INGENUITY ON MARS:
The Little Copter That Could
PAGE 12

AUTOMATION:
The Future of Astrophotography
PAGE 60

LUNAR OBSERVING:
Ghost Craters on the Moon
PAGE 52

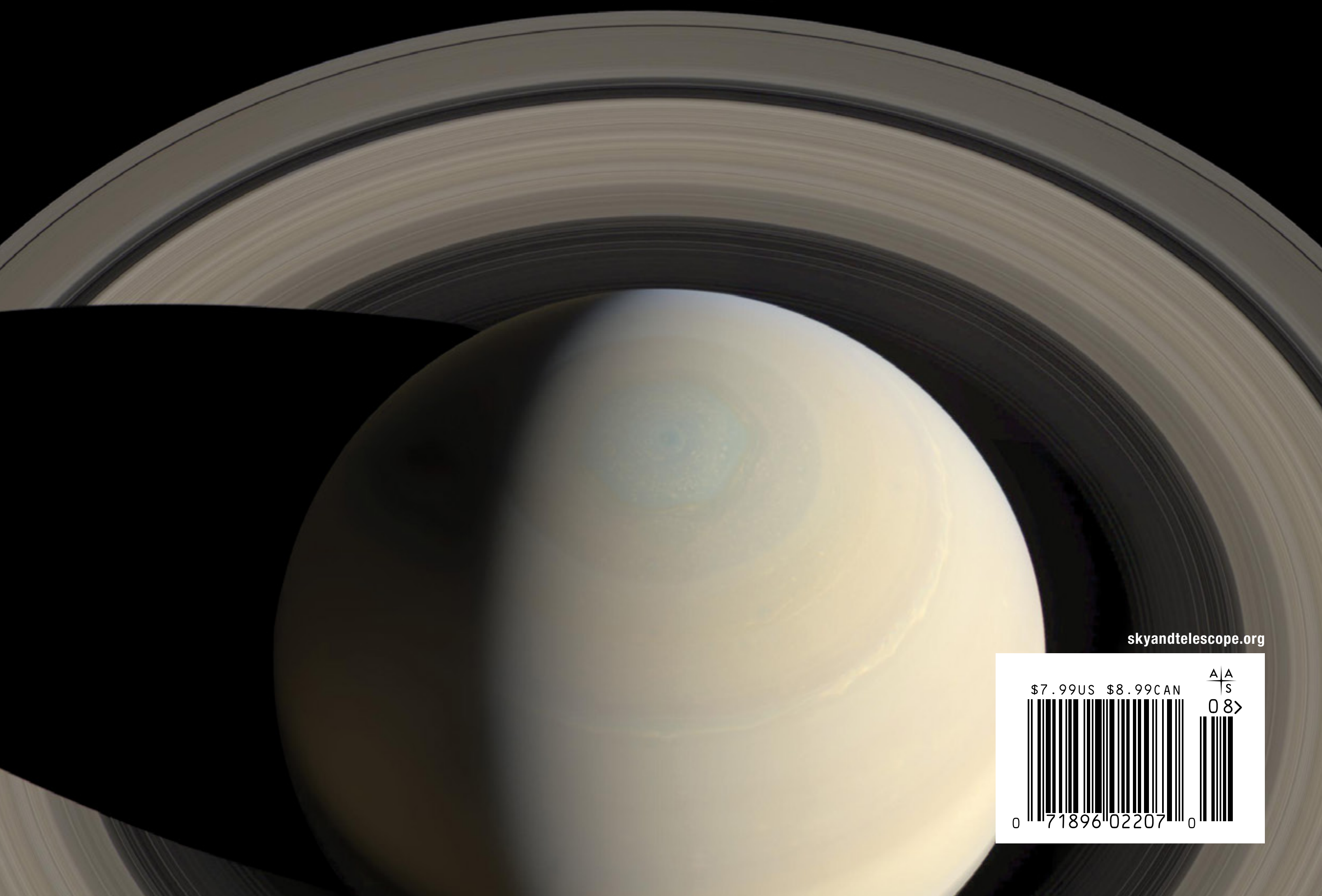
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

AUGUST 2022

DISCOVERING
Saturn's Ring Spokes

Page 28



skyandtelescope.org

$7.99US $8.99CAN


QHY600

CONTENTS

SKY&TELESCOPE
THE ESSENTIAL GUIDE TO ASTRONOMY

August 2022 VOL. 144, NO. 2

20

FEATURES

OBSERVING

S&T TEST REPORT

COLUMNS / DEPARTMENTS

STEFAN BINNEWIES / JOSEF PÖPSEL

ON THE COVER

Mosaic of Saturn as seen by Cassini, by amateur G. Ugarkovic

NASA / JPL-CALTECH / SSI / G. UGARKOVIC

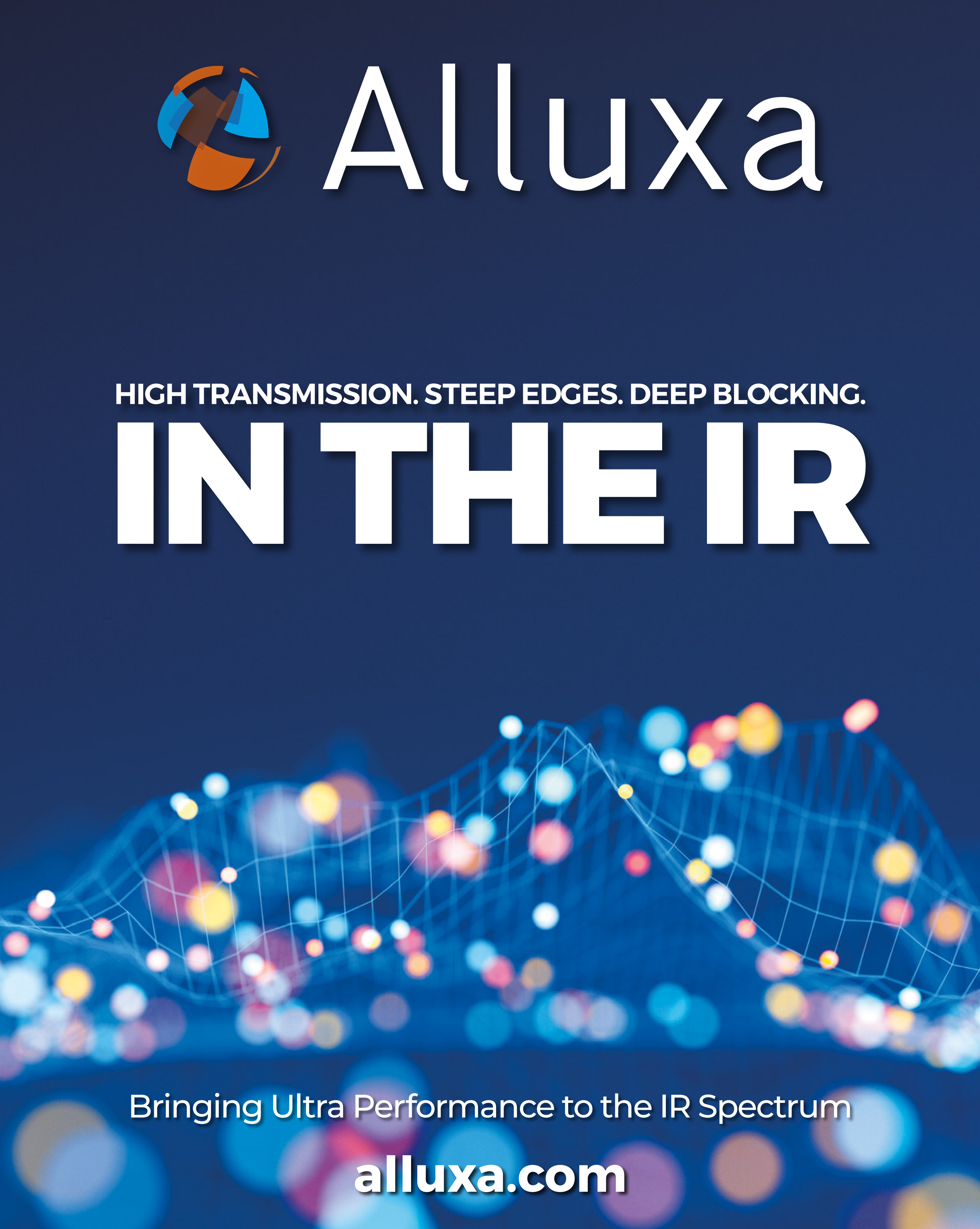
ONLINE

NEWSLETTERS
Have the latest astro news sent straight to your inbox, or be the first to know about our tours and products.
skyandtelescope.org/newsletter

ASTRONOMY EVENTS
Check out our calendar for upcoming exhibits, star parties, and more — or add your event to our listings!
skyandtelescope.org/astronomy-events

DIGITAL EDITION
Use the email connected to your subscription to read our latest digital edition.
skyandtelescope.org/digital

SKY & TELESCOPE (ISSN 0037-6604) is published monthly by AAS Sky Publishing, LLC, owned by the American Astronomical Society, 1667 K Street NW, Suite 800, Washington, DC 20006, USA. Phone: 800-253-0245 (customer service/subscriptions), 617-500-6793 (all other calls). Website: skyandtelescope.org. Store website: shopatsky.com. ©2022 AAS Sky Publishing, LLC. All rights reserved. Periodicals postage paid at Washington, DC, and at additional mailing offices. Canada Post Publications Mail sales agreement #40029823. Canadian return address: 2744 Edna St., Windsor, ON, Canada N8Y 1V2. Canadian GST Reg. #R128921855. POSTMASTER: Send address changes to Sky & Telescope, PO Box 219, Lincolnshire, IL, 60069-9806. Printed in the USA. *Sky & Telescope* maintains a strict policy of editorial independence from the AAS and its research publications in reporting on astronomy.


Alluxa
HIGH TRANSMISSION. STEEP EDGES. DEEP BLOCKING.
IN THE IR
Bringing Ultra Performance to the IR Spectrum
alluxa.com

For the Record

SKY & TELESCOPE HAS ALWAYS held a lofty aspiration: to be the magazine of record for amateur astronomy. I realize that might sound boastful, to claim such elevated ground for ourselves, but I consider it a provocation. To deem *S&T* a magazine of record, even solely for our modestly sized community of hobbyists, is to bare ourselves to perpetual scrutiny, to be held accountable for our errors, and to unfailingly adhere to a high standard of excellence.

What does it mean to be a magazine of record? Google won't help you here. Searching the term will bring up music-industry publications as well as issues with "record" in their title, such as *Architectural Record*. But "newspaper of record," a term that arose a century ago in reference to *The New York Times*, came to mean a paper scrupulous about accuracy and verifiable reporting, as well as one serving as an archival chronicle of major events of the day. In today's heterogeneous world, it might be hard for any newspaper to make that claim. But niche publications such as ours arguably still can.

▲ From our first issue in 1941 to today, *S&T* has prided itself on being the magazine of record for amateur astronomers.

A key aspect of holding to that high-minded benchmark is setting the record straight. Our cover story this month does that regarding the first confirmable observations of the "spokes" in Saturn's rings (see page 28). We often run these kinds of stories. In the past year alone, we've done pieces on who really discovered stellar proper motion (contrary to what many sources state); exactly when a truly useful set of star charts initially appeared; and who deserves credit for first accurately describing the gegenschein, that faint "counterglow" sometimes seen in the night sky opposite the Sun's position.

A corollary to setting the record straight is highlighting individuals and discoveries that might not have gotten the attention they deserve. Again just in the past year, we've published a look at the little-known Venus-transit adventure of Charles Mason and Jeremiah Dixon (of Mason-Dixon Line fame), a cover story on the groundbreaking contributions of Henrietta Swan Leavitt, and a feature on how the Mesopotamians pioneered astronomical computing.

Even as we strive to ever be the magazine of record for our community, we know we can't be comprehensive. We realize we're not the only trusted source on astronomy out there. And we accept that setting the record straight includes owning up to our mistakes. We do that in For the Record (see page 7) and in our online errata pages (see, e.g., **https://is.gd/2021errata**).

Lastly, we know we can count on you, our astute and eagle-eyed readers, to help keep us honest. Thank you.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

EDITORIAL
Publisher Kevin B. Marvel
Editor in Chief Peter Tyson
Senior Editors J. Kelly Beatty, Alan M. MacRobert
Science Editor Camille M. Carlisle
News Editor Monica Young
Associate Editor Sean Walker
Observing Editor Diana Hannikainen
Consulting Editor Gary Seronik
Editorial Assistant Sabrina Garvin

Senior Contributing Editors
Dennis di Cicco, Richard Tresch Fienberg, Roger W. Sinnott

Contributing Editors
Howard Banich, Jim Bell, Trudy Bell, Monica Bobra, Ronald Brecher, Greg Bryant, Thomas A. Dobbins, Alan Dyer, Tony Flanders, Ted Forte, Steve Gottlieb, David Grinspoon, Shannon Hall, Ken Hewitt-White, Johnny Horne, Bob King, Emily Lakdawalla, Rod Mollise, James Mullaney, Donald W. Olson, Jerry Oltion, Joe Rao, Fred Schaaf, Govert Schilling, William Sheehan, Mathew Wedel, Alan Whitman, Charles A. Wood, Richard S. Wright, Jr.

Contributing Photographers
P. K. Chen, Akira Fujii, Robert Gendler, Babak Tafreshi

ART, DESIGN & DIGITAL
Art Director Terri Dubé
Illustration Director Gregg Dinderman
Illustrator Leah Tiscione
Web Developer & Digital Content Producer
Scilla Bennett

ADVERTISING
Advertising Sales Director Tim Allen

AMERICAN ASTRONOMICAL SOCIETY
Executive Officer / CEO, AAS Sky Publishing, LLC
Kevin B. Marvel
President Paula Szkody, University of Washington
President Elect Kelsey Johnson, University of Virginia
Senior Vice-President Geoffrey C. Clayton, Louisiana State University
Second Vice-President Stephen C. Unwin, Jet Propulsion Laboratory, California Institute of Technology
Third Vice-President Adam Burgasser, UC San Diego
Treasurer Doris Daou, NASA Planetary Science Division
Secretary Alice K. B. Monet, U.S. Naval Observatory (ret.)
At-Large Trustees Hannah Jang-Condell, University of Wyoming; Edmund Bertschinger, MIT; Jane Rigby, NASA Goddard Space Flight Center; Louis-Gregory Strolger, Space Telescope Science Institute

Editorial Correspondence
(including permissions, partnerships, and content licensing): Sky & Telescope, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA. Phone: 617-500-6793. E-mail: editors@skyandtelescope.org. Website: skyandtelescope.org. Unsolicited proposals, manuscripts, photographs, and electronic images are welcome, but a stamped, self-addressed envelope must be provided to guarantee their return; see our guidelines for contributors at skyandtelescope.org.

Advertising Information:
Tim Allen: 773-551-0397
E-mail: tallen@skyandtelescope.org
Web: skyandtelescope.org/advertising

Subscription Rates:
U.S. and possessions: $56.05 per year (12 issues)
Canada: $71.05 (including GST)
All other countries: $86.05, by expedited delivery
All prices are in U.S. dollars.

Customer Service: Magazine customer service and change-of-address notices:
skyandtelescope@omeda.com
Phone toll-free U.S. and Canada: 800-253-0245
Outside the U.S. and Canada: 847-559-7369
Mailing address: *Sky & Telescope* Magazine, P.O. Box 219, Lincolnshire, IL 60069-9806, USA

Visit shopatsky.com
Shop at Sky customer service: shopatsky.com/help

Newsstand and Retail Distribution:
Marisa Wojcik, mwojcik@i-cmg.com
Comag Marketing Group

◀ In 1983, Comet IRAS-Araki-Alcock (C/1983 H1) passed just 0.03 astronomical units from Earth, the closest confirmed cometary approach in 200 years.

Comet IRAS-Araki-Alcock

"Saving Apollo 16," the Focal Point by Mark Gingrich (*S&T:* Apr. 2022, p. 84), reminded me of something that happened in May 1983, shortly after I'd started working at the Adler Planetarium in Chicago.

Comet IRAS-Araki-Alcock (C/1983 H1) made the front page of the Chicago newspaper. The next day, more than 200 people called to ask how to see the comet.

Answering those calls was part of my job, but the comet was only 2nd-magnitude, not much brighter than the limiting magnitude in the city. Worse, the comet had no tail obvious to the unaided eye. To see the comet reliably, one needed to know where in the sky to look. It would also have helped to drive an hour outside the city.

Almost no one who called knew how to find the Big Dipper. By mid-afternoon, I was getting tired of disappointing people.

At the time, Venus was bright in the evening sky. The temptation was strong to say, "Yep, that bright one, just after sunset. Can't miss it!" But I resisted.

Fred Ringwald • Fresno, California

Red Galaxies

In the article "An Unusual Home" by Shannon Hall (*S&T:* Apr. 2022, p. 34), she notes that one way to identify small galaxies apparently near a larger one as being more distant in the line of sight rather than genuine satellites is to see if they are redder than the other galaxy. However, dead galaxies will naturally be redder than ones still actively forming stars. Could this lead to astronomers overlooking genuine dead satellite galaxies, biasing the conclusions from the Satellites Around Galactic Analogs (SAGA) Survey?

