MORNING OF July 4, 1054, skywatchers around the world witnessed the appearance of a brilliant new star in Taurus. The event may have been depicted by an Anasazi artist in northwestern New Mexico. Visitors to the Chaco Culture National Historical Park can see a striking pictograph of a lunar crescent, a starlike object, and a hand. The star-moon pair may record a July 5, 1054, conjunction between the waning lunar crescent and the supernova.

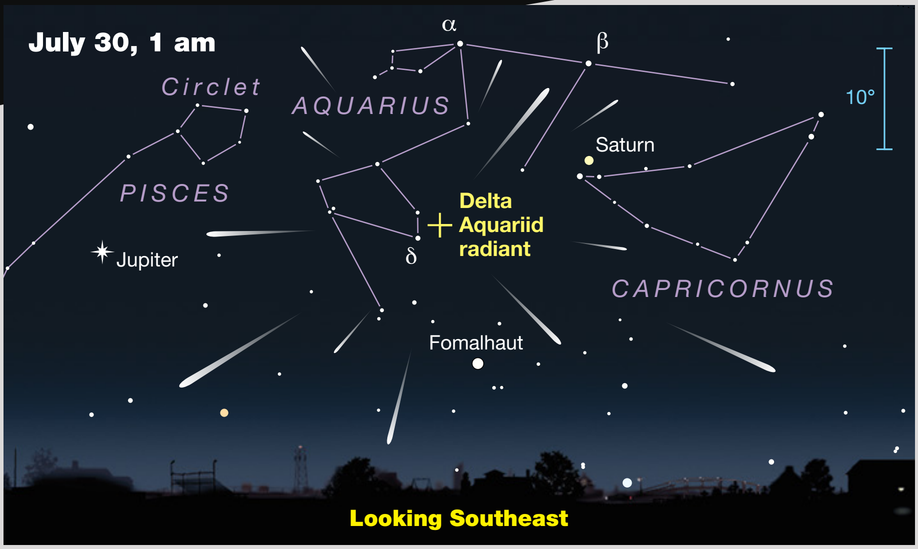
Reaching a dazzling magnitude –6, the supernova was visible by day and remained in view into April 1056. The detonation left in its wake a cloud of debris that caught astronomer Charles Messier's eye more than seven centuries later and inspired the compilation of his famous catalog of deep-sky objects. Today we know this supernova remnant as M1, the Crab Nebula.

Given that we've been waiting for nearly a millennium for a nearby supernova, it can be difficult to imagine how startling the sight must have been on that July dawn so long ago. However, thanks to Venus, we don't have to *imagine* any longer.

On the morning of July 13th, the brilliant Morning Star (magnitude –3.8) will shine less than ½° north of the position of the 1054 supernova (and the Crab Nebula, of course). Venus rises around 3:30 a.m. local daylight-saving time and climbs high enough in the east-northeastern sky to view in brightening twilight. Although the 13th is when Venus is closest to the correct position, the planet also stands about 1.3° from the Crab the mornings before and after the 13th.

By participating in this ancient replay we can partake in the wonderment ancestral skywatchers must have felt at seeing something so bright and inexplicable. If nothing else, we can at least visualize what a naked-eye supernova might look like even if the real thing never happens in our lifetime.

▲ No one knows for certain whether the pictograph at Chaco Culture National Historical Park depicts the supernova of July 4, 1054, but the Moon and star are a good match for the scene one day after the supernova appeared.



A Meteor Shower for Warm Nights

I'M EMBARRASSED to admit I've never intentionally looked at the Southern Delta Aquariid meteor shower. I've seen a few members fly by over the years and casually traced them back toward Aquarius but have never given the shower its due. This month, I have no excuses. While the stream is active from mid-July to mid-August, the peak occurs on the morning of July 30th. With the new Moon falling on the 28th, the timing is just about ideal.

Because the shower's radiant is located in southern Aquarius a few degrees west of Delta (δ) Aquarii, observers in the tropics get the best view and might see 25 meteors per hour between midnight and dawn. But there's no need to sniff if you live at mid-northern latitudes, where the radiant culminates due south at about 30° altitude shortly after 3 a.m. local daylight-saving time.

Up to a dozen meteors per hour may scratch the sky from a dark site. Be patient and enjoy the light show as the Milky Way wheels westward and Saturn, Jupiter, and Mars parade slowly across the south. Just don't forget to bring the bug spray.

The Southern Delta Aquariid shower is rich in faint meteors because the particles are dust-size and enter the atmosphere at a relatively moderate speed of 40 kilometers (25 miles) per second. The display's origins can be traced back to a comet that broke up about 9,500 years ago. From that chaos, Comet 96P/Machholz arose, along with near-Earth asteroid 2003 EH1 (responsible for the Quadrantid meteor shower), and the Marsden and Kracht comet groups. Material shed by Comet 96P is responsible for both the Southern Delta Aquariids and the Daytime Arietids, and plays a hand in the Quadrantids as well. The meteor flash you witness may be momentary, but the particle that produced it has a deep and tangled past.

There are several minor showers active around the same time as the Aquariids, including the Alpha Capricornids, which peak on the same date. Although they contribute just five meteors per hour, the Alpha Capricornids are known for slow-moving fireballs, with a few streaks brighter than Venus. The radiant lies about 3° northeast of Alpha (α) Capricorni and culminates a couple of hours earlier than the radiant for the Aquariids. If you're fortunate, you'll get to sample both meteor streams during your early morning outing.

Action at Jupiter

JUPITER RISES well before 1 a.m. local daylight-saving time at the start of July. By the time civil twilight begins, the planet has attained an altitude of better than 44°. On the 1st, Jupiter resides in the non-zodiacal constellation Cetus, where it shines at magnitude –2.4 and presents a disk 41″ across. By month's end, Jupiter is up before 11 p.m. and transits the meridian at roughly 5 a.m., just as the sky begins to noticeably brighten with twilight.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter is at its highest.

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

June 1: 3:20, 13:15, 23:11; **2**: 9:07, 19:03; **3**: 4:58, 14:54; **4**: 0:50, 10:46, 20:41; **5**: 6:37, 16:33; **6**: 2:28, 12:24, 22:20; **7**: 8:16, 18:11; **8**: 4:07, 14:03, 23:58; **9**: 9:54, 19:50; **10**: 5:46, 15:41; **11**: 1:37, 11:33, 21:29; **12**: 7:24, 17:20; **13**: 3:16, 13:11, 23:07; **14**: 9:03, 18:59; **15**: 4:54, 14:50; **16**: 0:46, 10:41, 20:37; **17**: 6:33, 16:28; **18**: 2:24, 12:20, 22:16; **19**: 8:11, 18:07; **20**: 4:03, 13:58, 23:54; **21**: 9:50, 19:46; **22**: 5:41, 15:37; **23**: 1:33, 11:28, 21:24; **24**: 7:20, 17:15; **25**: 3:11, 13:07, 23:02; **26**: 8:58, 18:54; **27**: 4:50, 14:45; **28**: 0:41, 10:37, 20:32; **29**: 6:28, 16:24; **30**: 2:19, 12:15, 22:11

July 1: 8:10, 18:05; **2**: 4:01, 13:57, 23:52; **3**: 9:48, 19:44; **4**: 5:40, 15:35; **5**: 1:31, 11:27, 21:22; **6**: 7:18, 17:14; **7**: 3:09, 13:05, 23:01; **8**: 8:56, 18:52; **9**: 4:48, 14:43; **10**: 0:39, 10:35, 20:30; **11**: 6:26, 16:22; **12**: 2:17, 12:13, 22:09; **13**: 8:04, 17:59; **14**: 3:56, 13:51, 23:47; **15**: 9:43, 19:38; **16**: 5:34, 15:30; **17**: 1:25, 11:21, 21:17; **18**: 7:12, 17:08; **19**: 3:03, 12:59, 22:55; **20**: 8:50, 18:46; **21**: 4:42, 14:37; **22**: 0:33, 10:29, 20:24; **23**: 6:20, 16:16; **24**: 2:11, 12:07, 22:03; **25**: 7:58, 17:54; **26**: 3:49, 13:45, 23:41; **27**: 9:36, 19:32; **28**: 5:28, 15:23; **29**: 1:19, 11:15, 21:10; **30**: 7:06, 17:02; **31**: 2:57, 12:53, 22:48

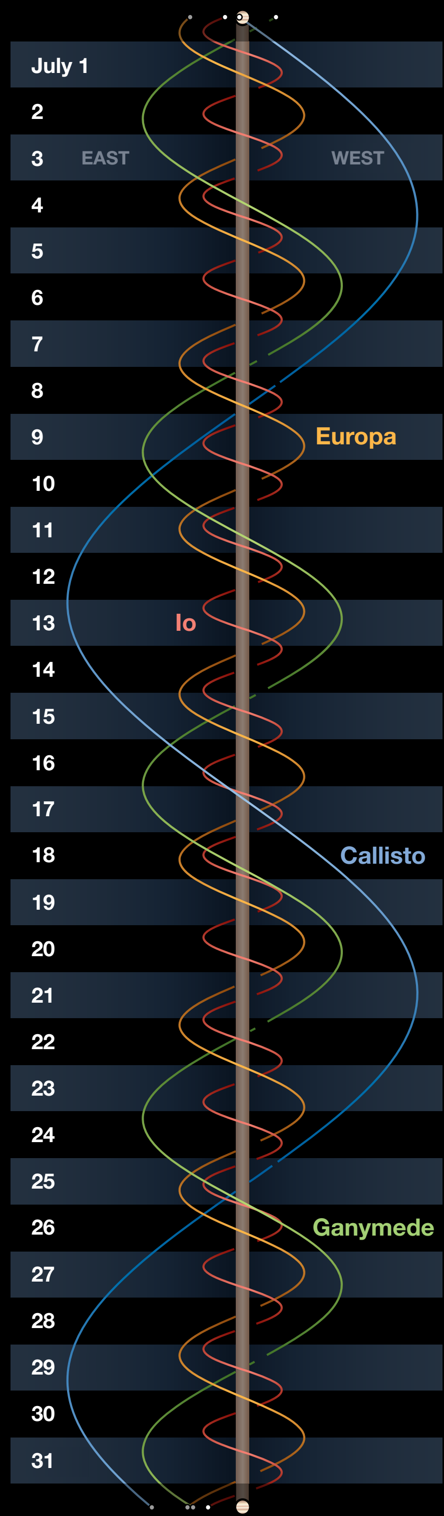
These times assume that the spot will be centered at System II longitude 21° on June 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 21° and 1²/₃ minutes later for each degree more than 21°.

Phenomena of Jupiter's Moons, July 2022

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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons

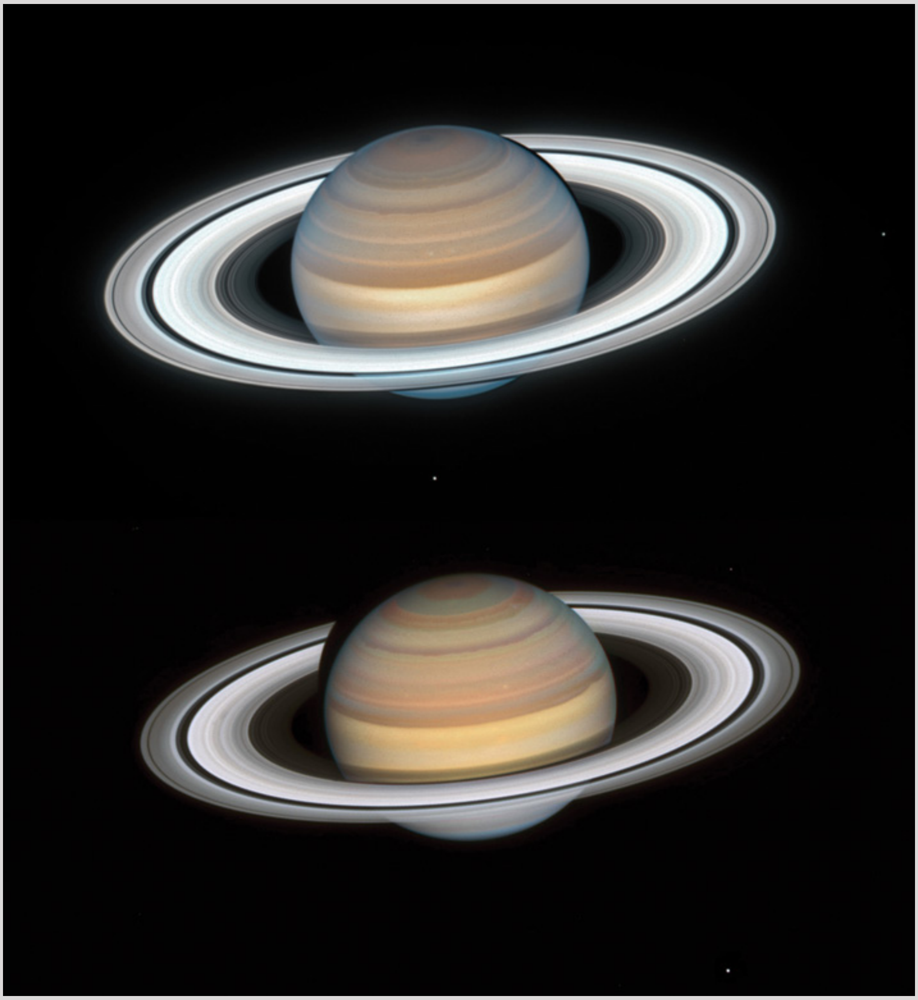


The wavy lines represent Jupiter's four big satellites. The central vertical band is Jupiter itself. Each gray or black horizontal band is one day, from 0^h (upper edge of band) to 24^h UT (GMT). UT dates are at left. Slide a paper's edge down to your date and time, and read across to see the satellites'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

Saturn's Seeliger Effect

Watch the planet's rings brighten at opposition.