Michael Baxter
London, England

Monica Young replies: *You make a good point that older galaxies will also look redder, so the SAGA team members had to be careful with their color cuts in order to not bias the survey. What they did was make two color cuts by galaxies'* g-r *and* r-i *colors. (The* g-r *color, for example, is the difference in an object's magnitude as measured in the* g *and the* r *bands.) Having two color measurements gave the team a crude photometric redshift for any given galaxy.*

Photometric redshifts are common in larger surveys with thousands of objects, but the key here was that the team was looking at such low redshifts that those formulae wouldn't apply, so they had to make their own.

Sirius and the Sun

Thanks to Bob King's "A Sirius Naked-Eye Challenge" (*S&T:* Mar. 2022, p. 48), I saw Sirius with the naked eye at 7:12 p.m. CDT on March 27th — the very minute the Sun's westernmost limb touched the horizon at my location in Ottawa, Illinois. I was surprised at how easy it was to see it in binoculars just 10 minutes before and just as surprised at how easy it was to lose. The naked-eye view came and went for a few minutes. Since some of the planets are occasionally brighter than Sirius, my next challenge will be to see them while the Sun is still up — when they're not at dangerously small elongations, of course. I've already seen Venus in the daylight.

Rick Wiegmann Koshko
Ottawa, Illinois

Spotting Mercury

The blurb at the end of Sun, Moon & Planets on page 46 of the April 2022 issue of *Sky & Telescope* notes, ". . . Gary Seronik never misses a chance to catch a mercurial Mercury appearance." I have the same outlook. Since January 2011, I've spotted Mercury at least once at every elongation. I usually start with binoculars or unaided eyes and occasionally try for the crescent with a scope.

On April 11, 2022, I glimpsed Mercury through a gap in the clouds with my 15×56 binoculars. On April 12th, I saw it again in clear skies three minutes after sunset with the same binoculars, then caught it with unaided eyes 25 minutes after sunset. Three minutes later, I was able to hold it steadily in view with unaided eyes. Sometimes it's easy to see Mercury with the naked eye; however, oftentimes it's difficult or impossible without optical aid.

This one makes 72 elongations in a row for me. Sort of like an old golfer, that score matches my age. I started in January 2011 with the hope of spotting Mercury at each of its seven elongations that year and just kept going.

I'm glad to see that someone else appreciates spotting Mercury.

Joe Stieber
Maple Shade, New Jersey

Across Philly for *S&T*

As an 80-year-old retired university professor and a serious, lifelong amateur astronomer, I very much enjoyed both William Sheehan and Klaus Brasch's "A Golden Age for Amateur Astronomy" (*S&T:* Nov. 2021, p. 14) and the letters it provoked (*S&T:* Mar. 2022, p. 6). In several cases, these letters were virtually pieces taken out of my own biography.

I particularly remember how I'd eagerly anticipated the monthly appearance of *Sky & Telescope* for sale at the Franklin Institute bookstore. This would provide an excuse for me to take a break from pursuing my PhD at the University of Pennsylvania and ride the subway-surface trolley toward downtown. I'd then buy a copy of *Sky & Telescope* at the bookstore of the Fels Planetarium and, sitting by the fountain, indulge my celestial fantasies, which were first created by Roy K. Marshall of Fels and his very early television shows under that hallowed dome, Percival Lowell's books, and the wonderful art of Wally Wood in E. C. Comics' *Weird Science* and *Weird Fantasy*. I still have, in mint condition, the comics and books, as well as my first scope: a 2.4-inch (60-mm) Unitron Model 114 refractor!

William Bonney
Moscow, Idaho

Sketching Markarian's Chain

I enjoyed Howard Banich's "Markarian's Marvelous Chain" (*S&T:* Apr. 2022, p. 22). It brought back strong memories of the night of April 5, 2008, when I viewed and sketched Markarian's Chain in my 10-inch Dobsonian with a 24-mm Hyperion eyepiece from Figueroa Mountain in California. That logbook entry ranks in the top five for me out of the 15 years or so that I've been observing. I often use it as an example in my high school classes on the importance of taking notes and the joy of reliving moments through them.

Even at a conservative 100 billion stars per galaxy, the idea of pondering the combined light of over a trillion stars at once staggers me.

Steve Riegel
Colorado Springs, Colorado

▲ Steve Riegel drew this sketch of Markarian's Chain in his logbook in 2008. North is down.

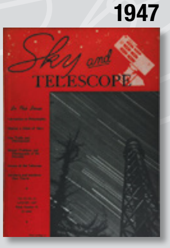
FOR THE RECORD

- In "Nearest Supermassive Black Hole Pair Discovered" (*S&T:* Apr. 2022, p. 10), François Schweizer and team identified the galaxy's double nucleus, and showed that one of them hosts an active supermassive black hole, in 2018. Karina Voggel and colleagues significantly improved the mass measurements for both black holes in 2022.
- On page 56 of the April issue, an astrophotographer reduces the effective noise by half each time they multiply the number of images by four.

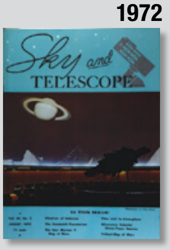
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1947



1972



1997

◖ August 1947

Eclipses or Not? "In Coma Berenices, the star known as Alpha or 42 is a visual binary with a period of 25.87 years. Its component stars are practically identical, of magnitude 5.2 and spectral class *F*5. . . . Dr. Luigi Jacchia, of Harvard College Observatory, finds this star to offer the interesting possibility of the eclipse of one component by the other . . .

"[At] their distance of about 50 light-years, these stars, if each is about the same size as the sun, should have apparent diameters of 0.0006 seconds, which makes the chances of eclipse seem not too favorable. . . . But in 1963, about April, [they will have roughly the same] minimum separation."

Despite the system's accurately known orbit, tipped almost exactly edge on to our view, astronomers failed to detect an eclipse in 1963 and again in 2015. The next chance is in 2040.

◖ August 1972

Wandering Phobos "At the Royal Greenwich Observatory, A. T. Sinclair has completed a comprehensive study of the orbital motions of the two natural satellites of Mars . . . One purpose of the new investigation . . . was to clarify the question of the secular acceleration of the satellite motions.

"This effect was first pointed out in 1945 by B. P. Sharpless at the U.S. Naval Observatory, who found that Phobos appeared to be gradually speeding up, at a rate that would put it 19 degrees ahead in its orbit by the end of a century. . . .

"Dr. Sinclair used a total of 3,107 observations of the two satellites . . . This analysis showed that the supposed speeding up of Phobos resulted from the observations made at the oppositions of 1877, 1879, and 1881. When these observations are omitted [the anomaly goes away]."

Sinclair's study closed the book on a wild suggestion by Russian astronomer I. S. Shklovskii. In 1959, he had noted that Phobos's odd motion could be accounted for if it were hollow (that is, something built by aliens).

◖ August 1997

Galaxy Survey "In five short years, a state-of-the-art telescope will measure the distances to one million galaxies. . . .

"It was with this dream in mind that the Sloan Digital Sky Survey (SDSS) was born. Nearly ready to begin its five-year journey through space and time, [the 2.5-meter reflector at Apache Point Observatory in New Mexico] will produce detailed color images of about a quarter of the sky [and lead to] a three-dimensional map of the universe's structure throughout a volume a thousand times larger than that probed by existing surveys."

Participant Gillian Knapp limited her article to initial expectations for the SDSS. With ever-evolving instrumentation and techniques, the survey goes on. Last year its scientific team issued Data Release 17.

METEORS

U.S. Space Force Releases Data on Bright Fireballs

THE U.S. DEPARTMENT OF DEFENSE has released data on nearly 1,000 bright fireballs, or *bolides*, that have hit our planet's atmosphere since 1988.

For years the Department of Defense (DoD) only issued basic information about these events. Now, via a collaboration between NASA and the U.S. Space Force, the DoD is making additional data on the brightest fireballs public to aid planetary defense research.

Many a meteor-shower watcher has seen a bolide, a streak as bright as Venus trailing through the sky. During such brilliant, seconds-long flashes, the atmosphere both ablates the meteoroid's surface and breaks apart the body. The fragments then undergo more surface contact with the atmosphere until most or all of the meteor has vaporized in the upper atmosphere.

Until now, researchers of such events had to rely on basic data available from U.S. government sensors: typically, the impact time, location and altitude, and approximate speed as well as occasional estimates of the fireball's total energy. Now, for the first time, scientists will have access to a crucial piece of information: how these explosions change in brightness over the few seconds it takes them to vaporize.

From a fireball's light curve, scientists can learn about the meteors themselves. "[Meteors'] response to increasing pressure from the atmosphere, represented by the light curves, is an indirect probe of their strength and structure," says Peter Brown (University of Western Ontario, Canada), a planetary scientist who has used publicly available fireball data in his own research. "By studying the light curves, we can indirectly infer the global strength of meter- to decameter-sized near-Earth objects." Such data can, for example, shed light on whether an incoming meteor is a fragment from an asteroid or a comet.

S&T's Sean Walker captured a bolide during the 2021 Geminids.

AN INTERSTELLAR METEOR?

One unexpected result to come from analysis of these fireball data is the identification of a possible interstellar bolide — that is, an impactor that originated from outside the solar system.

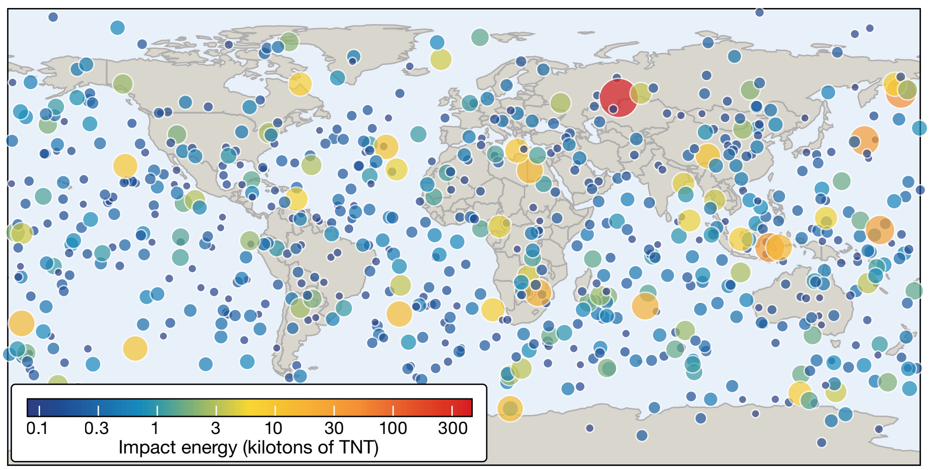
In 2019 Amir Siraj and Abraham Loeb (both at Harvard) reported on the arXiv preprint server that a half-meter meteor detected on January 8, 2014, was hurtling toward Earth on a hyperbolic orbit, one unbound to the Sun. They based the object's trajectory on the high impact speed recorded in the Center for Near Earth Object Studies (CNEOS): 44.8 kilometers per second (100,000 mph).

If this result pans out, it would precede the discovery of 'Oumuamua, thought to be the first interstellar object, by three years. Joel Mozer, the chief scientist of the Space Operations Command, considers the velocity data sufficiently accurate to indicate the meteor's origin outside the solar system. However, others don't think the evidence merits the extraordinary claim.

"The data being referred to is just for a very brief period as the bolide is detected passing through Earth's atmosphere," explains NASA planetary defense officer Lindley Johnson. "While further analysis by our U.S. Space Force source does confirm a relatively high velocity for this bolide, it is very hard to be conclusive about the origin of an object based on that sparse and short of data span."

■ MONICA YOUNG

Fireballs Reported by U.S. Government Sensors, April 1988 – April 2022



▲ This map shows bright fireballs that U.S. government sensors have recorded since 1988.

ALAN B. CHAMBERLIN (JPL / CALTECH)

SPACE & SOCIETY

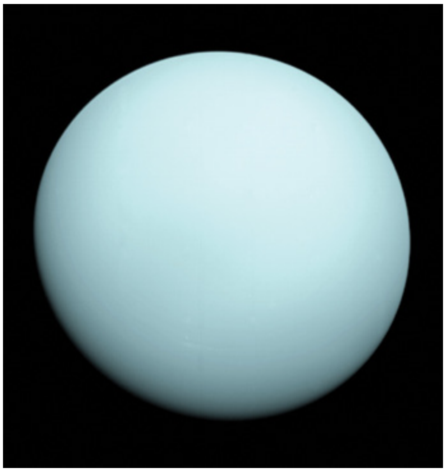
Planning the Next Decade of Planetary Science

THE NATIONAL ACADEMIES of Science, Engineering and Medicine have released the decadal survey for the planetary science and astrobiology community, providing marching orders for solar system exploration through 2032.

The decadal survey prioritized the development of a new flagship mission: the Uranus Orbiter and Probe. Costing on the order of $1 billion, this mission would send a Cassini-style spacecraft to the ice giant and its moons and will include a probe to enter the atmosphere. (Uranus won out over Neptune due to launch and trajectory logistics.)

The second-highest priority flagship identified in the report is a combination orbiter-and-lander that could head to Saturn's moon Enceladus. The Enceladus Orbilander would sample plumes emanating from geysers on the icy moon's surface.

The report also recommended the continued development and support of projects from previous decadals, such as the Perseverance rover and sample-caching mission as well as the under-construction Europa Clipper. As part of continued Mars exploration, the committees also prioritized a probe (the Mars Life Explorer) to seek extant life on the Red Planet.



▲ The Voyager 2 flyby of Uranus in 1986 provided us with our closest view of the enigmatic ice giant.

For lunar exploration, the survey recommended the development of Endurance A, a large sample-return rover that would visit the lunar south pole. It would collect 100 kilograms (220 pounds) of regolith, which Artemis astronauts would return to Earth.

The decadal also endorsed planetary defense and supports the NEO Surveyor mission, which would fly a mid-infrared camera to seek objects more than 140 meters in size.

The report did not recommend any specific missions for NASA's New Frontiers program but rather set themes for consideration. To support smaller-budget exploration under the Discovery and Small Innovative Missions for Planetary Exploration programs, the survey suggests a cost-cap increase for both mission classes.

In alignment with the astronomy and astrophysics decadal survey (*S&T:* Mar. 2022, p. 8), the planetary-science community highlighted the urgent need to promote diversity and equity in the field. Both reports also called for measures to monitor and mitigate the rising impact of satellite constellations.

"I think [the decadal] is a very compelling vision for space exploration for the next decade and beyond," says planetary scientist Jonathan Fortney (University of California, Santa Cruz).

■ **DAVID DICKINSON**

SOLAR SYSTEM

Where Did the Ice Giants Form?

CONVENTIONAL PLANET-FORMATION scenarios have Neptune and Uranus forming close to the Sun before migrating outward. But a new study to appear in the *Astrophysical Journal* shows that the ice giants could have formed right where they are now.

In the classic picture of planet formation, the dust grains in a protoplanetary disk clump together into larger and larger bodies. Once these bodies reach the mass of planetary cores, they gather gas from the disk.

But according to this classic scenario, planetesimal growth would have been slower farther away from the Sun. Uranus and Neptune, at their current distances, wouldn't have had time to amass their mantles before the gaseous disk had dissipated.

However, this picture neglects the role of *pebbles*, centimeter-size particles whose presence speeds up accretion onto planetary cores, such as those in Uranus and Neptune, argue Claudio Valletta and Ravit Helled (University of Zürich, Switzerland).

"The formation timescale problem, which was there for a very long time, from my perspective no longer exists," Helled says.

Valletta and Helled ran 24 versions of a simulation that followed the accretion of pebbles and gas onto a single planetary core, considering the growth of Uranus and Neptune individually. They successfully reproduced the ice giants' total mass as well as the heft of their gaseous envelopes. However, several of the simulation runs formed a planet missing heavy elements: up to 3 Earth masses' worth. Giant impacts might have delivered this missing mass, the team suggests.

André Izidoro (Rice University), who was not involved in the study, cautions that migration is hard to avoid. "As planets grow, especially when they become larger than one Earth or Mars mass, they start to move around," he says. Simulations have in fact demonstrated that Uranus and Neptune could have formed from a series of collisions among migrating protoplanets.

A future mission to Uranus (see above) might shed light on the planet's migration history or lack thereof. But regardless of what any such mission finds, understanding the ice giants' origin will likely bring together multiple processes. As both Helled and Izidoro repeatedly emphasized: It's complicated.

■ **JURE JAPELJ**

NASA / JPL-CALTECH

SOLAR SYSTEM

Europa Might Host Water Near Its Surface

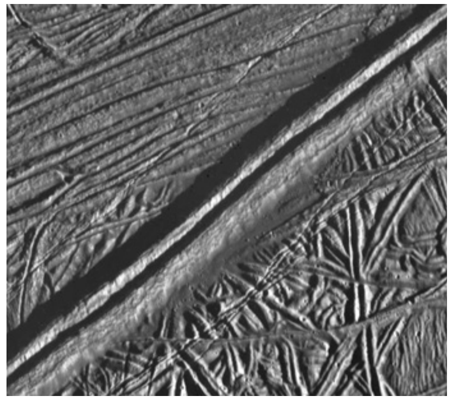
NEW RADAR MEASUREMENTS of Greenland's ice sheets suggest that water could be close to the surface of Jupiter's icy moon Europa. These results were published April 19th in *Nature Communications*.

Tidal heating from Jupiter sustains a vast water ocean beneath Europa's icy crust. But for life to exist, chemical interactions must occur. If some of that water ventures toward the surface, it could mix with chemicals from space and from other moons, says team member Dustin Schroeder (Stanford). "[Then] life has a shot."