In 1855, Cambridge University announced the Adams Prize for a work explaining the stability and appearance of Saturn's rings. The winner was a brilliant, 26-year-old Scottish scientist, James Clerk Maxwell. (He was also the only contestant.) In his essay "On the Stability of the Motion of Saturn's Rings," Maxwell used rigorous mathematical analysis to demonstrate that solid sheets of matter would be shattered by the slightest tidal disturbance, while liquid rings would have coalesced into visible satellites long ago. Only swarms of satellites far too small to be seen individually, each ". . . revolving round the planet with different velocities according to their respective distances," could account for the stability of the rings.



▲ Hubble Space Telescope images of Saturn on July 4, 2018 (16 days before opposition, top) and on September 12, 2021 (41 days after opposition, bottom) show the enhanced brightness of the rings relative to the globe as the illumination angle decreases.

NASA / ESA / A. SIMON (GODDARD SPACE FLIGHT CENTER), M. H. WONG (UNIVERSITY OF CALIFORNIA, BERKELEY), AND THE OPAL TEAM

Maxwell's conclusion echoed a shrewd guess posited by Paris Observatory astronomer Giovanni Domenico Cassini 150 years earlier in 1705. The ultimate proof of Maxwell's theory came from Pittsburgh, Pennsylvania, in 1895 when Allegheny Observatory astronomer James Keeler used a spectrograph and the Doppler shift to show that the inner parts of the rings orbit Saturn faster than the outer parts.

Eight years earlier, however, German astronomer Hugo von Seeliger called attention to a recurring spectacle that suggested that the rings must be composed of shoals of tiny satellites. When serving as the director of the University of Munich's observatory, Seeliger observed that Saturn's A and B rings are usually comparable in brightness to the canopy of clouds blanketing the globe. As the planet approaches opposition, however, the rings brighten dramatically, only to fade as the planet begins to recede.

At opposition, when Earth lies precisely between Saturn and the Sun, Saturn is illuminated from directly behind an earthbound observer. Seeliger surmised that from this vantage point every ring particle covers its own shadow, causing the rings to appear brighter. As opposition passes and the angle between Earth and Saturn increases, the shadows cast by foreground ring particles begin to fall on those in the background, causing the apparent brightness of the rings to diminish. Long known as the *Seeliger effect*, today this phenomenon is generally referred to as the *opposition surge* or the *opposition effect*.

The shadow-hiding phenomenon envisioned by Seeliger should be gradual and linear, but the observed brightness of the rings increases very rapidly for several days around the date of opposition. The Sun-Earth-Saturn angle never exceeds six degrees, but the lion's share of brightening occurs when that angle is reduced to less than half a degree.

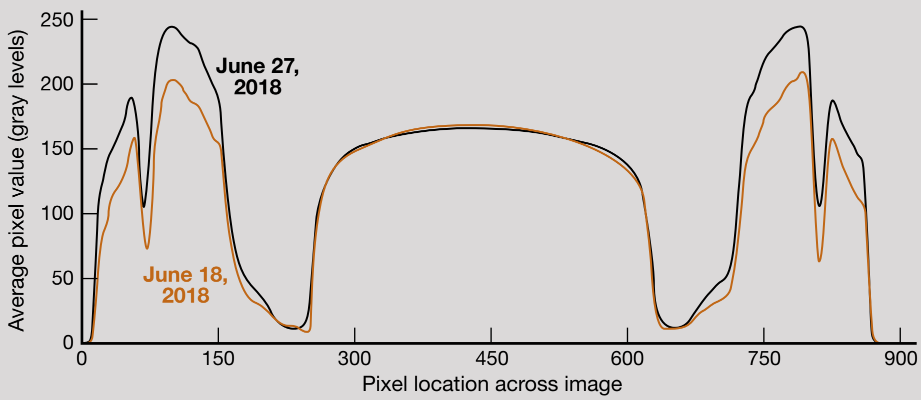
This abrupt spike, reported in 1893 by Gustav Müller of the Astrophysical Observatory at Potsdam, Germany, remained mysterious for almost a century. It's caused by the phenomenon known as *coherent backscattering*, first observed in the early 1980s by experimental physicists shining laser beams into turbid liquids.

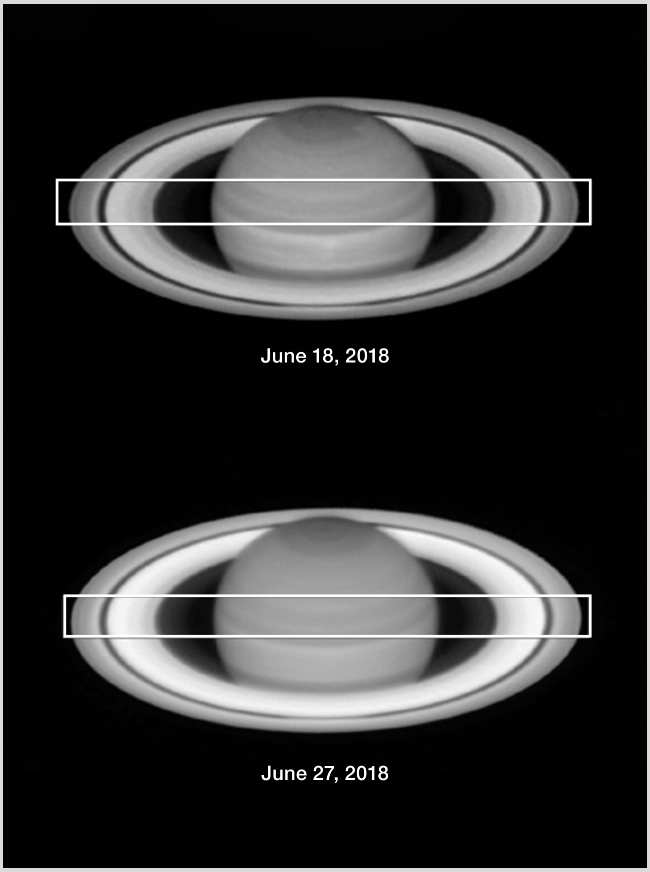
Coherent backscattering works like this: At very narrow angles of incidence, reflected light is enhanced when it strikes a microscopically rough surface covered with minuscule grains comparable in size to the light source's wavelength. If the distance between these particles is greater than one wavelength, light rays tend to multiply scatter in a backward direction and combine by constructive interference with incoming rays to produce an amplified reflection.

Photometric data from NASA's Hubble Space Telescope and the Cassini spacecraft supported by theoretical models and laboratory experiments indicate that the particles in Saturn's rings are covered with a powdery layer of submicrometer-size ice granules. While shadow hiding does contribute to the opposition surge, coherent backscattering is really the principal cause.

The opposition surge is slightly more pronounced in the blue-violet region of the spectrum than at longer, redder wavelengths. For reasons that are poorly understood, it's also locally more intense in the Cassini Division and the tenuous C ring, as well as at the outer edge of the A ring.

Although the opposition surge is very conspicuous in Saturn's rings, it has also been observed on the Moon, other planetary satellites, many asteroids, and even on Mars. At full Moon, for example, the brightness of every point on the entire lunar surface shines 40% brighter than just one day earlier. In fact, opposition surge is a nearly ubiquitous phenomenon exhibited by any solid surface containing minute irregularities, including terrestrial soils, frosts, and even canopies of vegetation.





▲▶ This 2018 pair of Saturn images recorded through a blue filter by Damian Peach were taken 9 days before opposition (right) and on the date of opposition (bottom right). The graph above plots the intensity of the swath of pixels within the boxes passing through the ansae of the rings in each photo.

While the opposition surge in Saturn's rings is visually striking, you can easily overlook it if you don't observe the planet regularly. Weather permitting, you should begin to monitor Saturn for at least two weeks before opposition, which occurs on August 14th this year. For a few days preceding and following this date, the A and B rings, inclined 14° to our line of sight, will appear about 1.7× brighter than they did at the beginning of the month, markedly outshining the globe. This will also present an excellent opportunity to glimpse the faint C ring, which will stand out boldly even in a 6-inch telescope on a night of steady seeing and good transparency. The opposition surge will even perceptibly change the planet's naked-eye brightness, increasing it by about 0.3 magnitude.

■ Contributing Editor **TOM DOBBINS** hopes to observe two Saturnian years.

GRAPH: GREGG DINDERMAN / S&T

Tiny Treasures in Sagitta

The celestial Arrow guides us to treasures both simple and subtle.

◀ **OPEN OR CLOSED?** Globular cluster M71 is only about 13,000 light-years away yet looks unimpressive in telescopes. The object is so loosely structured that astronomers once classified it as an open cluster. However, modern studies confirm that the members of M71 possess spectroscopic signatures consistent with those of other globular clusters. M71 is an immature specimen — one of the youngest and smallest globulars known.

RON BRECHER

"Small is beautiful." The old adage holds true for lots of things, including petite patterns in the night sky. To my delight, Sagitta, the Arrow, is one of them.

Sagitta's dart-like pattern comprises just four relatively dim stars and measures less than 5° in length. Moreover, at 80 square degrees, Sagitta's total area makes it the third smallest of the 88 official constellations. Clearly, the celestial arrow is no big deal. Yet Sagitta is distinctive in its own modest way.

Along with neighboring Vulpecula, the Fox, Sagitta resides deep in the summer Milky Way between Cygnus to the north and Aquila to the south. It's an errant arrow, aiming roughly eastward at nothing in particular — though if I were the Fox, I'd keep my head down.

Examining the Arrow

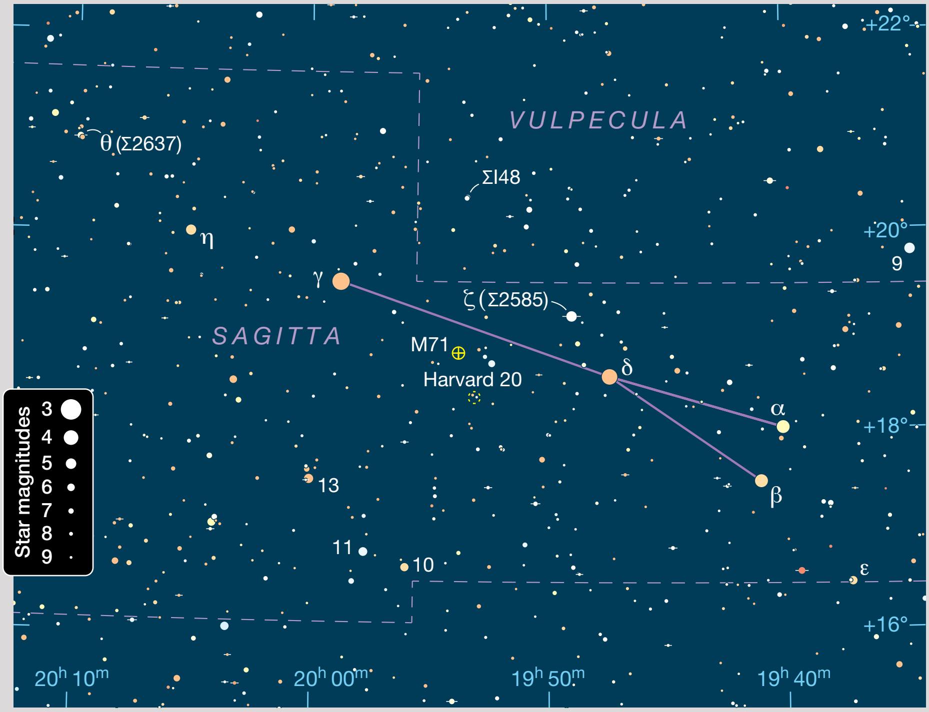
I can't see much of Sagitta in my dull-as-dishwater suburban sky, but it's pretty in binoculars. The western, "fletching" end is established by Alpha (α) and Beta (β) Sagittae, each shining at magnitude 4.4. Eastward from the Alpha/Beta pair is 3.8-magnitude Delta (δ) and, beside it, 5.0-magnitude Zeta (ζ). Further up the shaft is 3.5-magnitude Gamma (γ), the arrow's brightest point and nominal tip. My trusty 10×50 binoculars add an extra star, giving the suburban version of the Arrow a bit of added length courtesy of 5.1-magnitude Eta (η). Ken's deluxe Sagitta measures a whopping 6¼°!

Okay, so it's still not very big. I admit that even my stretch version contains few telescopic treasures for city-based observers. However, the objects are easy to locate, and a huge telescope isn't needed to appreciate them. I examined the Arrow on a reasonably clear evening last summer using mainly two scopes — a 4.7-inch (120-mm) f/7.5 apochromatic refractor, and an 8-inch (200-cm) f/6 Newtonian reflector on a Dobsonian mount.

I began by aiming the refractor at orangey Delta Sagittae, one of only two stars in the constellation I could spot with my bare eyes. From there it was a short hop to fainter Zeta less than ¾° northeast. Zeta looks single at low power, but it's a strongly unbalanced binary known as **Struve (Σ) 2585**. Its primary element is magnitude 5.0, while the secondary sun, 8.3″ away, is four magnitudes dimmer. My apochromat split the pair at 50×, and it was quite appealing at 100×.

From Zeta Sagittae, I re-aimed the apo 1° northeastward to a spot just across the Sagitta-Vulpecula border. There, at the foot of the Fox, my 8×50 finderscope picked up a 40′-long isosceles triangle, the baseline of which is anchored by two 7th-magnitude stars. The triangle's vertex to the east-northeast is marked by the superb low-power double **Struve Appendix Catalogue I 48 (ΣI48)**. Its 7.1- and 7.3-magnitude components, 41.7″ apart, make this an eye-catching "headlights" double. And those headlights gleamed nicely in my apo at 28×.

Also on my list was 6.6-magnitude **Theta (θ) Sagittae**, which glimmers 1.5° northeast of Eta (the tip of my arrow). Theta is a triple, also designated Σ2637AB and Σ2637AC. The 8.9-magnitude secondary (component B) lies 11.6″ from Theta, while the 7.5-magnitude tertiary (C) is separated by a breezy 91.9″. The triangular system was glorious in the apo at 28×.



▲ **LITTLE ARROW** Sagitta is tiny and dim but not hard to find in the band of the Milky Way between much larger neighbors Cygnus and Aquila. Oddly, neither Alpha (α) nor Beta (β) Sagittae is the constellation's brightest star — that honor goes to 3.5-magnitude Gamma (γ).

Main Messier Meal

After the appetizers, I was hungry for the main course: globular cluster **M71**. To be honest, though, M71 isn't a hearty meal. Viewed in a backyard telescope, this lower-tier globular is small, faint, and not very globular-like.

Deep-sky observers — me included — often comment that the visual appearance of M71 is somewhere between an unconcentrated globular and a remote open cluster. The little guy is only 7.2′ in diameter and glows lamely at magnitude 8.4. Its most prominent members are magnitude 12.1, and the vast majority are much dimmer. The lack of luster is a bit odd, given M71's distance of approximately 13,000 light-years — not far for a globular (brilliant M13 in Hercules is almost twice as distant).

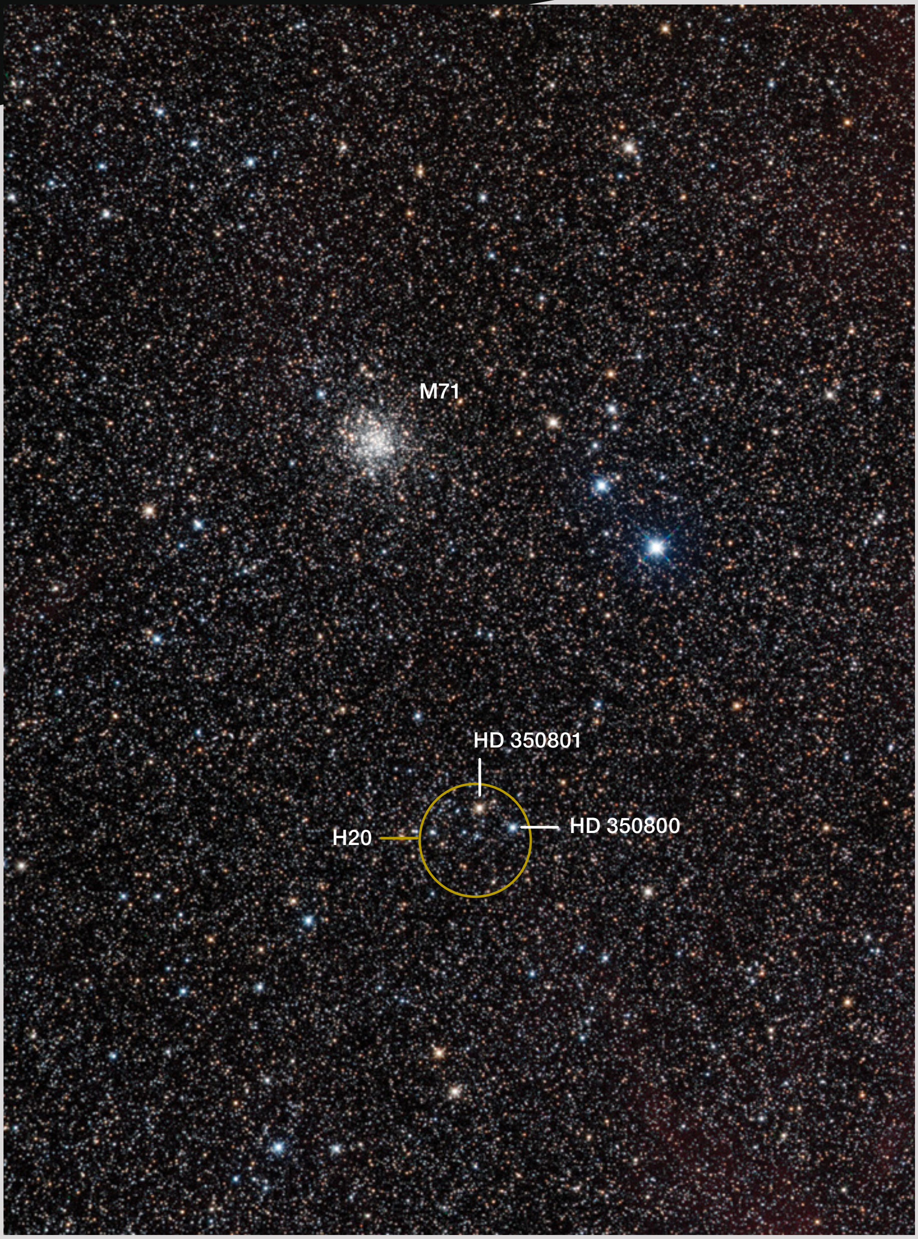
Fortunately, M71 enjoys a rich setting in the glorious summer Milky Way. Situated halfway between Delta and Gamma Sagittae, M71 lies 21′ east-northeast of 9 Sagittae, a 6th-magnitude marker 1.2° east of Delta. The scene is attractive — a couple of 9th-magnitude stars shine ¼° east-southeast of the globular, while a half-dozen mostly brighter ones (9 Sagittae among them) are clumped a similar distance westward. A 10th-magnitude guardian stands protectively near the northeast edge of the fragile cluster. Fainter sparks are everywhere.

That lovely field, spanning about 40′, showed beautifully in the refractor at 38×. M71 itself was a pale puff that resembled an uncondensed, tailless comet adrift in space. Upping the magnification to 100× turned the comet into a cluster. M71 exhibited a distinct graininess bordering on partial resolution, though with no concentration toward the center. Increasing to 129× didn't help, as the cluster's light was spread too thinly to observe effectively.

My 8-inch Dobsonian working at 50× framed the field perfectly. M71 exhibited individual stars at 75× and was pleasingly (albeit faintly) resolved at 175×. The outskirts of the cluster blended seamlessly into the surroundings. To my eye, it seemed as though a portion of the Milky Way had gathered into a ragged pile of grain. I estimated its diameter to be maybe 4′. Several leading lights — possibly foreground stars — were scattered atop the diminutive patch. One cluster-width northeastward, I detected a few more individual specks of light dotting the area between the hazy patch and the guardian star. In the end, the best view was had at 100×.

Some folks might dismiss M71 as a poor-quality globular. I disagree — I've seen way worse. My nomination for the worst glob blob (Messier division) is M72, in Aquarius. M72 is often a no-show in my pea-soup of a sky, whereas the lone Sagitta Messier manages to punch through the suburban murk. Give it a try!

Care for a little dessert? An obscure



◀ **BACK OF THE CLASS** Harvard 20 is a seldom-observed open cluster containing roughly 100 members. The distance to H20 is about 5,700 light-years — much closer than M71, yet far less conspicuous.

Sagitta Treasures

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Σ2585	Double star	5.0, 9.0	8.3″	19^h 49.0^m	+19° 09′
Σl48	Double star	7.1, 7.3	41.7″	19^h 53.4^m	+20° 20′
Σ2637AB	Double star	6.6, 8.9	11.6″	20^h 09.9^m	+20° 55′
Σ2637AC	Double star	6.6, 7.5	91.9″	20^h 09.9^m	+20° 55′
M71	Globular cluster	8.4	7.2′	19^h 53.8^m	+18° 47′
H20	Open cluster	7.7	~6′	19^h 53.3^m	+18° 21′

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.

open cluster cataloged as **Harvard 20** sits a mere ½° south-southwest of M71. Obscure or not, I figured H20 wouldn't be difficult to find because it's accompanied by two relatively isolated stars: 9.2-magnitude HD 350800 and, 2.7′ northeast, yellowy, 8.9-magnitude HD 350801. The latter actually overlays the northern edge of the cluster.

Astronomers think HD 350801 belongs to H20. Maybe so, but the other cluster members are significantly fainter. If we ignore the HD beacon, H20 is a sparse scatter of several dozen 11th- to 13th-magnitude stars 6′ to 9′ across (depending on the source consulted). Barely detached from its Milky Way surroundings, the cluster appears dimmer than its total visual magnitude of 7.7 would suggest. In short, H20 isn't much of a target for backyard scopes. I went after it anyway, but to ensure success I turned to a third scope — my 10-inch f/6 Dobsonian.

It was the right choice. Picking off the 9th-magnitude companion stars was a snap for the 10-inch at 48× and doubling to 96× produced a hazy suggestion of a cluster surrounding HD 350801. Cranked up to 169×, the scope pulled in a coarse scatter of a dozen or more dim stars. The roughly triangular assemblage aimed eastward, away from the HD leader. The cluster's southern edge was sharply defined by a string of four faint stars — a 12th magnitude pair westward and a wider, 11th-magnitude pair eastward. Curiously, something fuzzy at the threshold of vision lay in between the eastern set. Careful viewing at 218× confirmed my suspicion: It was a teensy double.

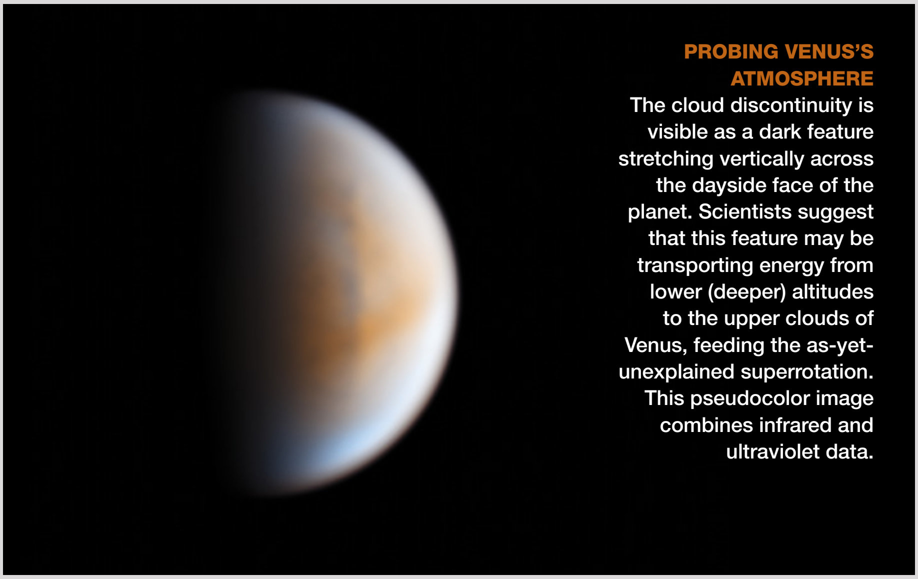
Harvard 20 isn't special, but it was a satisfying catch — especially from town. I hope you give it and the other Arrow objects the ol' college try.

■ Contributing Editor **KEN HEWITT-WHITE** has had Sagitta in his quiver for more than 50 years.

MASIL IMAGING TEAM

Cytherean Secrets

Here's a project for you if Venus's atmosphere intrigues you.



PROBING VENUS'S ATMOSPHERE The cloud discontinuity is visible as a dark feature stretching vertically across the dayside face of the planet. Scientists suggest that this feature may be transporting energy from lower (deeper) altitudes to the upper clouds of Venus, feeding the as-yet-unexplained superrotation. This pseudocolor image combines infrared and ultraviolet data.

EMMANUEL KARDASIS

Venus has enthralled humanity since the dawn of time with its brilliant presence in the twilit sky. And yet the second planet from the Sun jealously guards its secrets under a roiling, cloud-enshrouded atmosphere. Renewed interest in the planet next door is bubbling, with several new missions on the horizon (*S&T:* May 2022, p. 12). But the Japan Aerospace Exploration Agency (JAXA) orbiter Akatsuki ("Dawn" in Japanese) is already there now.

Venus's notorious sulfuric clouds occupy altitudes between about 48 and 70 kilometers (30 to 43 miles) above the planet's surface. The clouds are further subdivided into upper, middle, and lower levels. Below 56.5 kilometers, the clouds contribute to the infamous greenhouse effect that keeps the Venusian surface permanently out of view. Above that, there's a whole other phenomenon: The top cloud layer rotates at around 100 meters per second (more than 200 mph), which is some 60 times *faster* than the solid planet below it! We've known about this *superrotation* for more than a century now, but its origin still eludes us.