Schroeder and colleagues think they've found evidence for near-surface water in Europa's long double ridges, first spotted in images the Galileo spacecraft took in the 1990s. Now, observations made considerably closer to home suggest shallow water can create such peaks.

The team was originally studying Greenland's ice to improve sea-level predictions in the face of global warming. But in both surface elevation data and ice-penetrating radar images, which NASA's Operation IceBridge collected between 2015 and 2017, the team noticed double ridges similar to those on Europa. The Greenland double ridges formed when shallow water pockets refreeze and fracture the overlying ice. Similar pockets could form on Europa if water from the subsurface ocean were forced up into the ice shell via fractures.

"The model . . . is very compelling," says Kevin Hand (Jet Propulsion Laboratory), who was not involved in the research. However, Hand points out that while Greenland's ice sheet is almost pure water, Europa's ice contains high levels of sodium chloride. "The biggest question mark for me," he ponders, "is whether their mechanism for double-ridge formation could work with salty ice."



▲ A double ridge cuts across the surface of Europa in this image from NASA's Galileo, taken in 1997.

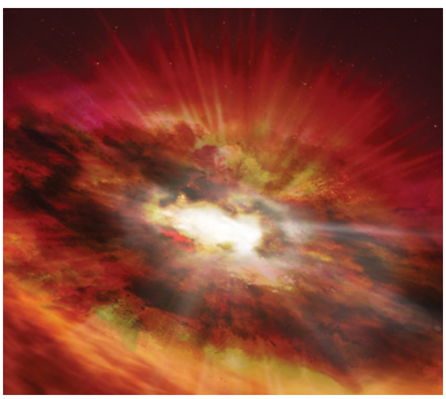
NASA's Europa Clipper, due to arrive at the moon in 2030, may confirm the mechanism at work. If so, Hand says, "double ridges on Europa may be enticing regions to explore in our search for signs of life."

■ COLIN STUART

BLACK HOLES

Hubble Image Reveals Possible Quasar Forerunner

ASTRONOMERS HAVE DISCOVERED a precursor to quasars, the brilliant beacons powered by gas-guzzling black holes with the mass of millions or even billions of Suns. The find may shed light on the quick evolution of quasars, which astronomers have spotted already fully grown already than 1 billion years after the Big Bang.



▲ A supermassive black hole grows inside the dust-shrouded core of a "starburst" galaxy, as shown in an artist's concept.

One of the best ways to know if a supermassive black hole is feeding is by the X-rays emitted from the material closest to its maw. However, the same conditions that feed central black holes — galactic collisions and vast flows of gas associated with bursts of star formation — can also hide those X-rays from view. Astronomers have found shrouded-quasar precursors relatively nearby, but if quasars can exist within the universe's first billion years, then their precursors should, too.

While reprocessing data from a Hubble Space Telescope field, Seiji Fujimoto (Cosmic Dawn Center, Denmark) and colleagues found just such an early quasar forerunner, reporting the results in the April 14th *Nature*. Dubbed GNz7q, the galaxy existed just 700 million years after the Big Bang. It's birthing some 1,600 Suns' worth of stars every year, and an emission line associated with this star formation confirms the galaxy's extreme distance.

The astronomers didn't detected any X-rays from GNz7q, but the object's observed brightness at infrared wavelengths shows a pattern similar to quasars, albeit reddened by obscuring dust. An active supermassive black hole inside this galaxy could be some 10 million times the Sun's mass and feeding at a fantastic rate.

There's a chance that, rather than a gas-guzzling black hole, there's instead a small core of intense star formation. Fujimoto and colleagues argue that's unlikely because the ultraviolet light would have to come from a compact region forming upwards of 5,000 solar masses a year. However, Ryan Hickox (Dartmouth College), who wasn't involved in the study, says that, though extreme, that's still a possibility based on observations of nearer galaxies.

Ultimately, more observations will help nail down what this distant galactic center holds, whether it be a giant, dust-shrouded black hole or an intense star factory. "Either way," Hickox says, "it is a very interesting object!"

■ MONICA YOUNG

ICY DOUBLE RIDGE ON EUROPA: NASA / JPL / ASU; QUASAR: NASA / ESA / N. BARTMANN

STARS

Meet Earendel, the Most Distant Star Observed

THE HUBBLE SPACE TELESCOPE has revealed a single star whose light has traveled 12.8 billion years to Earth. It's currently the most distant star known. The distance, published in the March 31st *Nature*, is a big jump from that of the previous record-holder, which existed in a universe about 4 billion years old.

The star, which the team has dubbed Earendel, belongs to a gravitationally lensed galaxy. The vast mass of a foreground galaxy cluster bends and magnifies the light from the more distant galaxy into a long, thin crescent nicknamed the "Sunrise Arc."

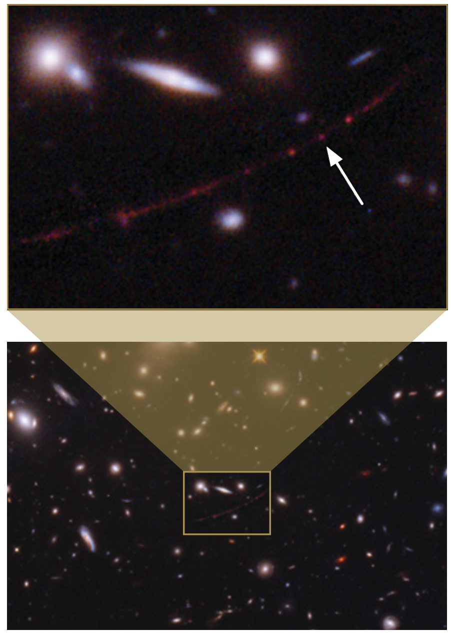
Brian Welch (Johns Hopkins University) and colleagues fit the Hubble images with multiple gravitational-lens computer models. While those models disagree on the exact amount of magnification, all of them agree that the lensing has magnified the star by at least 1,000 and maybe up to 40,000 times. The models also put an upper limit on the object's size, which must be less than about two light-years across. That largely rules out the possibility that the object is a star cluster rather than a single star or star system.

Based on Earendel's brightness, the group estimates that the star is massive, containing the equivalent of tens or even hundreds of Suns. Given the age of the universe it resides in, Earendel is not likely to be one of the very first stars, though, known as Population III. Nevertheless, at its great mass, it's no doubt an early fuser of heavy elements.

For stellar archaeologist Anna Frebel (MIT), who wasn't involved in the study, the discovery is a fantastic find: "Early massive stars must have produced the first elements and driven chemical evolution, so having observations at hand that support this notion is wonderful."

Team member Dan Coe (also at Johns Hopkins) is the principal investigator of approved upcoming observations with the James Webb Space Telescope, which will improve estimates of the star's mass, temperature, and spectral type, not to mention confirm its extreme distance.

■ MONICA YOUNG



▲ Gravitational lensing smeared a distant galaxy into the "Sunrise Arc" (red crescent, top) and magnified one of its stars (arrowed), nicknamed Earendel, by at least 1,000 times.

SCIENCE: NASA / ESA / BRIAN WELCH (JHU) / DAN COE (STSCI); IMAGE PROCESSING: NASA / ESA / ALYSSA PAGAN (STSCI)

IN BRIEF

Listen: Martian Soundscape

Two microphones on Mars, carried on NASA's Perseverance rover, are for the first time revealing the sounds of another planet. One sits on the mast of the SuperCam instrument, 2.1 meters (7 feet) above the ground. The second is on the Entry, Descent and Landing Camera, a meter above the ground. Because sound transmission in the thin, carbon dioxide–based Martian air is weaker than on Earth and drops sharply with frequency, the loudest ambient sound is that of the wind. Mars is otherwise a quiet place. In addition to measuring the speed of sound on Mars (*S&T:* July 2022, p. 8), scientists also used the microphones to monitor instrument performance and test rover equipment. Sylvestre Maurice (University of Toulouse, France) and colleagues presented preliminary results on April 1st in *Nature*. Listen to the sounds of the Martian wind, Perseverance's wheels clanging on rocks, and the rover's zapping laser: **https://is.gd/soundsofMars**.

■ JEFF HECHT

Asteroid Mission to Apophis

NASA has granted a mission extension to the Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (Osiris-REX) mission, which recently visited and sampled the asteroid 101955 Bennu and is due to drop off samples at Earth late this year. The spacecraft will continue to a new destination, reaching the near-Earth asteroid 99942 Apophis in 2029. This extended mission, budgeted at $200 million, will be redesignated Osiris-APEX (Apophis Explorer). The asteroid will be making its closest approach to Earth that April, passing within 32,000 km (20,000 miles, inside the orbit of geostationary satellites). "Osiris-APEX will detect Apophis about three weeks before the asteroid's close encounter with Earth, giving us time to monitor its rotation rate before and after the close encounter," says APEX principal investigator Daniella DellaGiustina (University of Arizona). The spacecraft will then spend 18 months surveying the stony asteroid. Investigations will inform planetary-defense strategies.

■ DAVID DICKINSON

A Giant in the Making

Astronomers have spotted a world just starting to come together in the outskirts of the disk around AB Aurigae, a star 2 million years young. Thayne Currie (National Astronomical Observatory of Japan) and colleagues discovered AB Aurigae b in images taken between 2016 and 2020 with the Subaru Telescope. The team obtained additional images with the Hubble Space Telescope in 2021 and dug up archival data, too. The images, spanning nearly 22 years, trace a giant clump's motion around the young star at around 90 astronomical units. Unlike most distant worlds amenable to direct imaging, this planet is still in the early throes of formation. The images thus do not capture light from the planet itself but rather from the hot gas around it. While astronomers think most gas giants come together via *core accretion,* Currie's team argued April 4th in *Nature Astronomy* that this planet is instead forming via the *disk instability*, in which a part of the protoplanetary disk collapses in violent fashion.

■ MONICA YOUNG

 by Jim Bell

TO THE SKIES The Martian helicopter took this image from a height of 10 meters (33 ft) during its sixth flight. The image looks west toward the Séítah geologic unit.

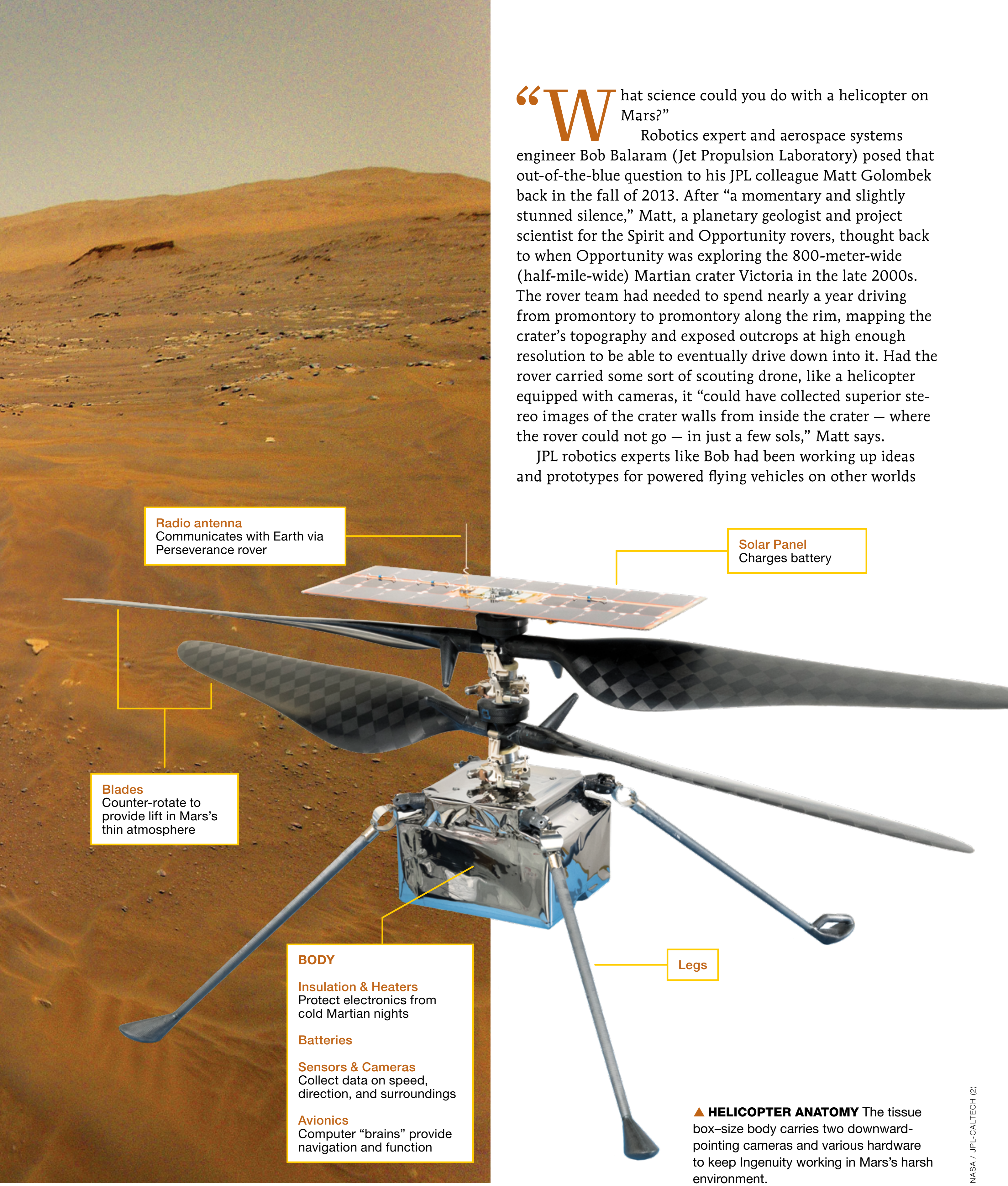
Flying with INGENUITY on Mars

It's thanks to bold creativity and tenacity that a small rotorcraft is now exploring the Red Planet.

"What science could you do with a helicopter on Mars?"

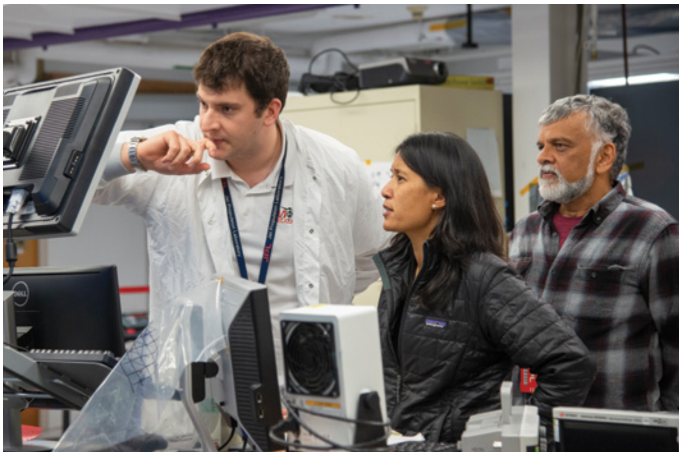
Robotics expert and aerospace systems engineer Bob Balaram (Jet Propulsion Laboratory) posed that out-of-the-blue question to his JPL colleague Matt Golombek back in the fall of 2013. After "a momentary and slightly stunned silence," Matt, a planetary geologist and project scientist for the Spirit and Opportunity rovers, thought back to when Opportunity was exploring the 800-meter-wide (half-mile-wide) Martian crater Victoria in the late 2000s. The rover team had needed to spend nearly a year driving from promontory to promontory along the rim, mapping the crater's topography and exposed outcrops at high enough resolution to be able to eventually drive down into it. Had the rover carried some sort of scouting drone, like a helicopter equipped with cameras, it "could have collected superior stereo images of the crater walls from inside the crater — where the rover could not go — in just a few sols," Matt says.

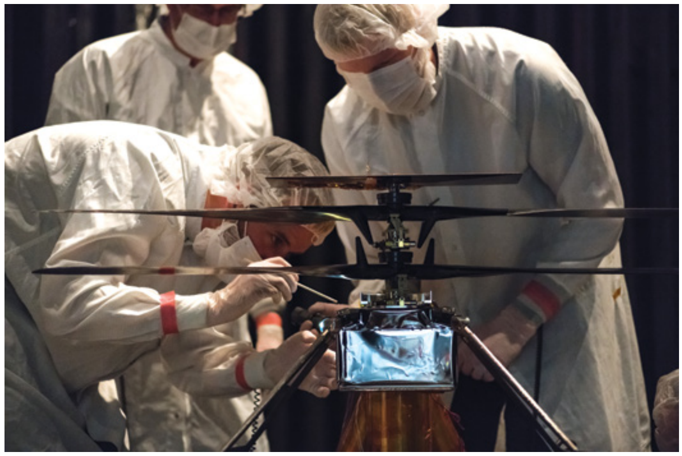
JPL robotics experts like Bob had been working up ideas and prototypes for powered flying vehicles on other worlds



▲ **HELICOPTER ANATOMY** The tissue box–size body carries two downward-pointing cameras and various hardware to keep Ingenuity working in Mars's harsh environment.

NASA / JPL-CALTECH (2)





▲▶ **DO THE HUSTLE** *Left:* Flight test leader Teddy Tzanetos, MiMi Aung, and Bob Balaram (from left to right) observe a flight test inside JPL's Space Simulator in January 2019. *Center:* Team members attach a thermal film to the helicopter's fuselage in February 2019. *Right:* Engineers attach the helicopter to the rover's belly in August 2019.

for some time. Given that, and realizing that both the pace and the amount of science could be substantially enhanced with the help of a flying scout, Matt led a 2014 proposal to include a "Mars Helicopter Scout" on NASA's upcoming Mars 2020 rover mission. That JPL team included, among others, Bob as chief engineer and planetary missions camera expert Justin Maki as the imaging lead.

NASA didn't select the proposal to be part of the mission's scientific payload, opting instead for cameras, spectrometers, and environmental sensors to fly on what would eventually be named the Perseverance rover. But the fact that an advance scout could potentially enable significantly more and better science — by providing geologic context, identifying key outcrops for future analysis, and collecting 3D images to help improve driving — was not lost on the NASA officials putting the mission together. Nor was it lost on then-JPL Director Charles Elachi, who persistently and energetically continued to advocate to NASA Headquarters that they find a way to add such scouting capability to the mission. Elachi also helped direct some internal JPL research and development funding toward the idea, to continue work on the design.

Elachi's persistence and internal investments paid off in 2018, when NASA decided to include JPL's helicopter scout as a separately funded "technology demonstration" mission. Carried to Mars on Perseverance's belly, the helicopter was tasked with proving that controlled, powered flight by a remote-controlled robotic vehicle was possible on a planet hundreds of millions of kilometers away.

So began the adventure of doing what no one had done before: flying on Mars.

Make Haste

Time was short: The heli had to be mounted to the underside of the rover by the summer of 2019, in preparation for the rover to be fully tested that fall and then shipped to Cape Canaveral in early 2020 for its launch that summer. That left less than 18 months to build a working flyer — the blink of an eye compared with a typical NASA project schedule.

The small design and test team had to be nimble, working quickly and efficiently within a large and relatively risk-intolerant government organization that is not particularly well-known for being quick or efficient. The team shared similarities with JPL's earlier Sojourner rover team, Justin tells me, which labored back in the 1990s when he started his career at JPL to design the first wheeled vehicle that would drive on Mars. Both projects were technology demonstrations that had a "Skunk Works kind of team," he says, referring to a division at the aerospace giant Lockheed Martin: a small group operating semi-independently within a much larger infrastructure, trying to solve unprecedented and high-risk engineering problems.

Then-JPL systems engineer MiMi Aung also joined as proj-

LAB PHOTOS: NASA / JPL-CALTECH (3); TIME SERIES OF FIRST FLIGHT: NASA / JPL-CALTECH / ASU / MSSS

FIRST FLIGHT On April 19, 2021, Ingenuity lifted itself into the thin Martian air. These snapshots are from the movie Perseverance's Mastcam-Z took as the helicopter spun up its rotor blades, rose to 3 meters, rotated, hovered, and then touched back down.

ect manager, bringing her expertise with spacecraft-to-spacecraft communications technologies as well as knowhow from having led JPL's Guidance, Navigation, and Control Sensors section. MiMi describes the helicopter team's journey from the initial concept through design and testing as starting with a basic question: Is it possible to build and fly a helicopter on Mars at all? The team members took a fast-paced — yet also incremental and systematic — approach to answering the question, starting with prototypes and engineering models that they operated remotely inside JPL's "space simulator" thermal vacuum chamber, set up to simulate Mars with its thin and cold carbon dioxide atmosphere.

To achieve lift in an atmosphere with a pressure comparable to 80,000 feet above Earth's surface (where existing helicopters can't fly), they realized that they would need a super-lightweight fuselage and large, specially shaped rotor blades that could spin about 10 times faster than what is needed for terrestrial helicopters. They brought fans into the testing chamber to add wind, making flying even tougher but more realistic. They worked out how to communicate back and forth with the rover, essentially creating a mini local Wi-Fi network between the heli and its rover "base station." And they figured out how to enable the helicopter to fly autonomously: Relying on its own cameras, computers, and other systems, the craft has to make decisions in real time about how to stick to the flight plan, including adapting to changing conditions like wind gusts.

The team did its own research as well as leveraging ideas from the terrestrial robotic drone community. The only break the researchers would get was from Mars's weak gravity — about a third of Earth's — which would make it a bit easier to lift the solar panels, rotors, and landing gear, not to mention the computers, batteries, electronics, heaters, cameras, accelerometers, and laser altimeter housed inside the fuselage.

All of that work had to be done with the clock ticking and with the team knowing that any major test failure or other mishap could derail their ride to Mars. The team referred to itself as WENDY, for "We're Not Dead Yet," Matt says, because NASA only gave them a little bit of money at a time, tied to a deliverable that then led to the next short-term funding with a new deliverable. "So we never knew if we would actually get to the launch pad."

But they had their eyes on the final prize. "Our team really, really wanted to get to fly the helicopter at Mars," MiMi says. "As a result, as we accomplished each major milestone, we dared not celebrate fully — we had the attitude of 'not yet, not yet' at each step."

The resulting helicopter design is both familiar and alien. The dual lightweight, carbon-composite rotor blades each span 1.2 meters (almost 4 feet) from tip to tip. They counter-rotate nearly at the Martian speed of sound in order to generate the required thrust. (A similar rotor spinning on Earth could lift more than 50 times as much mass, according to JPL's Håvard Grip, Ingenuity's chief pilot.) The fuselage is a relatively simple box a little smaller than a typical toaster and coated with Kapton film for thermal control. Rather than wheels or skids like most helicopters, this one's landing gear consists of four flexible, 38-cm-long (15-inch-long) angled legs made of tapered carbon-fiber tubes, with golf club–like feet designed to prevent the legs from digging into soft soil. Springy hinges at the legs' tops help soften the shock of landing. Power comes from six lithium-ion batteries inside the fuselage that are trickle-charged during the daytime by solar

Helicopters 101

Aircraft fly thanks to the inverse relationship between air's speed and pressure: The higher the speed, the lower the pressure. The curved top and flat bottom of aircraft wings force air to flow over the top faster than it does over the bottom, which causes suction and lifts the craft higher. An airplane zooms through the sky to move enough air over its wings to fly; a helicopter does the same thing by spinning its rotor blades.

NOTABLE FIRSTS

John Stringfellow's "Bat"
DATE: June 1848

LOCATION: Chard, England
FUEL: steam
DURATION: unknown
CRAFT WINGSPAN: 3 m (10 ft)

CLAIM TO FAME:
first powered flight

Wright Flyer
DATE: Dec. 17, 1903

LOCATION: Kitty Hawk, North Carolina
FUEL: gasoline
DURATION: 12 seconds
CRAFT WINGSPAN: 12.3 m (40.3 ft)

CLAIM TO FAME:
first crewed powered flight

Ingenuity Helicopter
DATE: Apr. 19, 2021

LOCATION: Jezero, Nili Fossae region
FUEL: solar
DURATION: 39 seconds
CRAFT WINGSPAN: 1.21 m (3.97 ft)

CLAIM TO FAME:
first powered flight on Mars

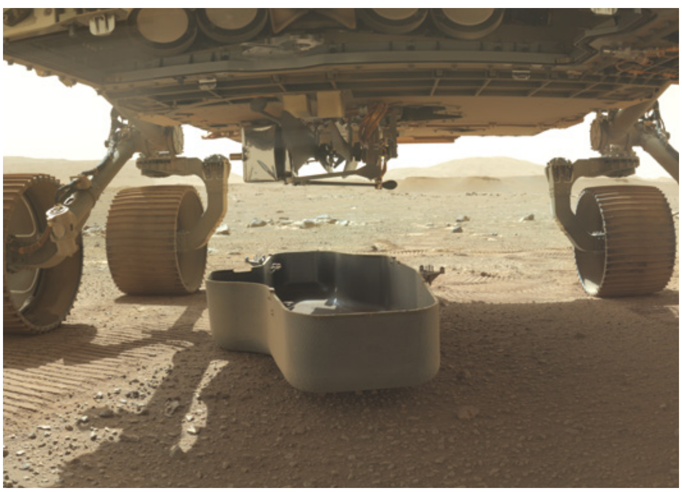
panels that the heli wears like a stationary hat on top of the rotors. The heli's small, omnidirectional radio antenna is mounted atop the solar panel. The entire vehicle has a mass of only about 1.8 kg (4 pounds), which weighs around the same on Mars as a 28-ounce can of tomato sauce does in your kitchen cupboard.

Once completed, the helicopter was carefully folded up, origami-like, and stowed on the underside of the rover's body in August of 2019. A lightweight, deployable debris shield covered it to protect it from the spray of pebbles and dust expected to be kicked up by the descent system's exhaust plumes during landing.

All the scout needed now was a name. In April of 2020, just three months before launch, Alabama high school student Vaneeza Rupani won NASA's nationwide contest to name the helicopter. She proposed Ingenuity. As she wrote in her contest entry, "Ingenuity is what allows people to accomplish amazing things, and it allows us to expand our horizons to the edges of the universe."

Fingers Crossed

Perseverance and Ingenuity launched on an Atlas V rocket from Cape Canaveral Air Force Station in Florida on July 30,



▲ **SHIELDS DOWN** Perseverance dropped the debris shield protecting Ingenuity on March 21, 2021, and peeked under itself with the WATSON camera on its robotic arm to take this image.

NASA / JPL-CALTECH / MSSS

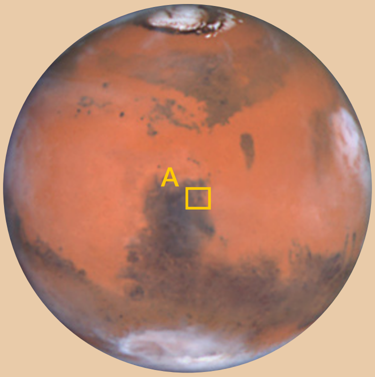
2020. After an uneventful cruise, the pair made a safe, gentle landing on the rocky and sandy floor of Jezero Crater on February 18, 2021. The fact that much of the final assembly, testing, and launch activities, as well as the preparations and practice for all operations on Mars, proceeded — in NASA speak — "nominally" while the world was in the grips of the COVID-19 pandemic is a true testament to the dedication and professionalism of the many thousands of people who made it all happen.

Once on the ground, the Perseverance rover team set about assessing the geological and environmental characteristics of the landing site and testing the rover's systems. The Ingenuity team, meanwhile, spent the early mission days working with rover scientists and engineers to identify a safe, football-field-sized "airfield" where the initial heli flights could be conducted. The Mastcam-Z team, which I lead as principal investigator along with Justin as deputy PI, eagerly participated in the photographic hunt for the right place to fly.

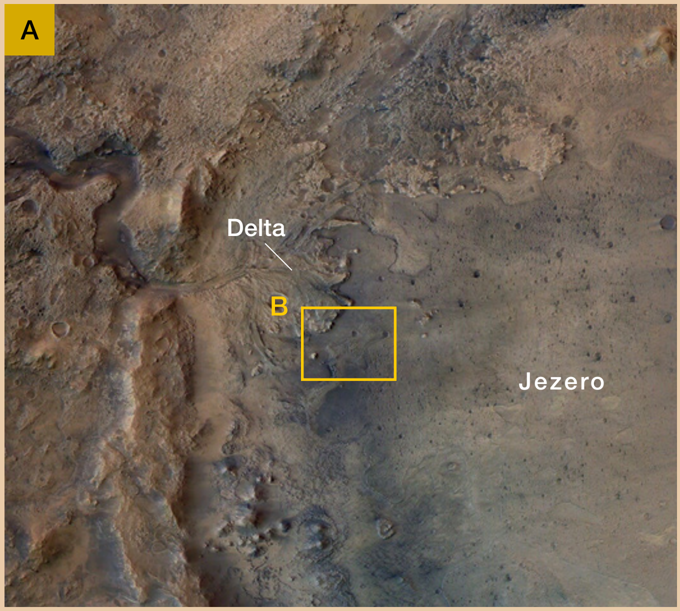
Perseverance's Octavia E. Butler landing site is in a relatively flat part of the crater floor. Using orbiter and rover images, the teams identified a nearby area that was large and rock-free enough to serve as a safe airfield. After checking out the rover's wheels and other systems needed for driving, Perseverance headed out. Along the way, the rover dropped the heli's protective debris shield onto the ground and took inspection photos of the folded-up helicopter using the arm-mounted WATSON camera. Once the rover arrived at the airfield, the teams began the many-sols process of slowly unstowing the helicopter and then gently dropping it the remaining 10 cm (4 in) to the surface. On April 3, 2021, Ingenuity finally "landed" on Mars.

But echoes of "not yet, not yet . . ." were still coming from MiMi and the helicopter team. There were still many steps to perform and systems to check out, including unlocking and testing the rotor blades and testing the communications link with the rover. While the heli team worked to inspect their little aircraft, the rover team moved Perseverance to a viewing location on a rocky plain about 70 meters away — close enough to take good images of Ingenuity using the rover's high-resolution Mastcam-Z cameras, yet a safe enough distance away in case of a flight mishap. The rover would spend several weeks exploring this area — named Van Zyl Overlook,

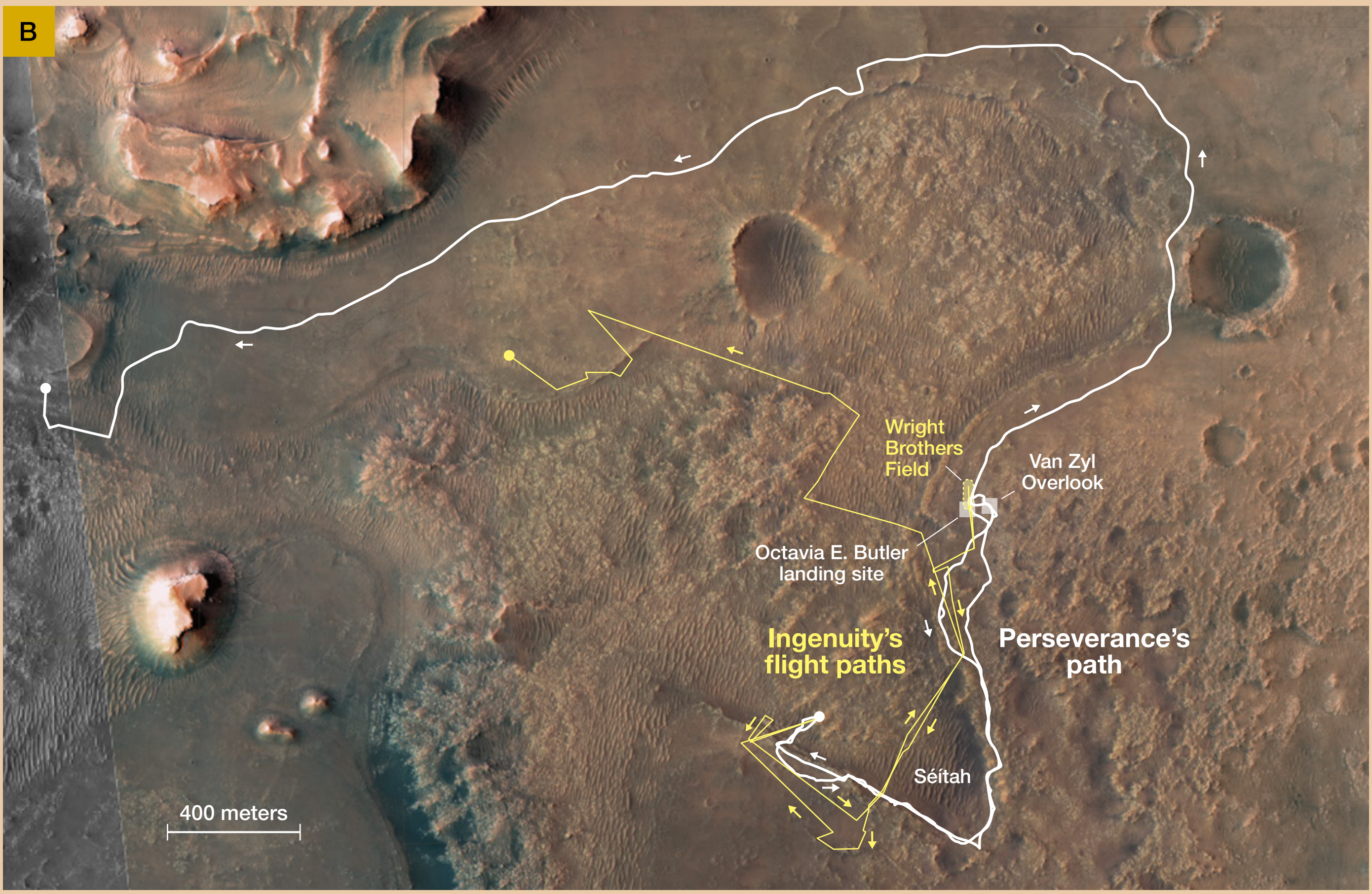
STOCKPILE Perseverance is the first sample-caching mission to Mars. As it trundles across the landscape, the rover drills and stores rock samples. A future mission will collect these samples and return them to Earth.



▲ **LOCATION IS EVERYTHING** Perseverance and its tagalong, Ingenuity, landed in the 45-km-wide crater Jezero, which lies just north of the Martian equator on the boundary between the fractured terrain of Nili Fossae and the ancient impact basin of Isidis Planitia.



▲ **A RIVER RAN INTO IT** An ancient delta along the crater's northwestern edge marks where a long-dry river flowed into Jezero. The delta's sediments would be an ideal place to find chemical or other evidence of microbial life, if it ever existed here.



▲ **TRAILBLAZING** At first, the helicopter kept close to the rover, but flight #9 took it across the treacherous Séítah sands. Subsequent flights explored features beyond the rover's path. As the pair headed for Jezero's delta they followed separate paths, with Ingenuity taking a shortcut across a sandy region that Perseverance had to skirt around. Locations are for May 1st. See where the duo are now at **https://is.gd/whereispercy**.