Odder still, in 2016 Javier Peralta (JAXA) and collaborators found in Akatsuki data an occasional disruption in the mid-level clouds that propagates at the equator even faster than the superrotating winds above it. This *cloud discontinuity* catalyzes changes in the properties of the clouds as it roars across the planet. Peralta notes this recurring phenomenon is present in archival data going back to the 1980s, though it has never been reported. Maybe it's time we started paying closer attention to Venus.

And that's exactly what Emmanuel Kardasis did.

An amateur takes the lead. An avid planetary observer, Kardasis began dabbling in near-infrared imaging of Jupiter in 2009 and within a few years was pointing his scope at the more challenging Venus. Eventually, he presented his observations at the European Planetary Science Congress in 2017, where he first met Peralta.

After their encounter, Kardasis embarked on his own investigation of the cloud discontinuity, by observing Venus himself and by trawling through the archives. On March 11, 2020, he noticed in his own data that the discontinuity had reappeared after an absence of four years. He immediately called on the amateur community for concerted near-infrared monitoring of Venus.

He and Peralta teamed up and analyzed the data from Akatsuki alongside those of the amateurs. They confirmed that the discontinuity is confined to the middle cloud level; its absence in the upper clouds suggests that the disruption dissipates at a certain altitude, giving clues to its origin. Kardasis published the team's findings in the February 2022 issue of *Atmosphere* (**https://is.gd/kardasis_atmosphere**).

Amateurs' coverage of Venus in the near-infrared was essential to the success of the project. Long-term monitoring of Venus's daytime mid-level clouds is otherwise sparse at best, in part because Akatsuki's near-infrared cameras aren't operational anymore. "Having observers spread out increased chances of witnessing the passage of the discontinuity, especially during the period when Venus's daytime side was smaller," Kardasis mentions.

Gear up. There's more to be done. If, like Kardasis, you're keen to investigate the clouds of Venus, you'll need an 8-inch or larger telescope, a planetary camera, and infrared filters, as well as image-capturing software and a data-processing package. Once you're happy with your images, you can upload them to the Planetary Virtual Observatory & Laboratory database (**https://is.gd/planetary_vol**; or you can go to the ALPO or ALPO-Japan websites). Don't forget to carefully log all your observing details: date and time, location, and equipment.

Ongoing amateur observations of Venus's dayside mid-level clouds should help crack several conundrums. For example, along with professional observatories' data of the nightside lower clouds, they'll probe the cloud discontinuity as it passes from the planet's dayside to the nightside and back. And amateurs' exploration of the superrotation phenomenon at multiple vertical levels will continue to yield exciting outcomes. Venus might not be able to hold onto its secrets so jealously anymore.

■ Observing Editor **DIANA HANNIKAINEN** is indeed enthralled with brilliant Venus.

PUSHING Glass

Grinding your own mirror can be great fun — and result in an excellent telescope.

I often tell people that making your own telescope mirror is easy: You just put two round pieces of glass together with grit in between them and push the top one back and forth over the bottom one about a million times, and voila, you're done.

That turns out to be not entirely accurate.

The actual number of strokes is a lot fewer, probably only 300,000 for a typical mirror. And I left out a few steps.

In my article on whether it was cheaper to buy or to build a telescope (*S&T:* Nov. 2021, p. 66), I discussed mirror making as part of the process, but if you decide to actually do it, how do you proceed? Let's get into the nitty-gritty — literally.

Here's the short version: You really do put the soon-to-be

▲ **DIFFERENT STROKES** Jerry and Kathy Oltion (left and top) work on their mirror blanks using hydrostone tools. Colin Miller (right) hogs out his mirror using a ring tool.

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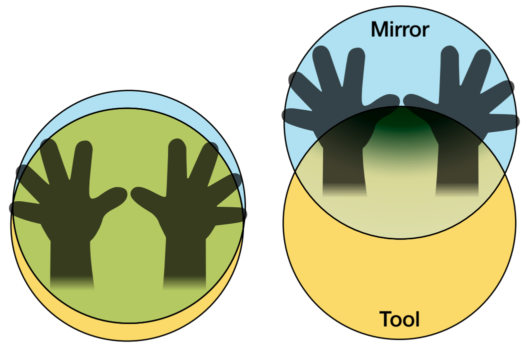


▲ **HOGGING OUT** When the mirror is centered over the tool (left), abrasion is even across the entire surface. When the center of the mirror is over the edge of the tool (right), gravity and the pressure of your hands cause more wear on the center of the mirror and the edge of the tool.

HOGGING ILLUSTRATION: GREGG DINDERMAN / S&T

mirror (called a *blank*) on top of the grinding tool and push it back and forth a lot. Whatever is on top slowly becomes concave, and whatever is on the bottom becomes convex. Once you dig it as deep as you want, you use finer and finer grits to undo the damage you did with the coarse grit, then switch to a polishing tool and continue pushing it back and forth until you've got a smooth surface again. Then you change your polishing technique to shape the surface into a parabola, coat the mirror with aluminum or silver, and put it in a telescope.

Now let's take a closer look at each of those steps.

Rough Grinding

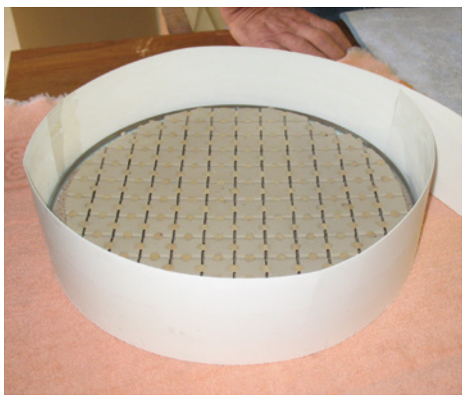
First off, how does pushing one piece of glass over another one make the top piece concave and the bottom one convex? Look at the illustration at the top-right. When the top piece is directly over the bottom piece, the grinding action is uniform across the entire surface, but when you push the top piece off-center, the action reduces to an ever-narrowing, football-shaped area of contact. Because the grit has less area to work on, but the weight pushing the two pieces together is more or less constant, the pressure per unit of area increases dramatically as the two pieces slide more and more off-center.

Because you're pushing down evenly on the top piece, most of that extra pressure is directed toward the center of the top piece and toward the edge of the bottom piece. That means the center of the top piece wears faster than its edge, and the edge of the bottom piece wears faster than its center. You rotate the mirror and the tool in opposite directions every few strokes in order to keep the mirror's curve symmetrical. (Grinding with mirror and tool in the same orientation creates a saddle shape — not what you want!) If there's room, progressively walk around the mirror as you work it. A 55-gallon drum full of water makes a great workstation, which led to the term "once around the barrel" to refer to a complete revolution of tool and mirror with respect to each other.

The illustration above is a bit exaggerated; the actual stroke you use only moves the mirror ⅙ of its diameter off-center in either direction, for a total stroke length of ⅓ the diameter. This is called the "One-third center-over-center stroke," and you'll become very, very familiar with it by the time you're done.

This first phase is known as the rough grinding or "hogging out" stage of mirror making. You can simply use another blank as your tool, but nowadays most mirror makers use a tool made of ceramic tile rather than a second piece of glass for the bottom piece. Either way, the method is the same.

Tile tools are simple to make: Take a mat of one-inch bathtub tile and cut it into a circle the size of your mirror. (You can either cut the tiles with a tile saw, bust them with pliers, or even simply cut away any tiles that stick out over the edge of the mirror.) Next, place the tool face-down on a sheet of plastic wrap over the mirror, add a dam of tape around the edge of the mirror, and pour an inch or so of liquid hydrostone or dental stone (waterproof types of plaster) over the



◀ **HOMEMADE TOOLS** *Top:* To make a tile tool, lay a tile mat on top of plastic wrap over the mirror blank, add a dam of paper or tape around the edge, and pour waterproof plaster (hydrostone or similar) over it. *Bottom:* When the hydrostone has set enough to remove but is still soft, separate the tool from the mirror, dig out the channels between the tiles, and you're ready to start.

tile mat. Let it harden, dig out the channels between the tiles, and there's your tile tool.

Hogging out can also be done with a small, round metal tool on top of the mirror, often referred to as a *ring tool*. By crossing the ring tool over the center of the blank with each stroke, the tool spends more time in the center of the mirror than on any given point on its edge, so the center wears faster than the edge. An iron pipe flange works really well as a ring tool.

How do you know when to stop hogging out? You decide ahead of time what focal length you want your finished mirror to be, and you calculate the depth of the required curve (called the *sagitta*) with the following formula:

Sagitta = $\text{diameter}/(16 \times \text{focal ratio})$

So, if you're making a 10-inch f/5 mirror, your sagitta is $10/(16 \times 5)$ = 0.125 inch.

Seriously: You don't have to make a cereal bowl; an eighth of an inch of depth in the very center, tapering off to nothing at the edges, is all you need.

On the other hand, a little more complicated math reveals that doing so removes almost five cubic inches of glass from the blank. And you're doing that one microscopic chip at a time. No wonder rough grinding takes several hours!

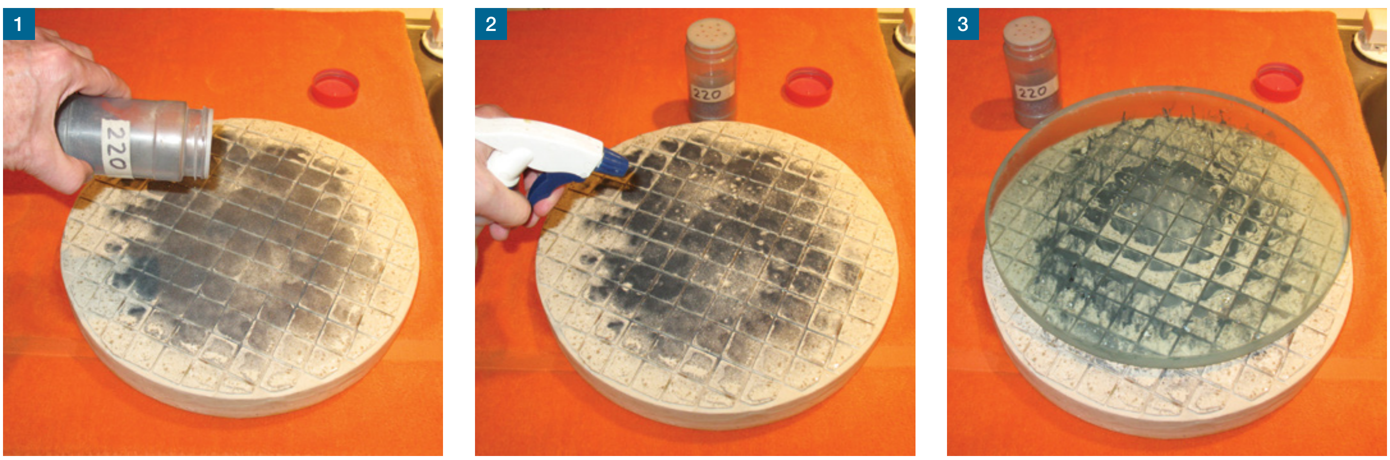
▲ **ONE-STOP PURCHASE** Several online retailers offer mirror-grinding kits. These packages come with all the grits you need, plus the tile mat and the hydrostone to make the grinding and polishing tools. Not shown here but included in a complete kit: a can of pitch.

Fine Grinding

Hogging out is usually done with 80-grit carborundum (silicon carbide) abrasive. When the pieces of grit tumble around between the mirror blank and the tool, they gouge out little bits of glass. You do this in a water slurry so the grit can move around freely, and to minimize airborne glass dust. (You really don't want to breathe glass dust.) The grit particles quickly wear down, though — within just a few minutes — so they need to be replaced. Each replacement of the grit is called a *wet*.

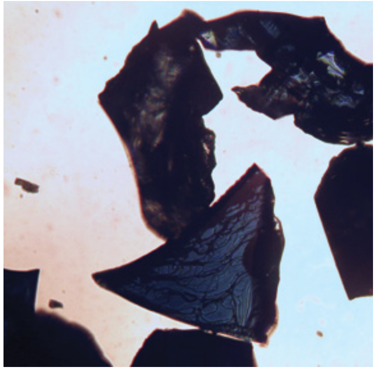
Most telescope makers don't actually grind all the way to their target sagitta with 80 grit. Such coarse grit leaves big pits in the glass, so you should stop a little short, say 80% to 90% of the way, and switch to 120 grit. (If you hogged out with a ring tool, you'll need to make a tile tool at this stage.) Grind for a couple of hours with that until you don't see any of the 80-grit pits anymore, then switch to 220, and on to finer and finer grits. With the medium grits, you can fine-tune the focal length by flipping the mirror and tool over and grinding with the tool on top. That will undo some of the sagitta, flattening the curve if you went a little too far with the coarse grits. The amount of correction you can make becomes less and less with each successive grit, so you want to be close to your final sagitta by the time you finish 220 or so.