MARS GLOBE: STEVE LEE (UNIVERSITY OF COLORADO), JIM BELL (CORNELL UNIVERSITY), MIKE WOLFF (SPACE SCIENCE INSTITUTE), AND NASA; JEZERO: ESA / DLR / FU-BERLIN / NASA / JPL-CALTECH; TRAVERSE MAP: GREGG DINDERMAN / S&T AND ESA / DLR / FU-BERLIN / NASA / JPL-CALTECH / UNIV. OF ARIZONA after the late JPL space scientist and Ingenuity advocate Jakob J. van Zyl — while always staying within line-of-sight radio contact with the helicopter.

The rover team also needed to be ready to document the first flight photographically. Several imaging systems on the rover are capable of modest-rate video imaging, including Mastcam-Z. Justin and I had talked many times in the years leading up to launch and arrival about the possibility that we might capture on video the first powered aircraft flight on another world. "How crazy cool would that be?" we both thought.

WRIGHT BROTHERS MEMENTO
In anticipation of Ingenuity's historic aviation achievement, NASA arranged for a small piece of cloth from the original *Wright Flyer* to be attached to the underside of the Martian helicopter's solar panel.

Our roughly 50-person team practiced taking movies several times by imaging Ingenuity's blade release and spin tests shortly after deployment, as well as some longer-distance practice sessions from Van Zyl Overlook prior to the first flight. But despite the practice and the checking and double-checking, we were still nervous when it came time for flight #1. Did we point and focus the cameras correctly? Did we coordinate the timing properly with the heli team for the start of the flight and the start of the movie? (Remember, all the commands have to be beamed to Mars in advance.) Could we really fit the thousands of video frames in the camera memory and downlink them back to Earth in a reasonable amount of time?

Finally, on April 19, 2021, the 58th sol of Perseverance's mission, Ingenuity was ready to fly, and the rover team was ready to support and document the flight. It was programmed to be a simple flight: spin up the rotors, takeoff and hover at a height of 3 meters (9 feet) above the ground, rotate the fuselage by 96°, and then descend to a gentle landing.

And it worked! Total flight time was about 39 seconds, and Mastcam-Z's two cameras captured it beautifully in both wide-angle and full-telephoto-resolution videos.

The helicopter team had finally realized its dream. "When we saw the altimeter data confirming our successful first flight," MiMi told me by email, "that was truly the first time that our team actually celebrated fully and 100%!!!"

▲ **SUCCESS!** Team members rejoice after receiving confirmation of Ingenuity's first flight.

Bird's-Eye View

Ingenuity's total flight time was about three times longer than Orville Wright's first crewed, powered airplane flight at Kitty Hawk almost 118 years earlier. To commemorate the achievement, NASA named Ingenuity's airfield in Jezero "Wright Brothers Field." The International Civil Aviation Organization (ICAO) even gave the airfield the ceremonial designation JZRO and the helicopter the official ICAO designator IGY, call sign INGENUITY.

Ingenuity undertook five tech demo flights. The remaining four flights, each more complex than the last, were conducted successfully between April 22 and May 7, 2021. Each was also successfully documented on video by the Mastcam-Z team, along with numerous still photos and time-lapse movies that Ingenuity took with its own cameras. Some of the videos also show Martian dust devils lazily drifting among the background hills, and flights #4 and #5 (and later, #13) show the best examples of how Ingenuity can create its own sort of dust devil, as the blade wash picks up and sweeps dust along its path above the ground. Each flight provided images and detailed engineering data on the helicopter's height and distance, and the videos document the way the vehicle sometimes had to fight the wind to maintain its stability. It was a real thrill for our team to be part of aviation and film history!

Flights #4 and #5 also have a sound track. Justin had heard the barely audible sounds of the test flights in the thin air of JPL's simulation chamber, but it wasn't obvious that we'd actually hear Ingenuity on Mars when Perseverance was hundreds of meters away. Yet once the SuperCam team filtered out the background sounds of wind from the microphone data, the faint, super-low-frequency *thrummmm* of Ingenuity taking off and flying is indeed audible in the videos.

After completing its tech-demo flights, Ingenuity transitioned into a new, extended mission called the *operations demonstration phase*, which is designed to show how an aerial scout vehicle might enhance the rover's science and driving objectives. Most of these flights have only been documented by the helicopter's own telemetry and images, as Ingenuity has often been too far away from the rover to resolve well, even using Mastcam-Z.

As of the end of Perseverance's first year on Mars, Ingenuity had completed 20 flights, including its longest-distance flight (#9) on July 5, 2021, during which it traveled 625 meters across a dune-filled region called Séítah (Navajo for "amidst the sand") to document an area that the rover could not travel across. Many of these flights have contributed significantly to Mars 2020 mission science, partly because Ingenuity's 13-megapixel color camera can easily resolve

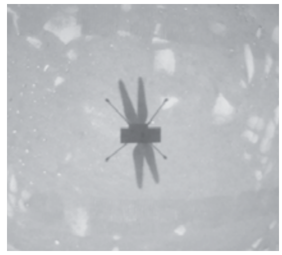
NASA / JPL-CALTECH

small rocks and other landforms that are both too far away for the rover to see well and too small to be seen at all in orbital images.

For example, helicopter images (and 3D topography derived from those images) over the south Séítah region helped rover drivers carefully plan a route for Perseverance a little ways in to what had previously been thought to be completely untraversable sandy terrain. Scientific analysis of the images also helped the team to identify two compelling outcrops in Séítah where the rover later collected samples, and to forgo collecting samples from another candidate site where the outcrop turned out to be much less exposed than planners had thought based on orbital and rover images. Many of these images have also been used to extend the rover's measurements of the tilts of the layered rocks that appear to form a boundary between Séítah and the rest of the nearby crater floor.

On one of the flights into Séítah, Ingenuity actually landed right on top of an ancient sand wave. The helicopter's measurements of the feature's unexpectedly low height, gentle slope, and pebbly surface revealed that it is a kind of wind-blown sand deposit known as a *megaripple*. A megaripple is potentially older than other kinds of sand deposits and could tell us something about ancient winds, because its larger grains make it harder for modern winds to erode and move it.

In a sense, and perhaps surprisingly given the helicopter's relatively short, 30-sol planned mission, Ingenuity has already answered Bob Balaram's original question: What science could you do with a helicopter on Mars? Lots, it turns out. And we are likely only at the beginning of this robot partnership, for NASA has extended Ingenuity's mission through at least September 2022, and the helicopter shows no signs of aging besides some dust.



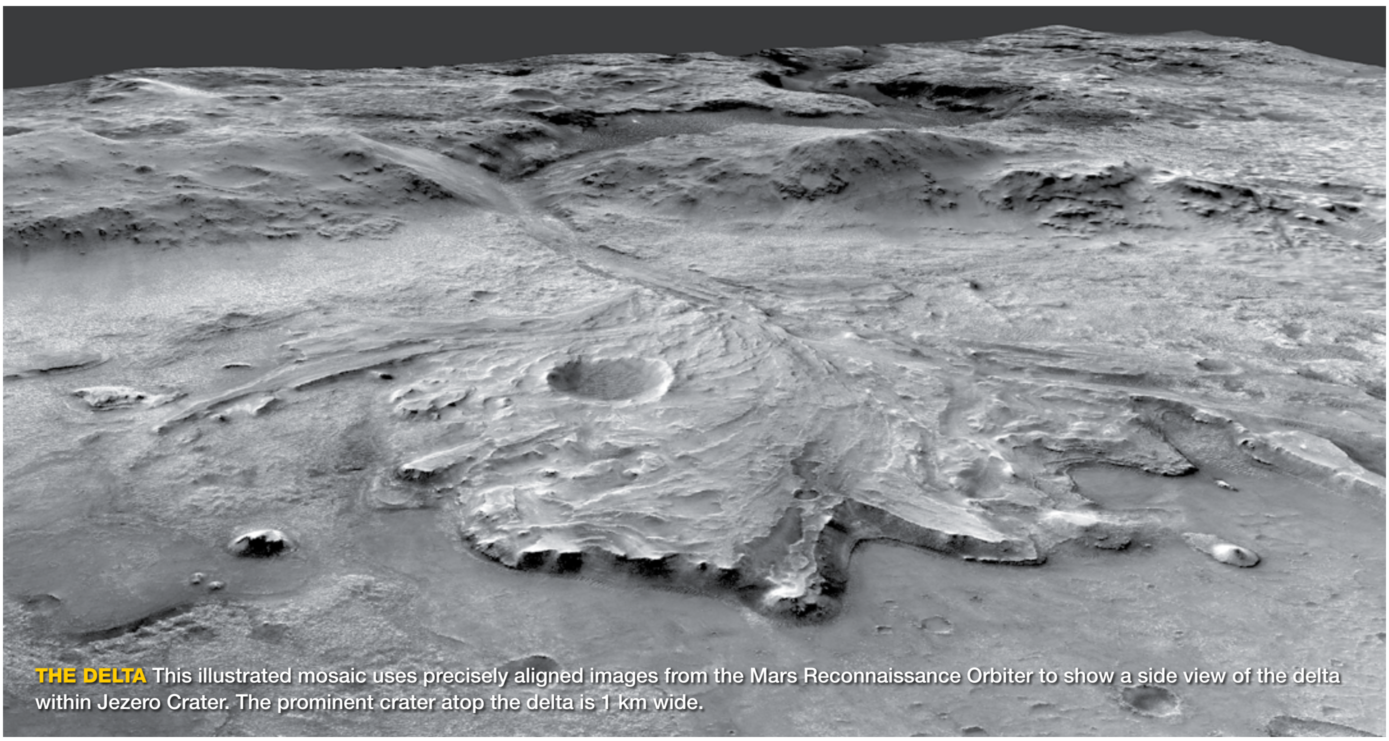
▶ **SHADOW SELFIE** Ingenuity's downward-pointed navigation camera took this image during the helicopter's second flight.

Perseverance and Ingenuity have now arrived at the mission's prime target, Jezero's famous fan-shaped delta. Formed by an ancient river, the delta's cliffs loom 40 meters above the crater floor. Its layered sediments could include lithified mud deposits, which have the potential to preserve ancient evidence for habitable environments and life.

The delta traverse will be filled with boulders, sand traps, and rugged terrain. The first Martian helicopter will have its work cut out for it, helping the rover navigate its way up a river channel. But gone are the days of "not yet, not yet" — Ingenuity's moment has come.

■ *S&T* Contributing Editor **JIM BELL** is a professor and planetary scientist in Arizona State University's School of Earth & Space Exploration. He has been a member of the science teams on every NASA Mars rover mission and two orbiter missions. He has also written nine popular science books, including *Discovering Mars* (2021), coauthored with science historian and *S&T* Contributing Editor William Sheehan.

Follow Ingenuity updates with the team's blog: https://is.gd/helicopterstatus. See Mastcam-Z's Ingenuity flight movies at https://is.gd/helicoptervideos.



THE DELTA This illustrated mosaic uses precisely aligned images from the Mars Reconnaissance Orbiter to show a side view of the delta within Jezero Crater. The prominent crater atop the delta is 1 km wide.

HELICOPTER SHADOW: NASA / JPL-CALTECH; VISUALIZATION OF DELTA: NASA / JPL-CALTECH / USGS


Vulpecula
Tropicus
Cerberus
et
Ramus
Hercules
TAURUS
PONIATOVII
OPHIUCHUS
QUILA
INOUS
Aequator
SCUTUM
SOBIESII
Sagittarius
Lactea
Ecliptica
Tropicus

A Visit to Taurus Poniatovii

The constellation may be no longer, but that shouldn't stop you from exploring its many lovely sights.

When I first learned the summer constellations as a young stargazer in the mid-1970s, a striking little group of stars caught my eye, and it has enthralled me ever since. Located southeast of Hercules and just north of the celestial equator, this collection looked to me like a small horned beast — a little celestial bull perhaps — charging eastward toward the dust lanes and clouds of the Milky Way. Was it a bright star cluster or a small constellation, I wondered? My *Norton's Star Atlas* (16th edition) showed these stars as a small, unnamed outcropping of Ophiuchus. So did my copy of H. A. Rey's *Find the Constellations*, which depicted them as the eastern shoulder and arm of Ophiuchus entangled with the Serpent's Tail, Serpens Cauda. Not much to see here, it seemed.

I eventually learned that these stars were indeed once a distinct — and now defunct — constellation called Taurus Poniatovii, or Poniatowski's Bull. In 1777, Marcin Poczobutt, director of the royal observatory at Vilna (today's Vilnius, in Lithuania), named it after Stanisław August Poniatowski, King of Poland and Grand Duke of Lithuania from 1764 to 1795. Poczobutt cataloged 16 stars, and Jean Fortin included them in 1778 in his *Atlas céleste de Flamstéed* as *Taureau Royal de Poniatowski*. Johann Elert Bode added many fainter stars to the asterism in his 1801 atlas *Uranographia*. As one of the few constellations named for 18th-century political figures — and a patently awkward little construct — it fell into disuse by the late 19th century. The name remains, though, to describe what currently is an asterism entirely within Ophiuchus.

But it's nevertheless a pretty little group, one I return to every summer. The fourth-magnitude stars 67, 68, and 70 Ophiuchi form the V-shaped head of the bull, while 5th-magnitude 66 Ophiuchi and the variable 73 Ophiuchi serve as the tips of a pair of little horns. The two stars at the hind end of the little bull are 3rd- and 4th-magnitude Beta (β) Ophiuchi (or Cebalrai) and Gamma (γ) Ophiuchi, respec-

◀ **REGAL CELESTIAL BULL** Named in honor of the reigning monarch of Poland and Lithuania in the second half of the 18th century, Taurus Poniatovii was a constellation in its own right for more than a century. The German astronomer Johann Bode was among several celestial cartographers to include the constellation in their atlases.

JOHANN ELERT BODE / PUBLIC DOMAIN

tively. The entire asterism spans 7°. In binoculars, the field is flecked with fainter 9th- and 10th-magnitude stars, especially around the head, which dips into the edge of the Milky Way (see, e.g., *S&T:* Aug. 2013, p. 45). Taurus Poniatovii also makes for a good base of operations to check in on nearly every category of deep-sky sight in this small patch of sky.

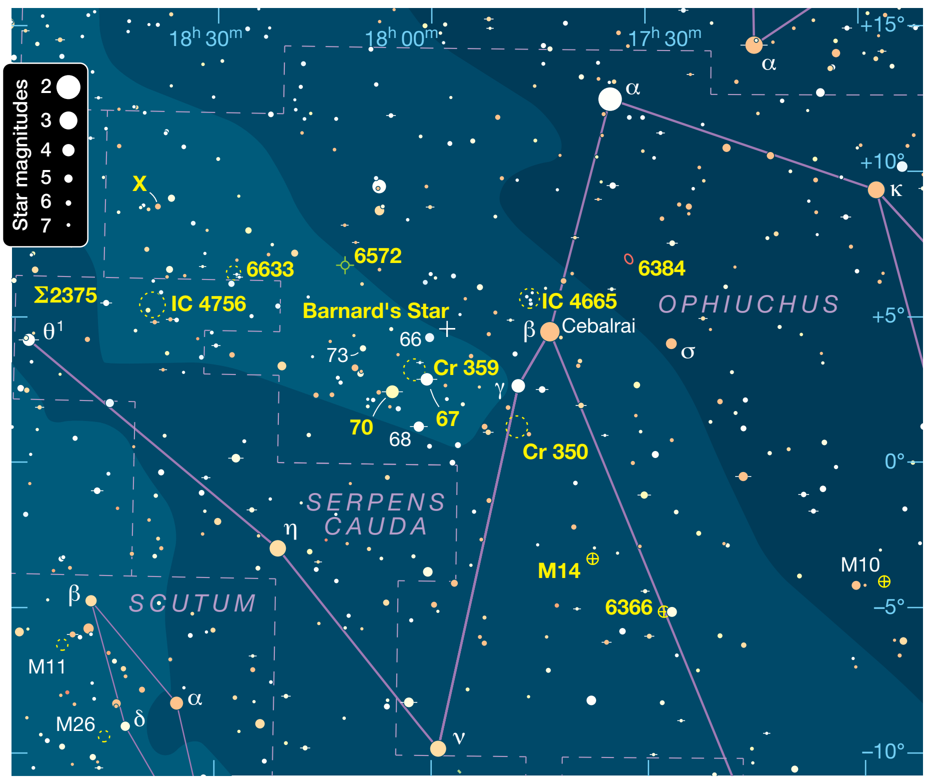
Young Star Clusters with a Common Origin

My youthful and untutored suspicion that the stars listed above form a cluster was only slightly off. There *is* an open star cluster here but, except for 67 Ophiuchi, the naked-eye stars of Taurus Poniatovii are not part of it. Cataloged as **Collinder 359** (and Melotte 186), the cluster appears as a loose and unconcentrated collection of stars spanning about 4° around the head of the little bull. It's ideal for binocular observing, and my 12×36 image-stabilized binoculars reveal perhaps two dozen mostly blue-white stars, though it's hard to tell at a glance which are true cluster members. A study published in 2006 using data from the 3.6-meter Canada-France-Hawaii Telescope (CFHT) identifies some 500 cluster members with the relatively young ages of 40 to 80 million years, assuming an average distance of about 1,470 light-years. The research suggests that these stars did form together, but it's unclear whether they remain gravitationally bound or if they have since dispersed into a loosely associated moving group, like the Big Dipper.