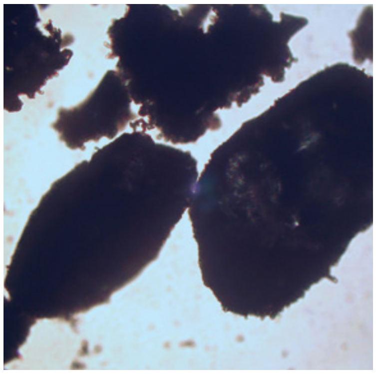
In the old days, mirror makers used carborundum all the way up to the end, but nowadays we switch to aluminum



▲ **WETTING THE TOOL** The process of spreading grit and working the blank is called a wet. 1: Spreading grit on the tool is convenient using a repurposed spice shaker — it doesn't take much for a single wet. 2: A spray bottle filled with water allows you to get the grit good and wet without washing it away. 3: The back-and-forth motion helps the grit dig into the glass, removing it one tiny chip at a time.

oxide after 220. The size of the particles is measured differently, so you move on to 25-micron, then 15-micron, and then 9-micron aluminum oxide. (Some people proceed all the way to 5-micron, but that's not necessary.) *Alox*, as it's sometimes called, is a gentler abrasive. The particles are more plate-shaped, shearing off high spots rather than gouging out pits. It gets you to the final stages of smoothness a lot faster than carborundum will.





◀ **WEAR AND TEAR** Silicon carbide grit starts out sharp and pointy (left) but quickly wears down into rounded particles (below).

Polishing the Mirror

When you get to 9-micron grit, the mirror floats back and forth across the tool with just a whisper of resistance from the abrasive. The surface looks smooth even under a magnifying glass. But the glass still appears frosted, and in terms of wavelengths of light, the surface is still a cratered disaster. It needs to be polished to crystal clarity before it can be used in a telescope.

That step is done with a *pitch tool*. Right: pitch, as in boiled tree sap. There's also synthetic pitch (called AccuLap), which has essentially the same characteristics as the natural stuff. We either pour a quarter-inch or so of it over the grinding tool, or we make a new hydrostone disk to pour it on (the preferred method in case you need to go back to the grinding tool later to remove a scratch).

The pitch tool is used with a very fine abrasive, cerium oxide, that embeds itself in the pitch and both wears away and pushes around glass molecules to smooth the surface. Channels cut or molded into the pitch lap let the polishing compound (a mixture of cerium oxide and water) sluice around during polishing.

Parabolizing

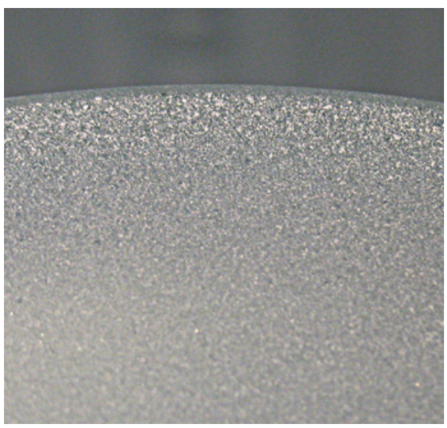
At the end of the polishing stage, you'll have a nearly perfect section of a sphere with a radius of curvature (the distance from a curved surface to its imaginary center point) that's twice the focal length of the mirror. Why a sphere? Because that's the only geometrical figure that allows you to slide one surface over another without high and low spots interfering with one another. If anything sticks out, it quickly gets worn down. So, as you do the fine grinding and polishing, you're wearing down all the high spots until your mirror is nearly perfectly spherical.

When I say "nearly perfect," I really mean it. If you're careful with your technique, you'll be within a tenth of a wavelength of light or so of perfection. All done by hand with tools and techniques that have changed very little in 350 years.

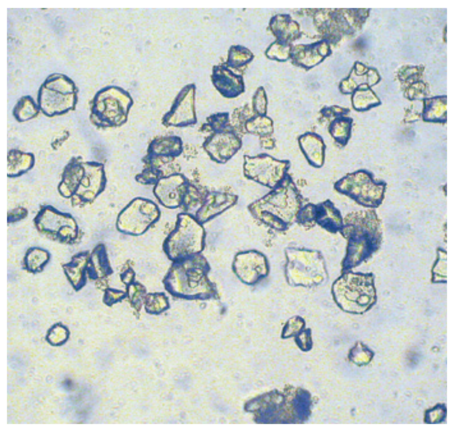
Alas, a spherical surface makes a poor telescope mirror. Incoming light that hits the outer part of the mirror focuses much closer to the surface than light that hits near the center. The focal point is smeared out into a focal line. In order to bring all the incoming light to a focus at the same place, the surface has to be changed from a spherical section to a paraboloid.

The problem is, the geometry of pushing one disk back and forth over another doesn't make paraboloids. Well, okay, it sort of does, because that's how we do it, but at this stage we're not making the paraboloid as the inevitable result of geometry

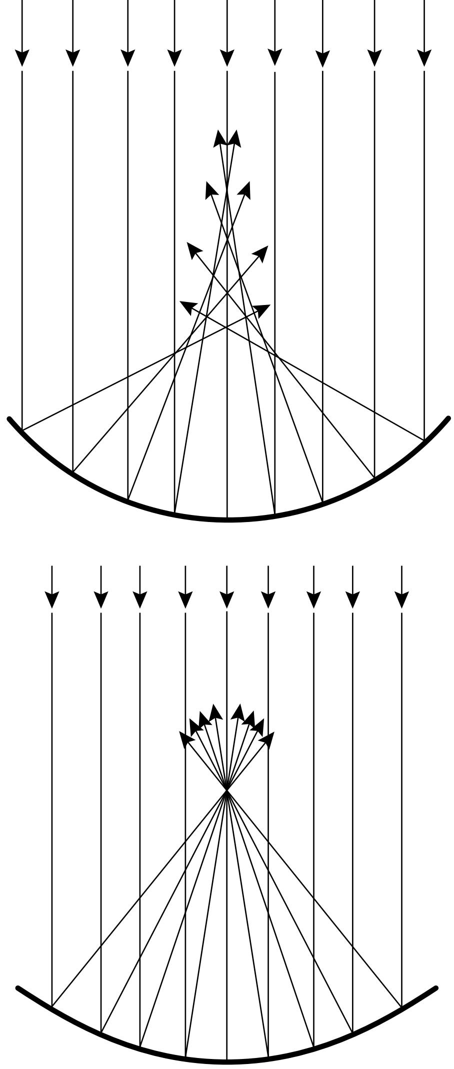
▲ **SLIGHT CHANGE** One cubic inch of glass is a lot to remove by abrasion. You'll remove five of these if you make a 10-inch f/5 mirror. A 30-inch f/3? 220 of 'em.



▲ **ROUGH SURFACE** Coarse grit leaves deep pits in the glass that require successive wets of finer abrasives to smooth out.



▲ **FINE POLISH** Aluminum oxide grit particles are more plate-like, so they shear off high spots rather than gouging into the mirror's surface.



◀ **FOCUSING POINTS** *Top:* A spherical surface is easy to make, but it doesn't focus starlight to a point. *Below:* The mirror must be parabolized in order to provide crisp focus.

anymore. We're altering our back-and-forth strokes to emphasize pressure on different parts of the mirror's surface, either increasing the focal length of the outer zones, decreasing the focal length of the center, or both. There's no happy equilibrium that will maintain a parabola indefinitely; you sneak up on it, and if you don't stop with the altered strokes at just the right moment, you go right on past a paraboloid and create a hyperboloid. And then all sorts of other shapes as everything turns into what we fondly call "a hot mess."

So we need to examine the surface profile while we parabolize so we don't overshoot our goal. The *Foucault test* used to be pretty much the only test a mirror maker would use. It's very accurate and has produced many excellent mirrors, but it's a fussy, math-intensive test that's really best for the final stages of parabolizing, not in the early stages when you just want to know if you're in the ballpark yet.

Fortunately, there's a great ballpark test method called the *Ronchi test* that has come into greater use over time. Its advantage is that the tester is easy to build (*S&T:* Aug. 2021, p. 74), easy to set up, and easy to interpret. In the Ronchi test, a spherical mirror will show a series of straight bars of light and dark, and the more parabolized the mirror becomes, the more those bars curve. You can use a computer program to generate the ideal curves for the parabola you want (Mel Bartels has an excellent tool that does so at **https://is.gd/ronchi**), and you can compare what you see against the generated pattern and keep tweaking your parabola until the patterns match.

With either the Foucault or the Ronchi test, you still finish out your mirror by examining what it does to actual starlight (called, appropriately enough, the *star test*). Nowadays, many mirror makers skip the Foucault test entirely and just go straight from Ronchi to star testing.

Once the mirror is parabolized, you can either send it off to be aluminized in a vacuum chamber or you can silver it yourself (*S&T:* Jan. 2020, p. 74).

Some Sage Advice

The above grinding and polishing techniques have changed very little over the years. Ring tools and tile tools have replaced glass tools, and the Ronchi test has gained ground over the Foucault test, but the general method of making mirrors is pretty much the same as ever.

What *has* changed are some of the misconceptions. One misconception was that a telescope mirror needed to be at least ⅙ of its diameter in thickness. That was because stress analysis showed that a thinner mirror could flex by at least a

▲ **POLISHING TOOL** Making a pitch tool is relatively straightforward. 1: First pour the molten pitch onto the substrate. 2: After the pitch has spread over the tool base, coat the mirror with cerium oxide and press it into the pitch in order to form a matching surface to the mirror's sagitta. 3: Allow the pitch to cool, but while it's still pliable, press channels into it for the cerium oxide slurry to flow into while polishing. Once completely cooled, you're ready to start the polishing stage.

FOCUS DIAGRAM: GREGG DINDERMAN / *S&T*

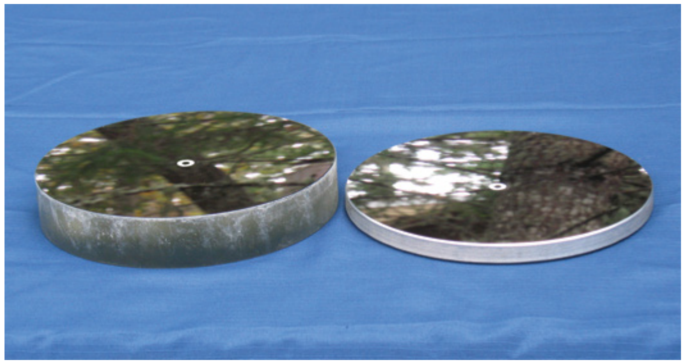
quarter wavelength of light, and a quarter-wavelength error could affect the view. Turns out that was needlessly conservative. Mirrors are typically 1/15 or even 1/20 of their diameter in thickness nowadays and they still work fine, thanks to advances in the design of the mirror cells that support them in the telescope. For an 8″ or 10″ mirror, 3/4″ plate glass is plenty thick if properly supported. And a bonus: Thinner mirrors mean shorter cooling times before they reach ambient temperature and can provide their best view.

Another misconception from the old days is that you should start with a small mirror, say a 6″, before trying an 8″ or a 10″ or larger. A 6″ mirror requires less hogging out, but that's about the only thing easier about it. It's too small for most people's hands, so it's hard to grip, and it tends to rock back and forth while polishing, so you often wind up with a ferocious turned edge. The hardest mirror I ever made was a 6″. You're far better off starting with an 8″ or a 10″, or even a 12″ if you have a little patience.

Patience is paramount. You need to go slow. At first that's because your muscles aren't used to this kind of motion and you need to build up your strength, but it's also because impatience leads to mistakes, and mistakes lead to impatience. Grinding mirrors is a Zen sort of thing. Breathe deep. Take your time. Savor each step. You're making an optical surface that'll be accurate to better than a quarter wavelength of light and doing it with hand tools — tools you made yourself.

Fast mirrors are popular nowadays. It's tempting to shoot for an f/3 wide-field mirror, but avoid going too fast (say faster than f/5) with your first attempt. Parabolizing becomes exponentially harder the faster you go. You need to develop the necessary skills before you tackle a fast mirror.

And lastly, if at all possible, find a mentor. Someone who can stand right there beside you and demonstrate the techniques of grinding, polishing, and parabolizing in person.



▲ **CHANGING TIMES** Old-school mirrors were 1/6 of their diameter in thickness. Modern mirrors are much thinner but work just as well.

Someone who can watch you do it and catch mistakes before you dig yourself into a hole you can't get out of. The success rate for people with a mentor at their sides is far, far (almost infinitely far) greater than for those who try to absorb it all from books or YouTube videos.

Above all else, approach mirror making as something to enjoy. Because you'll probably wind up doing it again and again and again.

■ Contributing Editor **JERRY OLTION** has probably done about 5 million mirror strokes so far.

FURTHER RESOURCES Many of the telescope-making concepts referenced in this article can be found in greater detail on the Springfield Telescope Makers website at **https://stellafane.org/tm/index.html**

Amateur Rhett Mackend makes Ronchi grating films for testing platforms. He can be contacted at **astromanrhett@gmail.com**.

▲ **CHECKING YOUR PROGRESS** The Ronchi test allows you to compare your mirror's surface with a computer-generated test pattern. This is performed by placing a tester with a Ronchi grating and light source at the mirror's radius of curvature (left). The Ronchi test pattern is visible when you look at the mirror through the grating that the light source also shines through (right).

Testing Two Askar Astrographs

We examine two of the latest offerings from a brand specializing in optics for astrophotographers.

Askar FMA230

U.S. Price: $629

Askar FRA500/5.6 APO

U.S. Price: $1,999
askarlens.com

What We Like

Sharp optics

Excellent fittings

Compact, modular design in the FMA230

What We Don't Like

Some off-axis aberrations in the FMA230

Slight chromatic aberration in the FRA500

Adding filters can be difficult

THESE DAYS, we're blessed with an abundance of quality telescopes for astrophotography, with new brands such as Askar continually offering tempting choices. I tested two of Askar's latest instruments, one from each of their two main series. The compact FMA230 resembles a short telephoto lens, while the larger FRA500/5.6 is more like a conventional telescope in both size and style.