The blue supergiant **67 Ophiuchi**, the anchor of Collinder 359, is a fine double star that easily splits — even in a pair of binoculars — into two blue-white components of magnitudes 4.0 and 8.1, separated by a wide 55″. A second line-of-sight component of magnitude 13.7 lies 6.6″ from the bright primary and presents a challenge for observers with 12-inch telescopes.

The CFHT study of Collinder 359 also suggests that the cluster may have a common origin with the adjacent and more concentrated open cluster **IC 4665**. Located 1.3° northeast of Cebalrai and about 4.5° from the center of Collinder 359, this dazzling collection of stars ranks as one of the best in the northern sky for binoculars or wide-field telescopes. It shines at magnitude 4.7, but with a diameter of 70′ its low surface brightness renders it barely visible without optics even under a dark sky. In my 12×36s I see perhaps a dozen stars, while my 100-mm binocular telescope at 23× shows a stunning vista of 50 to 60 uniformly blue-white stars arrayed in intertwined arcs. Given the cluster's relative youth, few of its stars have evolved into red giants. If your scope's field is inverted, look carefully at the inner stars of IC 4665 — after a time, you may see they form the word "HI" like a friendly cosmic greeting.

Make a quick stop about 1.5° south of Gamma Ophiuchi to peek at **Collinder 350**, which lies at a distance of 1,200 light-years. While nowhere near as rich as IC 4665, this ancient open cluster (pegged at 590 million years) appears sparse but appealing at 23× in my 100-mm binoscope. I see about 30 stars of magnitudes 9 to 11 spread over 40′ splayed out from the middle of the cluster in four spidery arms.



▲ **THE LITTLE CELESTIAL BULL** Explore deep-sky targets that today are in Ophiuchus and Serpens Cauda but that once were in Taurus Poniatovii.

A Pair of Speedy Nearby Stars

Now let's head to **70 Ophiuchi**, one of the three bright stars in the face of the little bull. At a distance of 16.6 light-years, 70 Ophiuchi ranks as one of the closest stars to Earth visible to the naked eye. It's also a beautiful double star with a yellow-orange primary of magnitude 4.2 and a red-orange secondary of magnitude 6.2. The star splits easily in an 80-mm telescope at about 80×.

The components of 70 Ophiuchi revolve around their common center of mass in a highly elliptical orbit every 88 years. On astronomical scales, this is speedy, which adds to the appeal of this little system. In 1984, when they were most recently closest, 2.3″ separated the stars; by 2028, that distance will increase to 6.7″. You could take advantage of 70 Ophiuchi's orbital motion to carefully record the changing position and separation of these stars over several years. The components make a full revolution over the

▲ **COSMIC GREETING** If southwest is up in your scope, you might see the sight of the stars of IC 4665 arrayed in a friendly celestial "HI." Don't give up if you don't see it at first — it's well worth the wait once you finally discern the pattern. Turn the page upside down to see it better in the image.

STEFAN BINNEWIES / JOSEF PÖPSEL

course of an average human lifetime and half a turn over the career of a dedicated stargazer. Astronomers established the masses of the primary and secondary as 0.9 and 0.7 solar masses, respectively. Since 1939, 70 Ophiuchi has served as a template to determine the masses of other, more distant stars based on their spectral types.

Taurus Poniatovii offers another target for a long-term observing project: **Barnard's Star**. This red dwarf features the largest proper motion of any star, about 10.4″ per year almost due north (see *S&T:* June 2022, p. 34). With an age perhaps twice that of our solar system, Barnard's Star lies just 6 light-years away (5.96 light-years, in fact) making it the closest star to Earth north of the celestial equator. Since E. E. Barnard first measured its proper motion in 1916, the star has traversed more than half a Moon diameter across the sky. You can easily record the star's motion against the background stars from year to year with carefully rendered sketches or with a sequence of images.

While intriguing, Barnard's Star gets no points for beauty. It's a dim-bulb red dwarf of magnitude 9.5 with an intrinsic brightness about 1⁄2500 that of our Sun and a mass just 16% as large. But as a near neighbor, this swift little star remains worthy of frequent observation. More aperture shows more color, but I can barely detect its red-orange hue with my binoscope in suburban skies.

A Summer "Double Cluster"

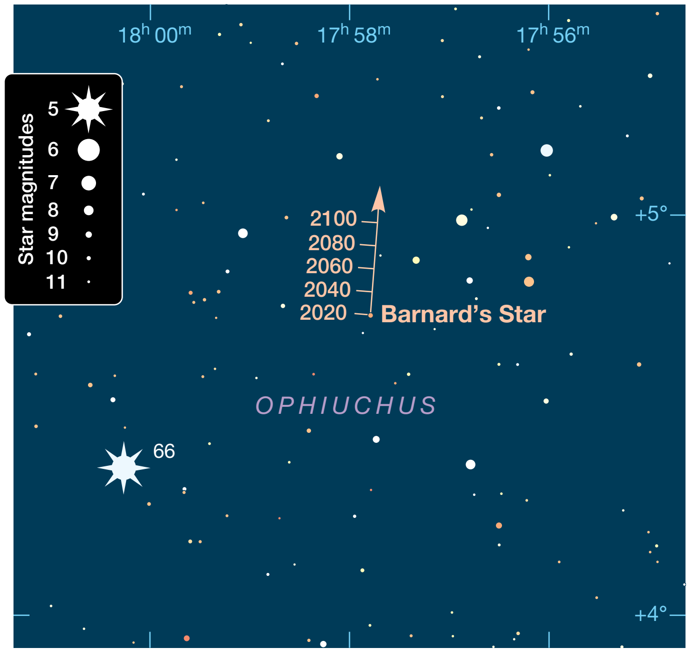
Wandering about 8° east-northeast of the approximate center of Taurus Poniatovii brings you to the superb open star clusters **IC 4756** and **NGC 6633**. Former *Sky & Telescope* editor Stephen James O'Meara dubbed them the Tweedledee and Tweedledum clusters, respectively. Others call the pair the

Ophiuchus Double Cluster, even if IC 4756 lies just over the boundary in Serpens Cauda.

IC 4756 spans 40′ and makes an excellent cluster for wide-field instruments and binoculars. You can easily see a lovely patch of some 80 to 90 stars set in a rich background. Although it's a bright magnitude 4.6, early telescopic stargazers such as Charles Messier, Jean-Philippe Loys de Cheseaux, and William Herschel missed it, likely because their narrow-field telescopes failed to discern the cluster's appearance. Even my old *Norton's Star Atlas* omits this sprawling star cluster, though it does show NGC 6633. Although IC 4756 is nearly lost in a rich portion of the Milky Way, it's a sparkling, ancient cluster, more than 600 million years old, with many aged, red-orange stars. In my binoscope at 42× with a 1.5° field of view, I see a loose collection of colorful stars slightly stretched in the east-to-west direction, arrayed in all types of shapes and patterns.

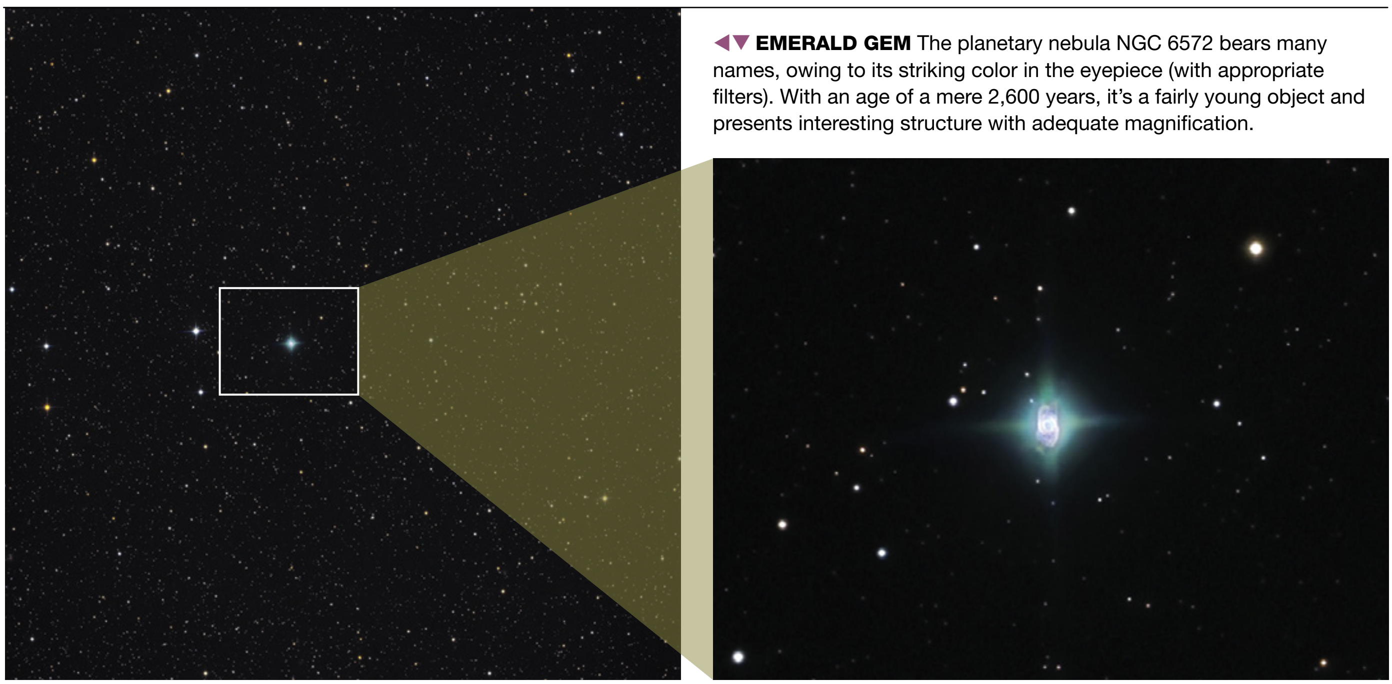
Scan about 1.7° east of IC 4756 to look for the fairly tight double star **Struve 2375**. Both components are whitish, one of magnitude 6.3 and the other of 6.7, with a separation of 2.6″. With my 10-inch Dobsonian I can just split them at 133× on a night of steady seeing. Each component is itself a very closely spaced pair, too close to be resolved directly in a backyard telescope.

Just 3° northwest of IC 4756, NGC 6633 appears about half as large, making it easier to discern from the rich background. In my binoscope at 23×, I see about 30 stars arranged in a thick bar extending northeast to southwest with a dozen more stars sprinkled outside this structure. The two clusters are about the same age and at comparable distances from us, so NGC 6633 is truly smaller in size. It spans about 7 light-years compared with IC 4756's 18 light-years. What NGC 6633 lacks in size it makes up for in sheer beauty. I see many patterns among these stars, including an obvious hook shape arcing eastward from the center of the cluster and ending at a bright 6th-magnitude star to the south.



▲ **STAR ON THE RUN** Barnard's Star will cover a distance of around 17′ in the next 100 years or so. Check in on it from time to time and you might start noticing differences in its position.

Variable-star enthusiasts can look about 3.5° north of IC 4756 to see **X Ophiuchi** at the vertex of an equilateral triangle formed with this cluster and NGC 6633. This star is a reddish Mira-type variable, one of the few such variables in a binary system. Its components are too close to split in amateur telescopes, but the non-variable companion serves to prop up the system's overall brightness when the



◀▼ **EMERALD GEM** The planetary nebula NGC 6572 bears many names, owing to its striking color in the eyepiece (with appropriate filters). With an age of a mere 2,600 years, it's a fairly young object and presents interesting structure with adequate magnification.

STEFAN BINNEWIES / JOSEF PÖPSEL (2)

JIM THOMMES (2)

▲ **TWEEDLEDEE AND TWEEDLEDUM** IC 4756 (top) and NGC 6633 make for a pretty pair of open clusters. The field of view for IC 4756 is 100′ while for NGC 6633 it's 60′. Foreground stars pepper both images, making it somewhat tough to identify cluster members.

primary fades to minimum every 338 days. Mira variables can brighten (or dim) by eight or nine magnitudes over their cycle, but X Ophiuchi only fades from magnitude 5.9 to 8.6. Also, Mira variables tend to get redder as they reach minimum brightness, but X Ophiuchi takes on the orange color of its fainter companion star as the primary fades.

Power Up and Go Deep

Let's increase the magnification and examine a few smaller deep-sky sights around Taurus Poniatovii, beginning with the planetary nebula **NGC 6572**. Sometimes called the Blue Racquetball or Emerald Nebula, this gemlike planetary exhibits intense blue-green color from doubly ionized oxygen atoms excited by the nebula's hot central star. The nebula lies twice as distant as the more famous Ring Nebula (M57) but shines almost twice as bright and covers 25 times less area. Because its brightness is squeezed into a 15″ disk, it's easy to spot. Resolving that tiny disk is another matter: The planetary appears starlike at low magnification but acquires some size above 70×. At 92× in my 10-inch Dob, I see a tiny but elongated glow. A wee hint of structure emerges at 184×. Like many small planetaries, NGC 6572 takes as much magnification as sky conditions allow. But unlike other planetaries, NGC 6572 has no outer halo and remains optically dense due to its relative youth. Most planetary nebulae last a few tens of thousands of years, but the Emerald Nebula formed from the last gasps of a dying star maybe around 2,600 years ago, making it just slightly younger than the city of Rome.

And what's this — a galaxy in Ophiuchus? Sure enough, just 3.7° northwest of Cebalrai lies the lovely barred spiral **NGC 6384**. Or at least it's lovely in Hubble Space Telescope images, where it displays stately spiral arms and intricate dusty tendrils and clots of new blue-white stars. To backyard telescopic observers, this 10th-magnitude galaxy presents a more modest sight. It spans about 6′ × 4′, and in my 10-inch Dob at 133× and 184× it appears as a featureless oval that's obviously brighter — though not stellar — towards the core.

▲ **BARRED BEAUTY** NGC 6384 poses elegantly at a distance of some 90 million light-years in Ophiuchus. Research suggests that the bar channels gas from the outer edges of the galaxy into the center, where it forms new stars. This image was obtained with a 24-inch telescope.

Deep-sky Sights of Taurus Poniatovii

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Collinder 359	Open cluster	3.0	4°	$18^h\ 01.1^m$	+02° 54′
67 Ophiuchi	Double star	4.0, 8.1	55″	$18^h\ 00.6^m$	+02° 56′
IC 4665	Open cluster	4.2	70′	$17^h\ 46.2^m$	+05° 43′
Collinder 350	Open cluster	6.1	40′	$17^h\ 48.2^m$	+01° 18′
70 Ophiuchi	Double star	4.2, 6.2	2.3″ – 6.7″	$18^h\ 05.5^m$	+02° 30′
Barnard's Star	Red dwarf	9.5	—	$17^h\ 57.8^m$	+04° 42′
IC 4756	Open cluster	4.6	40′	$18^h\ 38.9^m$	+05° 26′
NGC 6633	Open cluster	4.6	20′	$18^h\ 27.3^m$	+06° 30′
Struve 2375	Double star	6.3, 6.7	2.6″	$18^h\ 45.5^m$	+05° 30′
X Ophiuchi	Variable star	5.9–8.6	—	$18^h\ 38.4^m$	+08° 50′
NGC 6572	Planetary nebula	8.1	15″	$18^h\ 12.1^m$	+06° 51′
NGC 6384	Barred spiral	10.4	6.2′ × 4.1′	$17^h\ 32.4^m$	+07° 04′
M14	Globular cluster	7.6	11′	$17^h\ 37.6^m$	–03° 15′
NGC 6366	Globular cluster	9.5	13′	$17^h\ 27.7^m$	–05° 05′

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.

▲ **SPARSE CLUSTER** Metal-rich NGC 6366 is classified as a globular, but it's of very weak central concentration, giving it its raggedy appearance. But don't overlook it — you'll find it about ¼° east of 4.5-magnitude 47 Ophiuchi, the bright star in the image above.

RON BRECHER

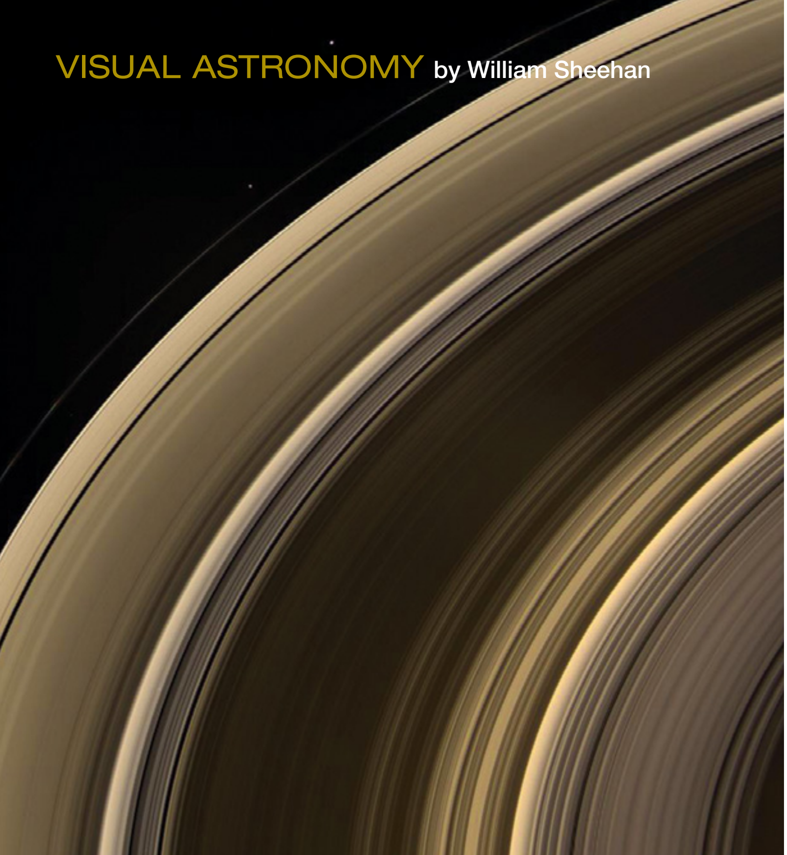
You might be tempted to pass this one over. But it's unusual to see even a modest galaxy so near the Milky Way. That position means the field is attractively peppered with foreground stars — something that's definitely worth a look.

Ophiuchus is best known to deep-sky observers for its harvest of globular clusters. Most notable are M10 and M12, which lie about 18° southwest of Taurus Poniatovii. But closer to the asterism are two globulars of note. **M14** sits about 6.5° southwest of Gamma Ophiuchi, in a sparse field that's striking for the absence of stars brighter than 10th magnitude thanks to dust clouds that obscure the background stars and the cluster itself. M14 is about 30,000 light-years away, making it twice as distant as M10 and M12. At magnitude 7.6, it's also fainter. But M14 is *intrinsically* brighter than both, and it even outshines M13 in Hercules. Through the telescope, though, M14 isn't quite as spectacular. In my 10-inch Dob at 133× I see a granular halo about 6′ across and a round, uniform core about half as wide. The entire cluster spans around 11′ in total.

Slew roughly 3° southwest of M14 to find the more challenging globular **NGC 6366**, some 15′ east of the yellow-white, 4.5-magnitude star 47 Ophiuchi. This little cluster measures about 13′ across, making it bigger than M14, but it's nearly two magnitudes fainter despite a distance of just 11,000 light-years. The globular features a low surface brightness and weak central concentration. In the 10-inch at 184× I see only a uniform glow with hints of granularity.

And with that, our tour of Taurus Poniatovii ends. We've seen a pleasing selection of deep-sky objects — a good haul for a patch of sky not much wider than your hand held at arm's length. This little celestial bull serves one more purpose, at least for me. Just as the Pleiades and Hyades hint at a coming winter when they rise in the east on summer mornings, a first glimpse of Taurus Poniatovii ascending hind-end first, swollen by perspective over the horizon in the predawn sky during the frigid weeks in January, gives hope for a summer yet to come. And as the summer nights arrive at last, I never miss a chance to revisit the deep-sky sights in this part of the sky.

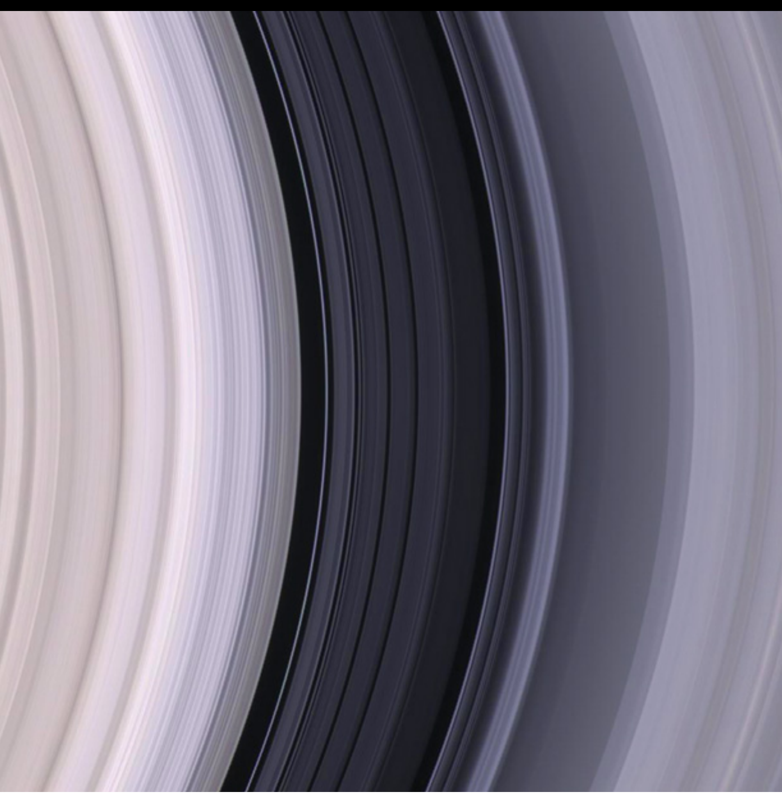
■ **BRIAN VENTRUDO** is a Calgary-based writer, scientist, and longtime amateur astronomer. Ventrudo writes about astronomy and stargazing at his website **CosmicPursuits.com**.



In 1850, Harvard College Observatory astronomers William Cranch Bond and his son George Philips Bond discovered a new inner ring of Saturn. The feature was subsequently designated ring C, and British astronomer William Lassell dubbed it the *crepe ring*. The Bonds used the 15-inch refractor at Harvard for their discovery, while William Rutter Dawes in England employed a 6⅓-inch refractor when he independently discovered the ring in 1850. Subsequently, observers found it quite easy to verify the diaphanous ring's existence — Thomas William Webb even glimpsed traces of it in a 3.7-inch refractor. But if it was this easy to see, how could it have escaped detection for so long? Had it, as Webb suggested, somehow grown more luminous over time?

Webb's idea never seemed very plausible, given the magnitude of change that would have been necessary to have such a striking impact on the crepe ring's visibility. One explanation attributes the feature's apparently sudden appearance to a psychological effect called *directed attention* (what might now be called *expectation bias*). Dawes himself hinted at the possibility in a letter describing a visit by his friend Lassell, who possessed a fine 24-inch equatorial reflector:

Seeing Saturn's Ri



> *On December 2 [1850] Mr. Lassell came to see me . . . and the next night, the 3rd, being fine, I prepared to show him this novelty, which I had told him of and explained by my picture; but naturally enough, he was quite indisposed to believe it could be anything he had not seen in his far more powerful telescope. However, being thus prepared to look for it, and the observatory being darkened to give every advantage on such an object, he was able to make it all out in a few minutes . . .*

Other examples of directed attention affecting the perception of fine detail in the rings would multiply in subsequent years.

Early astronomers thought Saturn's rings were solid because they looked so in telescopes. But the famous French mathematician Pierre-Simon Laplace showed that could only be possible if the rings were eccentrically placed relative to the planet — a precarious and unstable arrangement that would always be on the threshold of collapsing into chaos.

◀ **RINGED WONDER** Without doubt, Saturn and its magnificent rings are one of the telescopic wonders of the universe, and among the first targets for beginning observers. The rings have been objects of study for centuries, starting with Galileo all the way to modern robotic satellites such as the Cassini orbiter, which recorded these views.

NASA / JPL / SPACE SCIENCE INSTITUTE (2)

As the idea of solid rings fell out of favor, the apparent translucency of the new C ring led to a brief heyday for fluid rings, an idea the younger Bond promoted. As if on cue, his colleague Charles W. Tuttle confirmed this notion with an extraordinary observation made on October 20, 1851, with the 15-inch Harvard telescope working at a magnifying power of 861×. Tuttle wrote: "The divisions were not unlike a series of waves; the depressions corresponding to the spaces between the rings, while the summits represented the narrow bright rings themselves. The rings and the spaces between were of equal breadth."

Though many observers have noted that the inner part of ring B has a dusky appearance (Dawes and the Jesuit astronomer Angelo Secchi described a series of "step-like concentric bands of shading"), the impression of waves seems to have been an embellishment — the result of expectation bias.

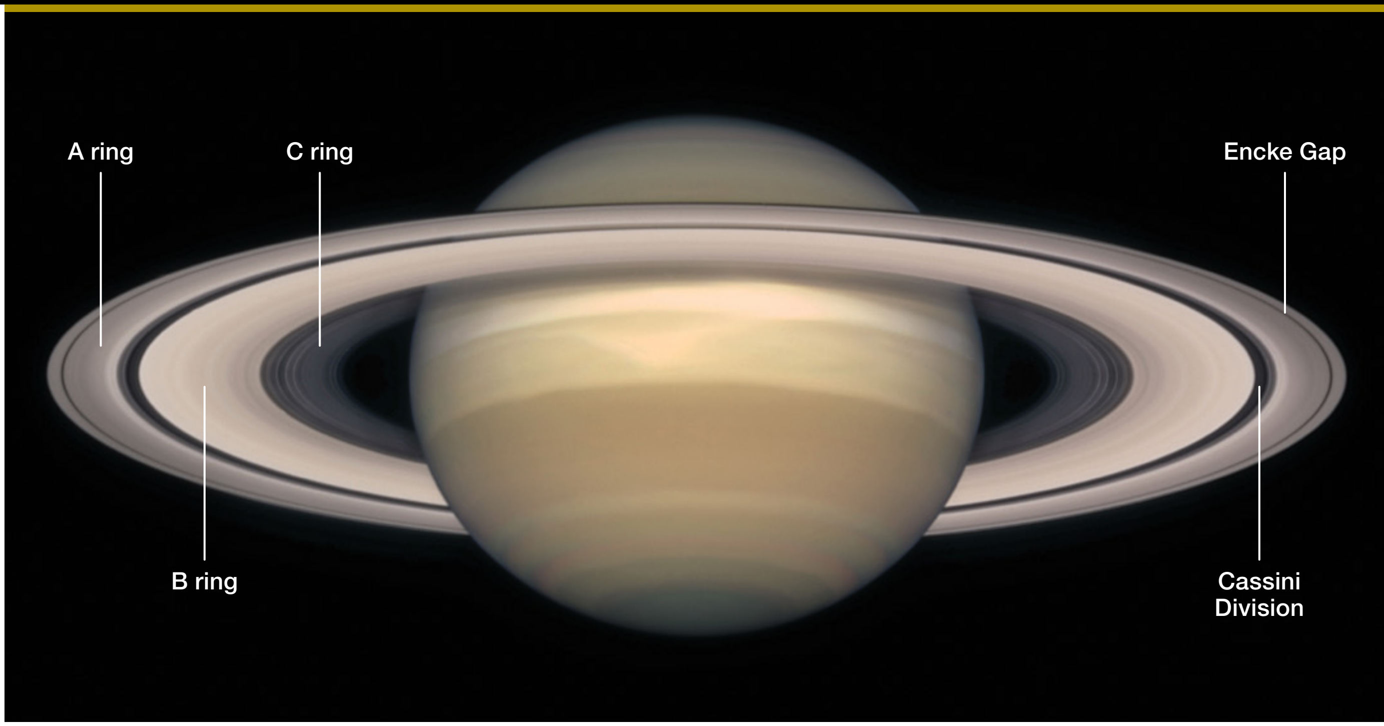
◀ **RING FINDER** The Great Refractor of the Harvard College Observatory, with its 15-inch Merz & Mahler lens, briefly held the distinction of being the largest telescope in the United States. William Cranch Bond and his son George Phillips Bond discovered Saturn's dusky C ring using the instrument.

It was the brilliant Scottish physicist James Clerk Maxwell who showed mathematically that neither solid nor fluid rings could exist, and that the stability of Saturn's rings must be because they consist of minute particles traveling in Keplerian orbits around the planet. Waves were banished and, in their place, orbital resonances involving satellites and ring particles came into favor. The conspicuous Cassini Division corresponds to the strongest orbital resonance, 1:2, with the moon Mimas. Eventually, orbital resonances explained other, narrower ring divisions, too. Everything seemed to fit.

While Maxwell's theory accounted for minor divisions within the rings, no one foresaw the possibility of radial mark-

ng Spokes

Discovering these mysterious features was a 20th-century triumph for 19th-century observing techniques.



▲ **RING-SYSTEM ANATOMY** The main rings and divisions referred to in the text are indicated in this photo. Galileo Galilei was the first to see the rings, in 1610, while the Cassini Division and Encke Gap were both known by the end of the 19th century.

HARVARD 15-INCH REFRACTOR: G.W. PATCH / HARVARD LIBRARY ARCHIVES / PUBLIC DOMAIN; RING DIAGRAM: *S&T* DIAGRAM, BASE IMAGE: NASA / THE HUBBLE HERITAGE TEAM (STSCI / AURA) ings extending across them. Nevertheless, observers noted such features from time to time. In February 1887, Charles Émile Stuyvaert worked with the 15-inch Cooke refractor of the Royal Observatory of Belgium to record radial markings in both the A and B rings. In 1896, legendary observer Eugène Michel Antoniadi used the 9-inch refractor at Camille Flammarion's observatory at Juvisy-sur-Orge, in France, and reported similar markings in the A ring. He had the impression that the ring might be "breaking into fragments."

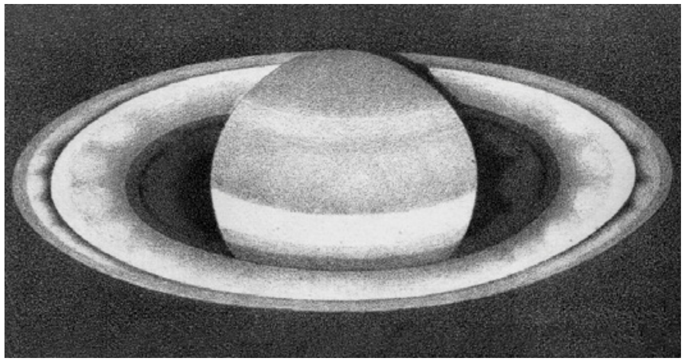
Into the Unexpected

These observations became widely known thanks to Arthur Francis O'Donel Alexander's magisterial 1962 book, *The Planet Saturn: A History of Observation, Theory and Discovery.* However, they were generally dismissed as quaint artifacts from a bygone era of visual planetary observing — much like the famously discredited canals of Mars.

In general, scientists regarded using telescopes to observe planetary detail as passé in an era in which professional astronomers increasingly relied on photography and, ultimately, spacecraft reconnaissance to advance their research. Nevertheless, in the 1970s a few amateurs continued to champion visual planetary observing. The most successful was Stephen James O'Meara.

Inspired by the efforts of the Bonds, Tuttle, and Philip Sidney Coolidge, O'Meara was studying Saturn with the Harvard Observatory's 9-inch refractor (the stuck dome of the more famous 15-inch rendered that instrument inaccessible at the time), when Harvard astronomer Fred Franklin asked if O'Meara would assist in an observing project.

Among the many conundrums of planetary astronomy at the time was the so-called *quadrupole brightness asymmetry* in Saturn's A ring — an azimuthal variation of about 10% in the surface brightness of the ring (*S&T:* July 2021, p. 52). French astronomer Henri Camichel discovered the anomaly in photographs captured at France's Pic du Midi Observatory in 1958.



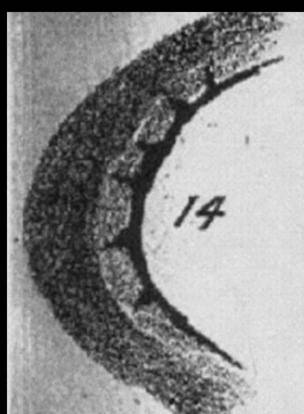
▲ **SUBTLE SHADINGS** One of the most intriguing renderings of Saturn is this one by Émile Stuyvaert, recorded on February 8, 1887, while using the 15-inch refractor of the Royal Observatory of Belgium. It's one of few drawings made in the visual era that shows spokelike markings in the inner part of the B ring — though it also shows them on the inside of the A ring and even in the crepe ring, indicating the features were likely illusory.

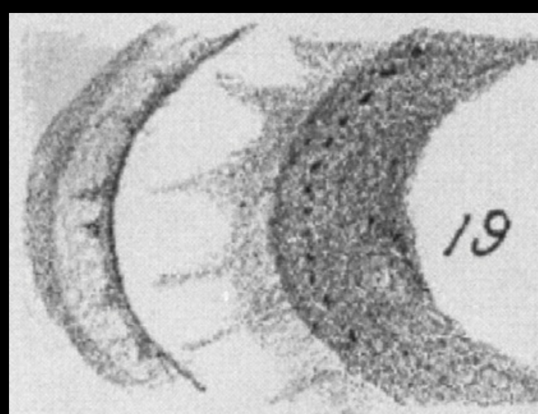
Franklin, a ring specialist, attributed the brightness variations to gravitational interactions (clumping) among the ring particles. In the mid-1970s, while Franklin was overseeing photometric measurements with the 16-inch Boller and Chivens reflector at Harvard's Oak Ridge Observatory, he suggested that O'Meara embark on a simultaneous visual campaign with the 9-inch. Within a month, just before Saturn was lost in conjunction with the Sun, O'Meara succeeded in recording 0.1-magnitude brightness variations in the A ring that agreed with the Oak Ridge photometric studies.