Both units are intended primarily for imaging, thus their designation as *astrographs*. However, they can also be used for observing when fitted with the included visual backs, which accept 2-inch accessories. Using samples sent on loan from Askar in China, I tested each model both by eye and by camera.

The Astrographic Pair

Both astrographs feature three-element objective lenses that include two low-dispersion ED glass elements intended to reduce chromatic aberrations. The scopes differ in their rear flattener lenses.

Unlike most telescopes, these astrographs follow the photographic naming convention, in which camera lenses are referred to by their focal length rather than aperture — the FMA230's name comes from its 230-mm effective focal length. However, its 50-mm-diameter objective lens actually has a focal length of 275 mm, making it an f/5.5 instrument, as per the label on the tube. The included four-element 0.84× reducer/flattener lens, required for photography, takes the instrument down to its eponymous focal length of 230 mm at f/4.6 — relatively fast for an astrograph, though a bit slow for a 200-mm-class telephoto lens.

The 230-mm model I tested is the newest in the FMA series (as of early 2022), which includes the even smaller FMA135 and FMA180. The trio of FMAs come with brackets cut with the Arca-Swiss standard used with many tripod heads. As such, all of the FMA series are advertised as being usable for daytime subjects. But the lack of a diaphragm

▲ The FMA230 is 25 cm (10 inches) long when fully assembled for imaging and weighs just 1.6 kg (3.5 lbs).

▶ The FMA230 provides a field 8.8° by 5.9° wide on a full-frame sensor. This portrait of central Auriga is a stack of seven 4-minute exposures with a filter-modified Canon Ra camera at ISO 800, at the small astrograph's f/4.6 focal ratio.

ALL PHOTOS BY THE AUTHOR

and their fine helical focusing, while superb for astrophotography, make them less than ideal for most terrestrial targets, except perhaps for those at a fixed distance like a bird feeder or nest. I found the closest focus point for the FMA230 to be 15 meters (50 feet).

The larger FRA500's name refers to the 500-mm focal length of its main lens, though astronomers are more likely to think of it as the 90-mm aperture telescope it really is. The instrument is a Petzval design that includes a pair of lenses (a front three-element and a rear doublet) to achieve the stated f/5.6 focal ratio.

An optional 0.7× reducer lens takes the FRA500 to f/3.9 and 350-mm focal length. However, at the time of my testing in early 2022, this accessory reducer was undergoing design changes, and a sample unit was not available to us.

At the time of testing, the FRA500 was the newest in a family of FRA astrographs. The FRA400 has a 72-mm lens, while the FRA600 has a 108-mm lens, both at f/5.6 with a quintuplet design like the mid-sized FRA500. An even newer 60-mm f/5 FRA300 has since been announced.

▲ All the FMA230's parts can unscrew from each other. The metal dew cap extends 50 mm (2 inches) and is threaded to accept 58-mm photographic filters.

The FMA230 Mechanics

The little FMA230 has a solidly built, black-metal tube that can be separated into several components for air travel or inspection at airport security. The modular design reminds me of the Japanese Borg brand of astrographs.

The scope includes red anodized tube rings and mounting plates. While fashionable and attractive, I find such finishes are easily scratched. In particular, the dovetail plates soon become marked by the clamps and set screws of some mounts. The FMA230 includes an 18-cm-long (7-inch), Vixen-style standard dovetail for attaching it to a mount or star tracker.

The aforementioned helical focuser's motion proved smooth and precise, though in the sub-freezing temperatures of a Canadian winter night, the lubrication stiffens, making the focuser control difficult to turn. I also found that the focuser's tiny lock screw is impossible to adjust with gloves on.

The tube components are well blackened inside, though in some test images I did notice an odd flare, likely produced by a bright star just outside of the camera frame.

The rear adapter ring on the reducer has 48-mm threads on the camera side to accept large-aperture T-rings for DSLR and mirrorless cameras, or the nosepiece tubes of cooled CMOS cameras. The adapter ring separates from the reducer to reveal a recessed, threaded well on the telescope side that accepts standard 48-mm filters. However, as with any such recessed filter wells, screwing filters in and out is fiddly, with fingers inevitably touching the filter. Changing filters also requires removing the camera.

There is no rear camera-angle adjuster as such. Rotating the camera is a matter of loosening the four bolts on the felt-lined tube rings and rotating

▲ Without camera adapters, the FRA500 is 38 cm (15 inches) long with its dew shield retracted and weighs 5.4 kg (11.9 lb).

▶ The larger FRA500 astrograph presents a 4° by 2.7° field with full-frame sensors, perfect for many targets along the Milky Way such as these nebulae in Auriga. This is a stack of ten 6-minute exposures at f/5.6, with a stock Canon R6 camera at ISO 800.

the entire tube, camera and all. With such a small tube, that works just fine.

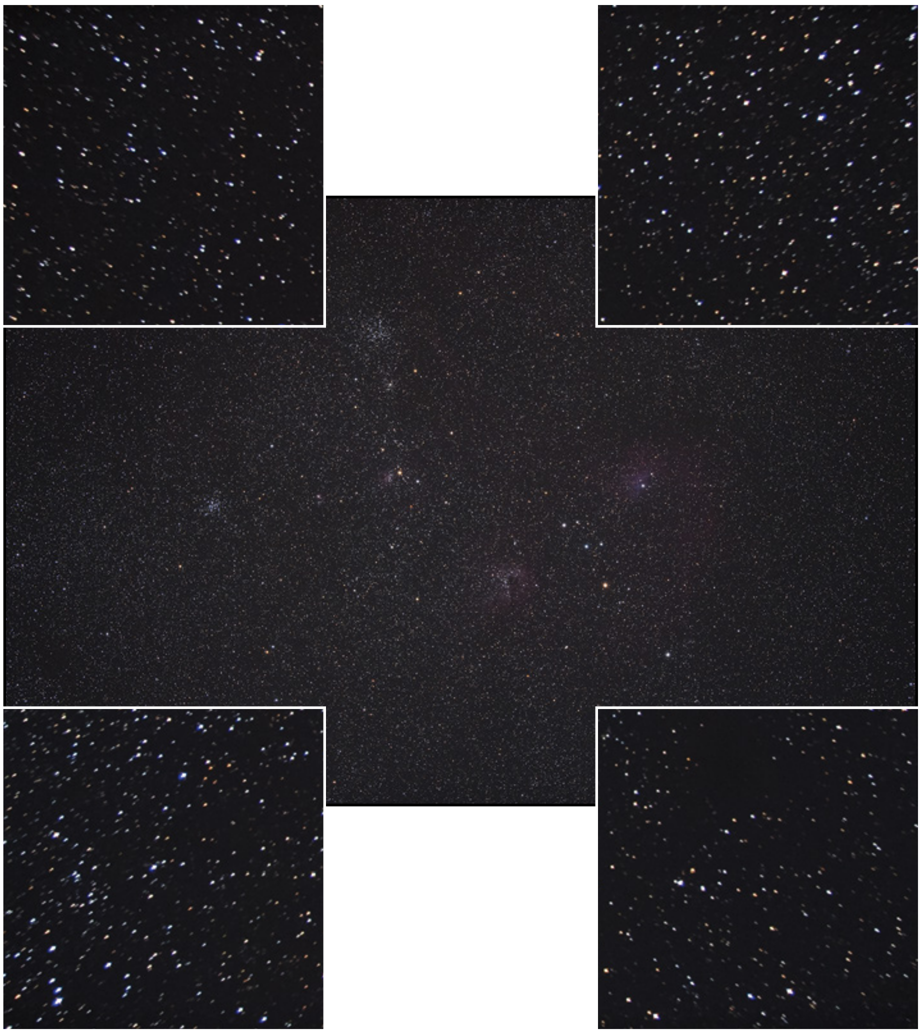
Optical Performance

Unlike some astrographs that require special star diagonals or that can't accept an eyepiece at all, both instruments can be converted to visual use quite easily with the supplied visual backs. I performed a high-power star test on each instrument, which can reveal aberrations that might go unnoticed in undersampled images.

When used visually, eyepieces reached focus on the FMA230 using a standard 1¼-inch prism star diagonal. Achieving focus with premium 1¼-inch mirror diagonals (which often have longer bodies), or with any 2-inch diagonal, requires removing the small extension tube that goes between the focuser and main tube, as the instructions advise. This worked well, and the little scope filled the field of even a massive Tele Vue 41-mm Panoptic eyepiece — an incongruous combination, but one that worked, yielding a whopping 10° field of view!

The more typical combination of a 1¼-inch-barrel 24-mm eyepiece (with a 68° apparent field) yields 11× and a 6° true field, similar to 10×50 binoculars. Testing the optics at 80× with a 3.5-mm eyepiece, bright stars showed textbook perfect Airy disks with no astigmatism, and just a tiny trace of spherical and

▼ In the FMA230 paired with a full-frame (36 × 24-mm) sensor, star images begin to elongate with astigmatism and lateral chromatic aberration beyond about a 32-mm imaging circle and are noticeably elongated at the extreme corners.

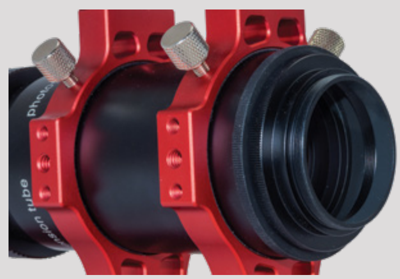


FMA230

▲ The front triplet lens is fully multi-coated. While the tube interior is ribbed, it has minimum baffling, as the rear aperture is almost the same size as the front.

▲ The focuser shifts the objective over a range of 19 mm. A scale marked in roughly ⅒ mm increments aids in resetting to a previous focus point.

▲ The removable top bracket serves as a handle and is machined with a 12-cm (4.7-inch) long Synta standard channel for finderscopes and guidescopes.



▲ The two rings have ¼-20 sockets on either side, as well as two M5 metric threaded holes, for bolting on other accessories. The rear cell has an M48 male thread.

chromatic aberrations in the extra-focal diffraction patterns. This is a sharp little telescope.

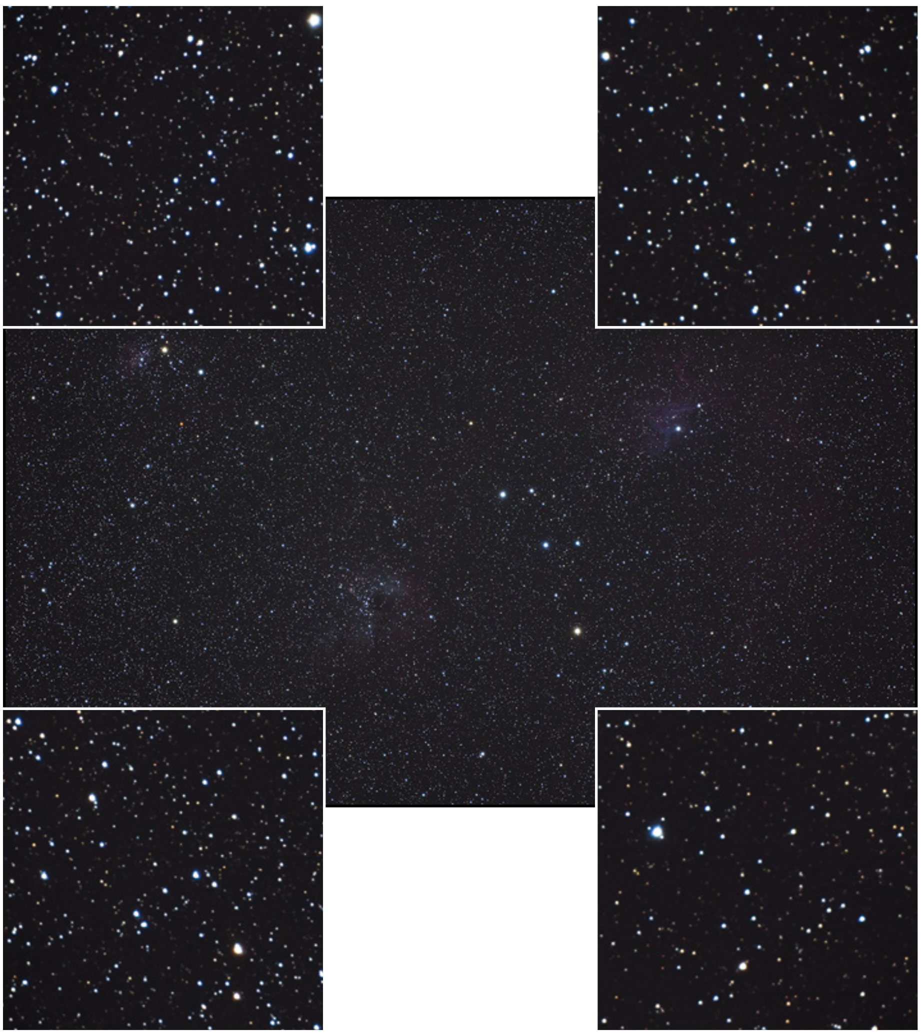
As expected based on the visual evaluation, photographically the FMA230 proved tack-sharp on axis. While the FMA230 fills a full-frame camera sensor, the stars at the corners of the field turn into tiny colored streaks at the pixel-peeping level. As with other lenses, colored halos from the lateral chromatic aberration evident at the corners can be corrected in processing by "defringing" using software filters such as those found in *Adobe Photoshop*'s *Camera Raw* or techniques to do the same in *PixInsight*. I saw no sign of tilted optics or skewed mechanical connections in either astrograph — stars looked the same at each edge and in every corner.

The 92-mm FRA500

Turning my attention to the FRA500, the conical camera adapter rings included with the bigger astrograph are Askar's unique solution to offering several thread sizes and spacings. Together, they provide the optimum 55-mm back focus required for a DSLR camera.

However, in a previous experience with this set of rings I found they could bind and seize onto the focuser. When that occurred, their conical shape made them extremely difficult to grip in order to remove them. As a pre-emptive

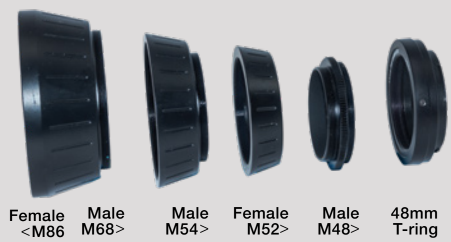
▼ The integrated field flattener in the FRA500 did its job very well. Stars are sharp to the corners, with the only niggling flaw being the slight blue halos that were most obvious toward the corners. This minor flaw is easily correctable in post processing.



FRA500

▲ The front triplet lens is fully multi-coated. The tube interior is well blackened and ribbed, with a single baffle at the sub-diameter flattener lens halfway down the tube.

▲ The focuser's motion is smooth and has a 10:1 fine-focus knob. The focuser is lockable, while the bottom includes bolt holes to accept a motor drive.



▲ The adapters offer M68, M54, and M52 threads, while the final ring has an M48 thread for attaching a camera or T-ring adapter. The final ring also accepts 2-inch (48-mm) filters in its filter well.

▲ The focuser has a standard shoe that accepts quick-release finderscopes. The tube rings each have five M6-thread sockets on either side. This photo shows the 2-inch visual back in place.

measure, I applied a film of light grease to the threads of the FRA500's set, avoiding any issues with binding during my testing.

Like the FMA230, the FRA500 includes tube rings and a dovetail mounting plate. The top handle on the rings is slotted to accommodate other accessories, such as a small guide-scope. The bottom plate is a 4-inch-wide Losmandy-style plate. Those wanting to pair this scope on a mount that accepts only the narrower Vixen-style dovetail bars will need to replace this piece.

Orienting your camera with this instrument is a bit different than the FMA230 since the focuser itself doesn't rotate, and turning the entire tube to reorient the focuser requires an Allen key to loosen the tube rings, which is an inconvenience. Instead, the focuser has a locking camera-angle adjuster that turned smoothly and did not shift focus when rotated. So, framing a camera was easy, though there are no angle markings on the rotator for making precise turns, which would be helpful when shooting mosaics.

Although each Askar instrument came with a signed inspection certificate, my FRA500 arrived with some minor cosmetic blemishes. But, overall, the unit is well-made.

FRA500 Optics

The focuser of the bigger FRA500 offers an M86 male thread, which accommodates either the conical camera adapter set or the included 2-inch visual back. All the eyepieces I tested reached focus with a 2-inch star diagonal. Under high-magnification testing, stars in focus showed a nearly perfect Airy disk and clean first diffraction ring, with no astigmatism, even on cold winter nights when optics can be pinched by contracting lens cells.

In focus, bright stars were colorless, with no blue or magenta halos of chromatic aberration. Extra-focal diffraction patterns showed a touch of asymmetry either side of focus, indicating slight spherical aberration. The diffraction pattern had a mild magenta rim inside focus and a cyan rim outside

▲ The FMA230 (left) comes in a gift box but does not include a carrying case, though it is small enough to slip into a typical camera bag. The FRA500 (right) comes with a foam-fitted aluminum case that holds the scope (with rings attached) and space for the camera adapters.

of focus from residual longitudinal chromatic aberration. Ditto on crater rims and the limb of the Moon — they were colorless in focus but showed the same slight tints when just out of focus.

I compared the FRA500 to a Sharpstar 94EDPH, a similar-sized telescope from Askar's companion brand. In star tests, images in the two telescopes looked identical, and both scopes cleanly resolved close double stars such as Castor, with generous dark sky between the component suns.

Photographically, star images in the Askar 500 appeared sharp right across images produced by a full-frame sensor, though stars at the extreme corners were elongated ever so slightly. This is field-flatness performance as good as I've seen in the many apo/flattener combinations I've tested over the years.

Recommendations

The little FMA230 is suitable for framing wide Milky Way star fields and dark dust lanes, and even small constellations. While a 200-mm telephoto camera lens can provide a similar field of view, most will need to be stopped down to f/4 or f/5.6 to approach the image quality of the FMA230. And a camera lens won't have the ease of image rotation and mounting features offered by astrographs like these Askar models. At about $630 from U.S. suppliers, the FMA230 is also less expensive than most 200-mm telephoto lenses, though of course the FMA lacks features such as auto-focus and aperture diaphragms.

The small astrograph's size and light weight make it ideal for overseas trips to exotic locations, while its short focal length is a good match for a star tracker mount — a compact and portable combination.

Out of the box, the bigger FRA500 is a superb visual and photographic instrument. The optional f/3.9 reducer should provide the attractive choice of an even wider field and faster speed when needed, but not having a sample of the reducer for testing, I can't say how well that combination works. However, the FRA500's native f/5.6 speed is fast enough for most imaging purposes with the aid of a guidescope and autoguider, and it will work well mated to a small equatorial mount for a lightweight observing rig to take to dark skies.

The similar telescope in the Sharpstar line, the 94EDPH, also works very well (I know, I own one!), and it costs about $200 less than the $2,000 for the FRA500, once you factor in the $300 for the required EDPH reducer. But the FRA500 offers the flexibility of being able to work photographically at two focal lengths and fields of views, though by adding its extra cost f/3.9 reducer.

We are certainly spoiled for choice these days, and this pair of Askars are fine options for anyone looking for a wide-field astrograph. Or two!

■ **ALAN DYER** is coauthor with Terence Dickinson of the new fourth edition of *The Backyard Astronomer's Guide*, described at **BackyardAstronomy.com**.

◀ OBSERVATORY SYSTEM

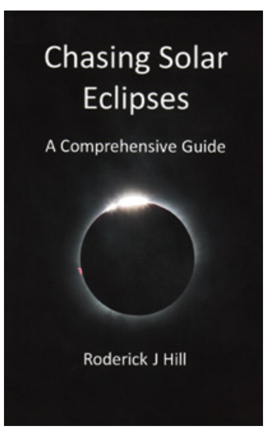
ASA Astrosysteme America, the U.S. distributor for Astrosysteme Austria, unveils a new instrument package for universities and amateurs alike. The ASA RC600 + DDM100 + polar wedge (starting at $98,000) pairs an ASA RC600 corrected Ritchey-Chrétien telescope with a DDM100 mount on an equatorial wedge capable of sub-arcsecond resolution and tracking. The RC600 tube assembly is a 23.6-inch (600-mm) f/2.5 corrected Ritchey-Chrétien astrograph with fused-silica primary and secondary mirrors that produce a 100-mm image circle. The telescope can also operate at f/7 with the removal of its reducer/corrector lens. Its DDM100 direct-drive mount is capable of slewing up to 50 degrees per second and uses the company's ASCOM-compatible *ASA Control ONE* observatory automation software. See the company's website for additional details.

ASA Astrosysteme America
444 Brickell Ave., Suite 51270
Miami, FL 33131
585-314-3198; astrosysteme.com/en-us

◀ BIG BINOS

Orion Telescopes & Binoculars announces a pair of right-angle binoculars. The Orion GiantView BT-120 90-degree Binocular Telescope ($2,799.99) features 120-mm (4.7-inch) f/5.5 twin objectives to generate bright views of the night sky. The BT-120 accepts standard 1¼-inch telescope eyepieces and comes with a pair of 18-mm, 65° eyepieces providing 37× magnification. Its interpupillary distance ranges between 54 and 76 mm, depending on the model of eyepieces used. The BT-120 uses BAK-4 Porro prisms to produce a right-reading view without vignetting. The binoculars weigh 9.2 kg (20¼ lbs) and attach to a heavy-duty tripod or other solid mount via a ¼″-20 threaded socket. Each purchase includes a sturdy, foam-lined carry case and a limited 1-year warranty.

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



◀ ECLIPSE GUIIDE

Self-described umbraphile Roderick J. Hill releases *Chasing Solar Eclipses: A Comprehensive Guide* ($39). The book offers helpful information for first-time eclipse observers and seasoned shadow chasers alike. It starts with chapters explaining the four different types of solar eclipses, some history, and the celestial mechanics involved. Additional sections detail how to safely observe these events as well as other unique phenomena to watch for before, during, and after totality. Hill details what equipment to take along when traveling to the path of totality and the various ways to photograph the event. An extensive section describes each of the solar eclipses visible from 2021 through 2060.

Chasing Solar Eclipses
Available from Amazon
https://is.gd/ChasingEclipses

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

Making Artificial Stars

Starbirth in your home workshop is easier than you think.

I LIVE IN THE PACIFIC NORTHWEST, where it's cloudy from September through April. We call that telescope-building season. I try to grind a mirror and build a scope every winter just to stay in practice. Trouble is, the final stage in mirror-making is the star test, but I can never count on a star being visible when I need it.

Likewise, the final arbiter for collimation is also the star test, but no matter where you live, if you pick a cloudy night to tune up your telescope, you're out of luck.

Or are you? Of course not! You can make your own star. Here's how.

Assembling enough hydrogen in one place would be problematic, so we'll do it with a more modest light source: a simple, light-emitting diode shining through a ⅛-inch hole.

Wait, shouldn't the hole be smaller than the resolution limit of the telescope? Yes, it should — in order to create the *Airy disk* (a central dot surrounded by diffraction rings) and out-of-focus diffraction pattern needed for accurate testing. But contrary to popular belief, that doesn't mean the light source itself has to be that small — just the image you examine with your telescope.

People have come up with several tricks to reduce the size of the observed light source: Pinholes in foil. Shining a flashlight onto a ball bearing or reflective Christmas ornament. Fiber optics painted on the end with a pinhole in the paint. Machined orifices. Simple distance. Or various combinations of all the above.

But the simplest, most effective system may be this artificial star made by New Jersey ATM John Deriso. The design goes back a ways, but this is the nicest build I've seen. John uses a white LED behind a ⅛″ mask placed 11.1″ away from a 9.7-mm Plössl eyepiece inserted into a length of PVC pipe. Using the simple lens equation (see box above), he calculated that the image visible in the eyepiece would be 0.0045″ in diameter, which is just what he needed for his 12-inch f/10 Schmidt-Cassegrain telescope if he placed the artificial star 200 feet away. (The minimum distance for artificial-star placement is generally considered to be 20 times the focal length of the telescope. Note that this may not be far enough for fast optics.)

LENS EQUATION

$$\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$$

where u and v are the distances from the lens to the object and to the image, respectively, and f is the focal length of the lens. The size of the resulting star image is v/u times the diameter of the mask.

▲ *Left:* The eyepiece end of John's artificial star faces the telescope. In theory, the eye lens should face the light source and the field lens should face the telescope, but with a Plössl eyepiece's symmetrical design, it doesn't matter. *Right:* John designed his artificial star to have two brightness levels.

JOHN DERISO (2)

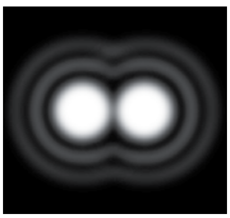
When I heard about John's artificial star, I just had to test this out myself. In the spirit of what I call CTG (cardboard, tape, and glue) engineering — see last month's column — I rolled a sheet of flat black neoprene foam into a tube, stuck an eyepiece in one end and a masked flashlight with a ⅛″ hole in the other end, and voila! I had a perfectly serviceable artificial star. With my Orion ShortTube 80, I was able to get a clean Airy disk inside my house at a modest distance of 30 feet. I did the same outdoors with an 8-inch Dobsonian at 100 feet.

And that's one reason why I like John's artificial-star design so much: None of the light is wasted in masking it down to a pinhole; it's squeezed down into a bright point by the eyepiece.

▲ A tube made of neoprene foam, a flashlight with a mask, and a Plössl eyepiece make a decent artificial star, too.

That means you don't need an insanely bright light — a single LED powered by a couple of AA batteries and a dropping resistor, or in my case a simple masked flashlight, will do fine.

John and I tried another neat experiment with our artificial stars. John reasoned that if the star created by the ⅛″ hole was diffraction limited at 200 feet, then two ⅛″ holes side by side should mimic a double star at the Dawes limit of his telescope. We each performed that experiment, and it works! You can just make out the elongated shape of the Airy disk. Moving the light source closer to the lens increases the separation of the artificial double star, to the point where we could easily pick out each "star" with some black space between them. Double-star nuts like me no longer need to wait for clear sky to practice our particular hobby. We can create our own double stars any time we want!



▲ The author's sketch of an artificial double star at about twice the Dawes limit of his telescope

The math behind all this is fairly simple, but it can be tedious to poke all the numbers into a calculator, so I've created a handy spreadsheet that will do it for you. You can access that at **https://is.gd/artistar**.

E-mail John for more information about his design at **olgazer@cgullz.com**.

JERRY OLTION (2)

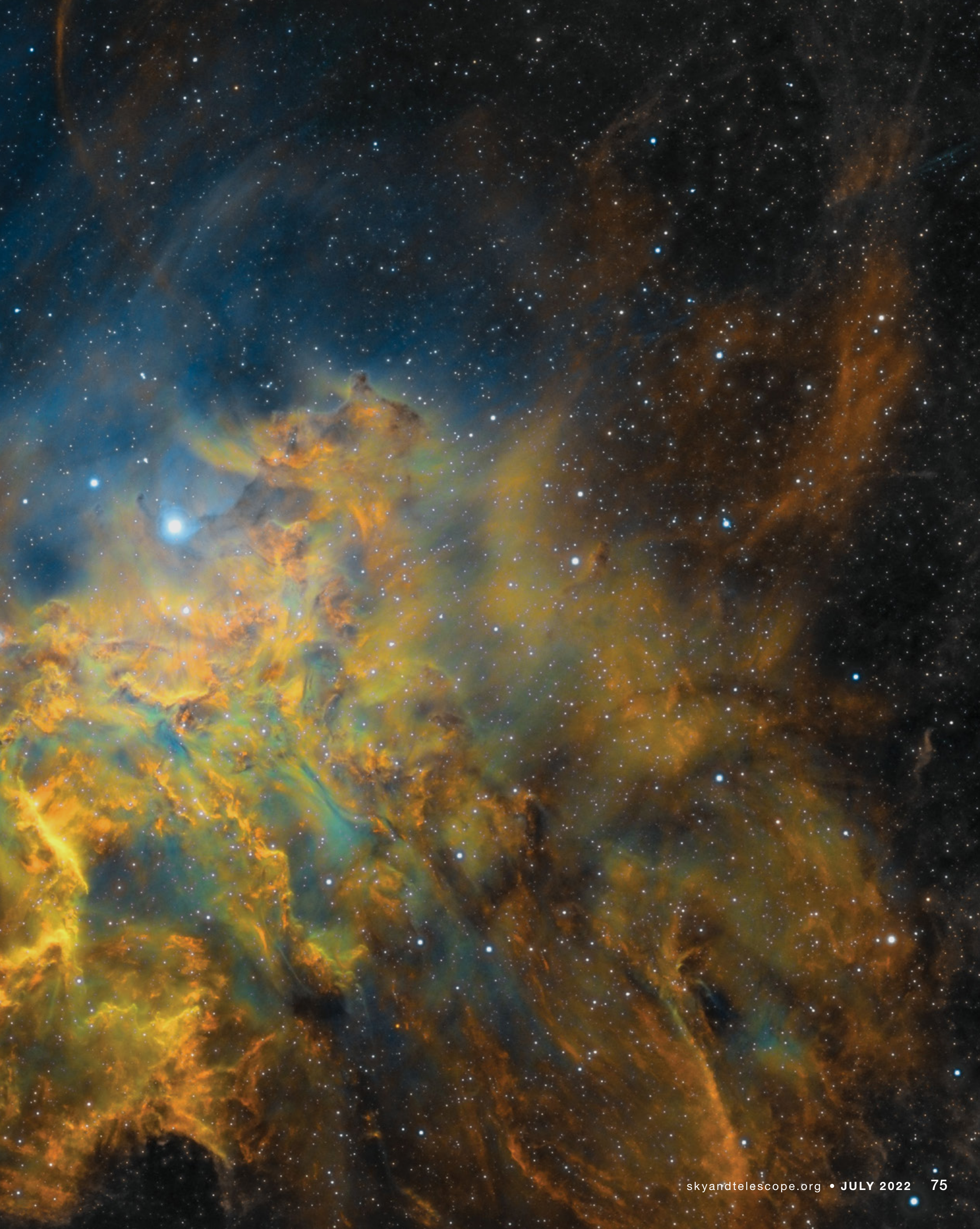
■ Contributing Editor **JERRY OLTION** doesn't let the idea of creating stars in his workshop go to his head.

PHOENIX RIDER

Stephane Rolland and Pascal Gouraud

Like a phoenix rising from the ashes with AE Aurigae on its back, the rippling lanes of gas and dust in IC 405 glow vibrantly against the darker regions of Auriga. North is to the left.

DETAILS: *Takahashi TOA-130NS refractor and ZWO ASI2600MM Pro camera. Total exposure: 38¾ hours through narrowband and color filters.*



▷ ANTENNAE GALAXIES

Basudeb Chakrabarti

NGC 4038 and NGC 4039 have been caught in a gravitational dance for the last half-billion years, creating long, antennae-like structures of gas, dust, and stars. The reddish regions near the merging galaxies' nuclei are bursting with star formation.

DETAILS: *PlaneWave CDK24 Dall-Kirkham telescope and FLI ProLine PL9000 camera. Total exposure: 4⅓ hours through LRGB filters.*

▽ NEBULOSITY IN CYGNUS

Emil Andronic

These ionized streaks of hydrogen gas and dust, known as LBN 326 (top left) and LBN 313 (bottom right), appear to course through the galaxy between Deneb and Delta Cygni.

DETAILS: *TS Optics 65-mm Quadruplet Astrograph and ZWO ASI294MC Pro camera. Total exposure: 16 hours through Hα and RGB filters.*

BRIGHT SPIRAL
Ralph MacDonald
M81 in Ursa Major is one of the brightest galaxies in the sky. This grand-design spiral's arms are full of young, bluish stars and reddish star-forming regions. North is to the right.
DETAILS: *Celestron C11 Schmidt-Cassegrain and ZWO ASI294MC Pro camera. Total exposure: 6 hours through Optolong filters.*

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Event Calendar

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

May 7
ASTRONOMY DAY
Everywhere!
https://is.gd/AstronomyDay

June 2–5
CHERRY SPRINGS STAR PARTY
Cherry Springs State Park, PA
cherrysprings.org

June 3–5
MICHIANA STAR PARTY
Vandalia, MI
michiana-astro.org

June 18–25
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCSP2022

June 22–25
BRYCE CANYON ASTRO FESTIVAL
Bryce Canyon National Park, UT
https://is.gd/brca_astrofest

June 22–26
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 22–26
YORK COUNTY STAR PARTY
Susquehannock State Park, PA
http://yorkcountystarparty.org

June 23–26
EASTERN SIERRA DARK SKY FEST
Mammoth Lakes, CA
https://is.gd/EasternSierraDSF

June 23–26
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
https://is.gd/WIObserversWeekend

June 24–27
RASC GENERAL ASSEMBLY
To be held virtually at:
https://rascga2022.ca/

June 29–July 3
GOLDEN STATE STAR PARTY
Adin, CA
goldenstatestarparty.org

July 22–31
SUMMER STAR PARTY
Plainfield, MA
rocklandastronomy.com/ssp.html

July 24–29
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

July 26–31
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

July 26–31
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

July 28–30
ALCON 2022
Albuquerque, NM
alcon2021.info

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

BRUNO SANCHEZ-ANDRADE NUÑO / FLICKR

From Street to Streaming

The Manila Street Astronomers' pandemic-induced switch to virtual has been a surprising success.

FOR MANY YEARS, the Manila Street Astronomers (MSA), a local astronomy-outreach organization I'm involved with here in the Philippines, set up telescopes in public places and invited passersby to enjoy free viewings of the Moon or one of the planets. We witnessed joy and wonder in the people who peeked through our telescopes, we relished answering the crowds' many questions, and we enjoyed the camaraderie among us volunteers.

Sadly, COVID-19 halted all these events. But the itch to share the beauty of the heavens simply wouldn't go away. In one of our online discussions, we MSA volunteers thought of doing a livestreamed broadcast of the June 2020 partial solar eclipse.

We formulated a plan — a Zoom meeting that we'd stream to the MSA Facebook page. Two volunteers would give talks about eclipses and how to view them safely. Four others would project their view of the Sun through their telescopes (equipped with solar filters, of course) and, using video cameras connected to their computers, share the live images with the Zoom meeting. Another volunteer and I would act as anchorwomen and monitor the Facebook page for viewer comments and questions. Still other volunteers would prepare publicity materials that they'd circulate through social media.

Unfortunately, at the time of the eclipse itself, clouds covered the sky where our four telescopes stood. But as the saying goes, the show must go on. We pushed through with our plan, airing lively conversation about eclipses for the entire three hours of the partial solar eclipse, with our telescope-wielding volunteers on standby in case any gap appeared in the clouds above them. To help our viewers visualize the eclipse, we projected simulations from astronomy software.

Fortunately, other telescope users scattered throughout the country who had cloud-free skies overhead shared images with us of the partial solar eclipse from their scopes, allowing us, in turn, to display these pictures on our livestream.

Judging from the questions and comments we received during and after the livestream, our plan succeeded. Our viewers experienced the fascination for the eclipse that we'd hoped to convey.

Since then, we've undertaken several other similar livestreams that have included live viewings, including one we held on International Observe the Moon Night. Our livestreams acquired a name: Since we conduct most of these events on Saturday evenings, we call them AstroSabado ("Sabado" being the Tagalog word for Saturday).

Producing our AstroSabado episodes takes work, but we value the outlet it gives us to share our passion for astronomy. I, for one, think that taking our viewers' minds off the pandemic for just one hour and reminding them that beauty exists beyond this world and its problems make it worth all the effort. At the same time, we live for the day when we will once again be able to set up telescopes in public places and share the views in person.

LEAH TISCIONE / *S&T*

■ **CRISTINA MONTES** is an attorney, law professor, and writer in Manila, the Philippines. She has been an avid amateur astronomer since childhood.


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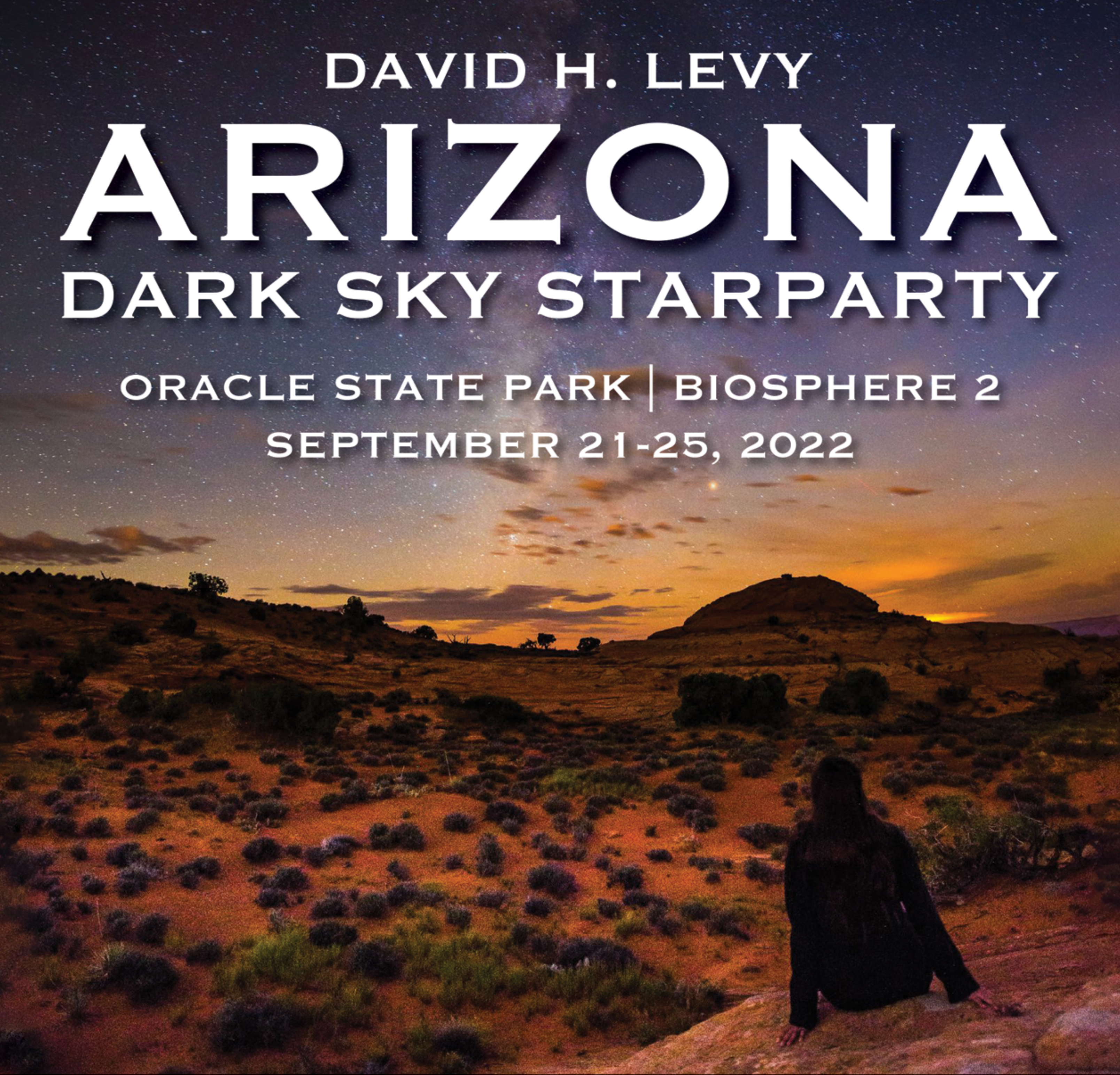

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