When the project ended, O'Meara began to wonder whether, despite the negative findings of professional astronomers, similar brightness variations might be detected in the B ring as well. So, he returned to the telescope, and on November 13, 1976 — just a few days before his 20th birthday — he spotted faint radial markings that he called "spikes" (now known as "spokes") on the eastern (morning) ansa of the B ring. He detected no such features on the western (evening)

STUYVAERT SKETCH SERIES: WILLIAM SHEEHAN / PUBLIC DOMAIN; STUYVAERT FULL DISK SATURN: THOMAS A. DOBBINS / PUBLIC DOMAIN

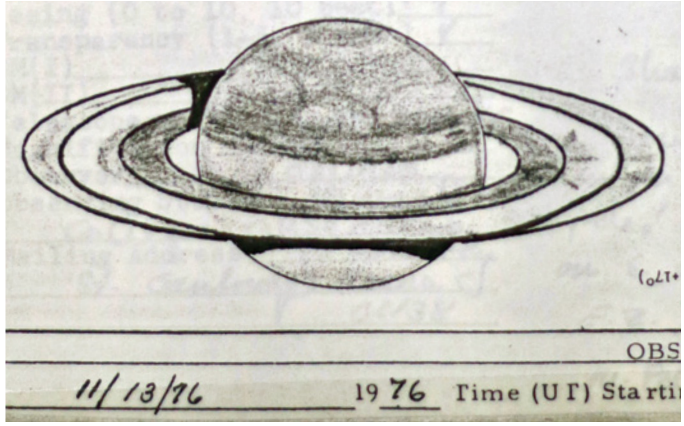
DETAILS REAL AND IMAGINED Saturn is a tantalizing and frustrating object for the observer. In addition to real features, various illusory and optical effects complicate the picture, as shown in these sketches by Belgian astronomer Émile Stuyvaert. His depiction of the B ring spokes might seem credible had he not also included them in the A and C rings.





▶ EAGLE-EYED OBSERVER Stephen James O'Meara stands against a background of the French Pyrenees in this August 1992 photo, when the author and O'Meara were invited to observe with the 1-meter reflector of the Pic du Midi Observatory — a facility renowned for its exceptionally steady seeing.

▶▶ SPOKES LOGGED This never-before-published O'Meara drawing from the Harvard Observatory logbook was made on November 13, 1976. It's one of the first sketches to show the spokes, depicted in ring B, but only on the eastern (right) side.



ansa. The spokes were extremely subtle and almost impossible to render accurately in a drawing. When O'Meara informed Franklin of what he had seen, the latter was supportive but perplexed. According to theory, radial features simply ought not to exist since the differential rotation periods of particles moving in Keplerian orbits would rapidly disrupt them. It followed that the spokes must be illusory.

Continuing his scrutiny of Saturn, O'Meara looked for similar features in ring A but failed to see any. The spokes in ring B, however, persisted, changing in number and shape over time. He submitted his observations to the *Journal of the Association of Lunar & Planetary Observers*, but the Saturn section recorder didn't include them in his annual report. In retrospect O'Meara would say, "I did not find one person, honestly, who ever supported me in this venture."

In August 1980, O'Meara ended his lonely, four-year study when Saturn and its nearly edgewise rings were lost in the solar glare. However, the Voyager 1 spacecraft would soon arrive at Saturn, setting the stage for one of the most unusual episodes in modern planetary science.

Doubting Professionals

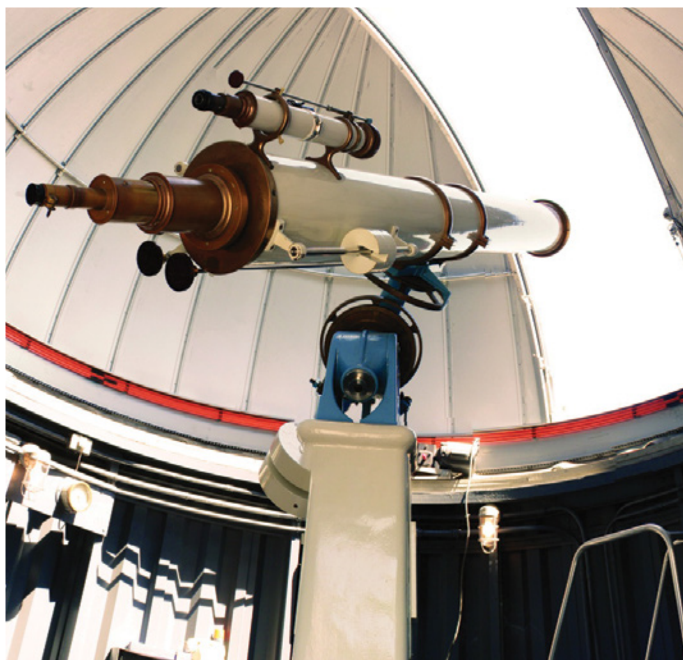
By the time Voyager 1 approached Saturn in November 1980, *Sky & Telescope* had hired O'Meara as editorial assistant. His colleague, Associate Editor Kelly Beatty, regularly presented him with fresh Voyager images, often teasing him with comments like, "I bet you can't see this through your telescope." Just before Beatty left for the Jet Propulsion Laboratory (JPL) in Pasadena to cover the Voyager-Saturn encounter, O'Meara showed Beatty his spoke drawings and said, "When you get out to California, give me a call when Voyager sees these radial markings in Ring B." O'Meara then departed for a vacation in Switzerland.

Famously, Voyager 1 did indeed capture spokes in Saturn's B ring. When the images first appeared on the screen at JPL, Beatty blurted out, "There's a guy in Cambridge who saw these through a 9-inch telescope four years ago." The news traveled quickly around the press room, and about an hour later, astronomer Bradford (Brad) A. Smith, Voyager's imaging team leader and designated "tour guide" for the JPL press conferences, entered the room. Bill Hartmann, a member of the Voyager imaging team, recorded the dramatic scene in his personal journal:

"Brad Smith comes in and asks Beatty about some earlier claim by Beatty that *Sky & Telescope* has found Earth-based telescope observers who recorded dusky near-radial 'spoke' markings in ring B.

"'Who?' Brad asks. 'What observations?'"

In response, Beatty proceeded to pull a copy of Alexander's book on Saturn from his bag, which contained drawings by Antoniadi showing spokelike markings in ring A. Smith, however, remained skeptical, noting that Antoniadi had shown the Encke Division (as it was then known)



▲ CLASSIC GLASS The 9-inch Clark refractor at Harvard College Observatory was used by O'Meara to make the azimuthal intensity observations that led to his discovery of B-ring spokes.

O'MEARA AND SKETCH: WILLIAM SHEEHAN (2); HARVARD 9-INCH: SEAN WALKER / S&T

in ring A in the wrong place, though others had gotten it right. Furthermore, the Voyager spokes were in ring B not A, and Smith remarked, "having them in the wrong ring is a pretty big error."

Smith had other reasons to be skeptical. He was an excellent observer himself and had worked with Clyde Tombaugh for years doing Earth-based planetary imaging at New Mexico State University before being named Voyager imaging team leader. He doubted that anything having such low contrast as the spokes could be seen visually in ground-based telescopes.

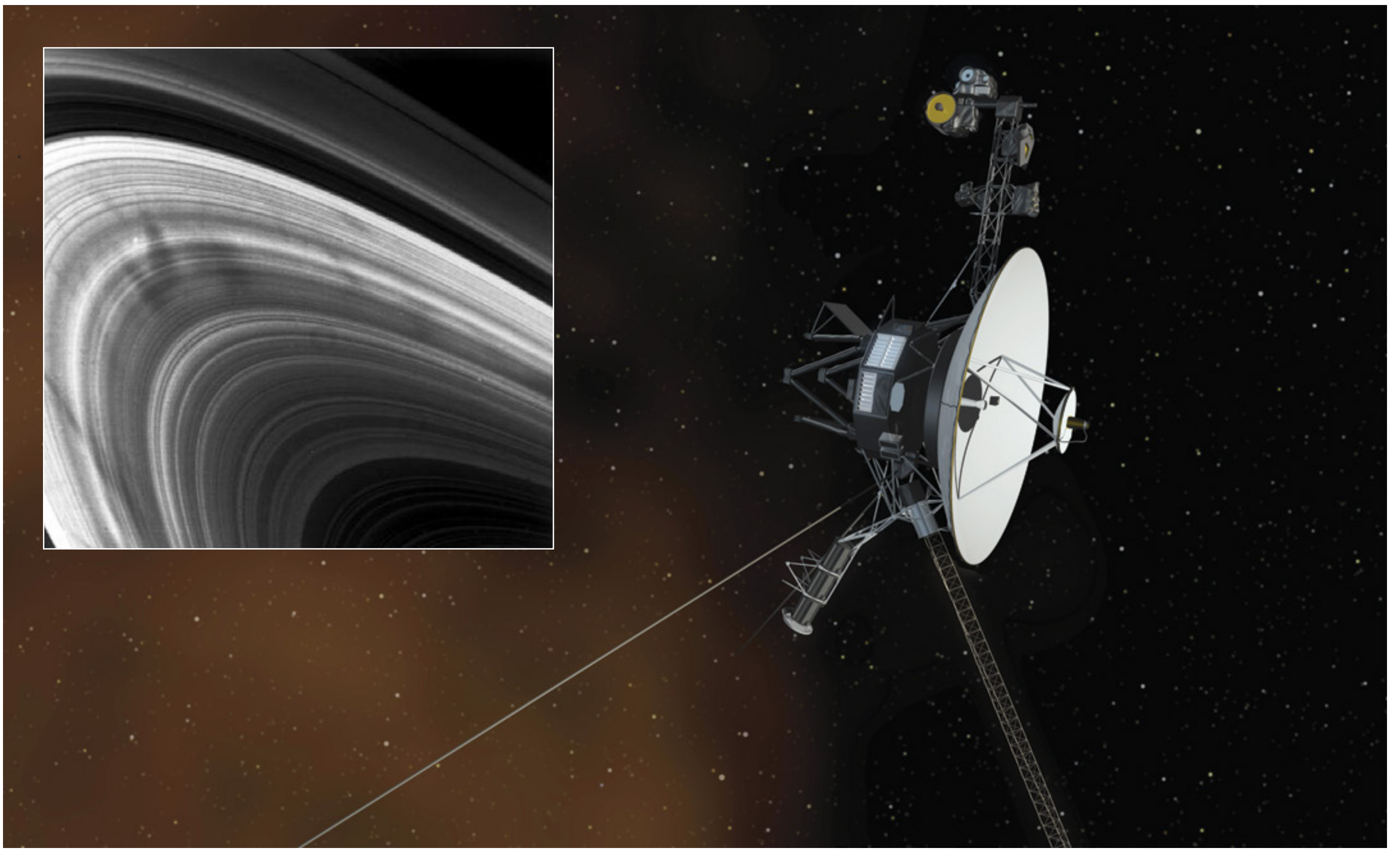
O'Meara, still vacationing in Switzerland, was of course unaware that Voyager had succeeded in imaging the spokes. When he returned to the magazine's offices, he found his drawings of Saturn on his desk where Beatty had placed them next to the Voyager images, along with a note of congratulations. All O'Meara said at the time was, "See, told you so." He then filed his drawings away and returned to work. Later he recalled his true feelings on being vindicated at long last. "What I really felt," he says, "was more like appreciation than elation, because unlike Herschel, the Bonds, and other observers, I got to live to see my observations confirmed by a spacecraft."

Soon afterwards *Sky & Telescope* Editor in Chief Leif Robinson got a call from the infamous tabloid *Weekly World News* asking about the keen-eyed astronomer in their midst. O'Meara suddenly found himself famous (at least by amateur astronomy standards). I was about the same age when I first learned about him in an article in *Discover* magazine and would have given my eye teeth to have made such a discovery. But not everyone had the same reaction. Smith, for instance, confided to me before his death that he never accepted that O'Meara had seen the B-ring spokes. Perhaps the Voyager imaging team leader found it a little embarrassing that his $865-million, high-tech spacecraft had been beaten to an important discovery by a young, keen-eyed observer with a 9-inch telescope.

For his part, O'Meara remained undaunted. He continued his unusual career as a strictly visual observer or, as he put it, a "nineteenth-century observer in the 20th (now 21st) century." Among his later achievements was the discovery of two bright spots on Uranus that led to an accurate determination of the planet's rotational period before Voyager 2 confirmed it in January 1986. Ironically, he did so by following an observing program suggested to him by none other than Smith!

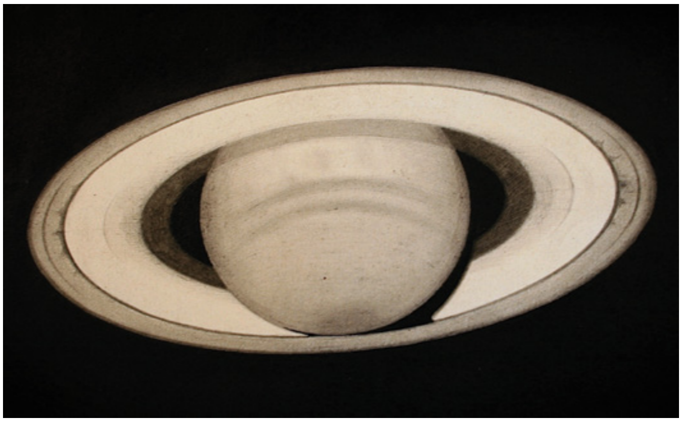
Spokes Come, Spokes Go

In an echo of the C-ring saga, once directed attention kicked in, observers began to regularly record Saturnian



▲ **OUTWARD BOUND** This illustration depicts Voyager 1 leaving the solar system and entering interstellar space in 2013, long after its 1980 encounter with Saturn. *Inset:* Voyager 2 followed its twin to Saturn and captured this high-resolution image of the ring spokes, on August 22, 1981. Even in spacecraft images, these delicate features exhibit very low contrast, which is why they're so challenging to observe with Earth-based telescopes. Remarkably, both Voyagers remain in radio contact today as they continue their epic journeys.

NASA / JPL-CALTECH (2)



▲ **MISSPOKEN TESTIMONY** Famed observer Eugène Michel Antoniadi drew Saturn on July 30, 1899, using the 9½-inch refractor at Camille Flammarion's observatory near Paris. Antoniadi's skill was legendary, but he has placed spokelike features in the A ring not the B ring. A version of this drawing appeared in Arthur Francis O'Donel Alexander's book *The Planet Saturn: A History of Observation, Theory and Discovery*.

▲ **STEADY SATURN** The author's drawing of Saturn made on August 1, 1992, depicts the planet's stunning appearance in the 1-meter Cassegrain at Pic du Midi Observatory. The site's steady seeing allowed productive use of magnifications as high as 1,200×. In addition to subtle spokes in the B ring (seen also by O'Meara), the intense blue hue of the planet's southern hemisphere was striking.

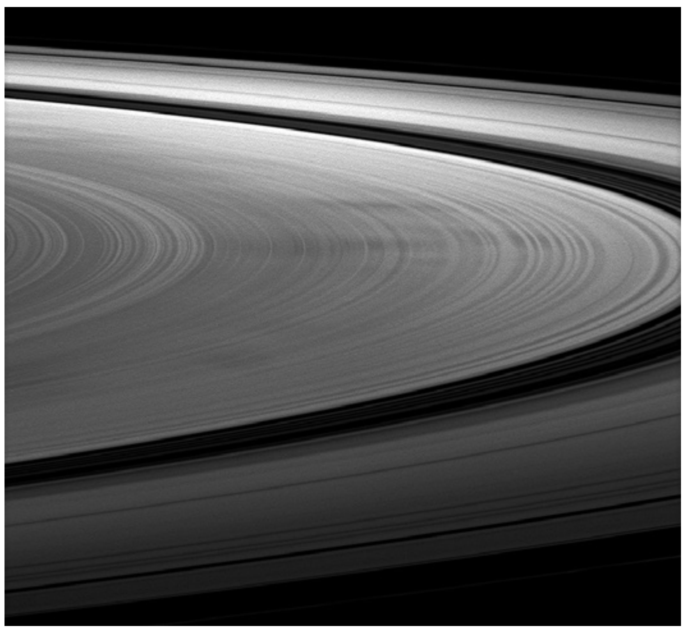
ring spokes. Famed astronomer Clyde Tombaugh, Smith's erstwhile mentor at New Mexico State University, regularly saw them in a 16-inch reflector from his backyard in Las Cruces, New Mexico. The 3.6-meter Canada-France-Hawaii telescope atop Mauna Kea obtained the first Earth-based images in 1996, while master planetary imager Donald C. Parker often recorded them at his home observatory in Coral Gables, Florida.

The Hubble Space Telescope also regularly captured the spokes from 1995 until 1998, when they dropped from sight for several years. Presumably the increasing inclination of the rings rendered them invisible. There was every confidence that the Cassini spacecraft would see the spokes again when it entered orbit around Saturn in 2004. It didn't.

Finally, in 2006, the features reappeared, and a secret regarding their visibility came to light. It seems that the spokes may only form when the Sun's angle over the ring plane is less than 17°. O'Meara's observations between 1976 and 1980, which took place when the Sun was between 3° and 16.5° above the ring plane, backed this up. With this finding in mind, historians reviewed a handful of earlier drawings, such as those by Stuyvaert, in which spokelike markings appear. However, none of the drawings were produced when conditions were right. It seems we still don't know enough about the true nature of the spokes to make definitive statements about their occurrence. Or to rule out the possibility they might also appear in the other rings (especially ring A, as seen by Antoniadi). Nineteenth-century observers may be vindicated yet.

The Sun's angle over the ring plane became less than 17° once again in January this year, though at the time of writing (April 2022) we know of no sightings or images showing the spokes. However, they're expected to become visible by the time Saturn reaches opposition this month. That's when observers have the chance to confirm once again William Herschel's maxim: "When our particular attention is once called to an object, we see things at first sight that would otherwise have escaped our notice."

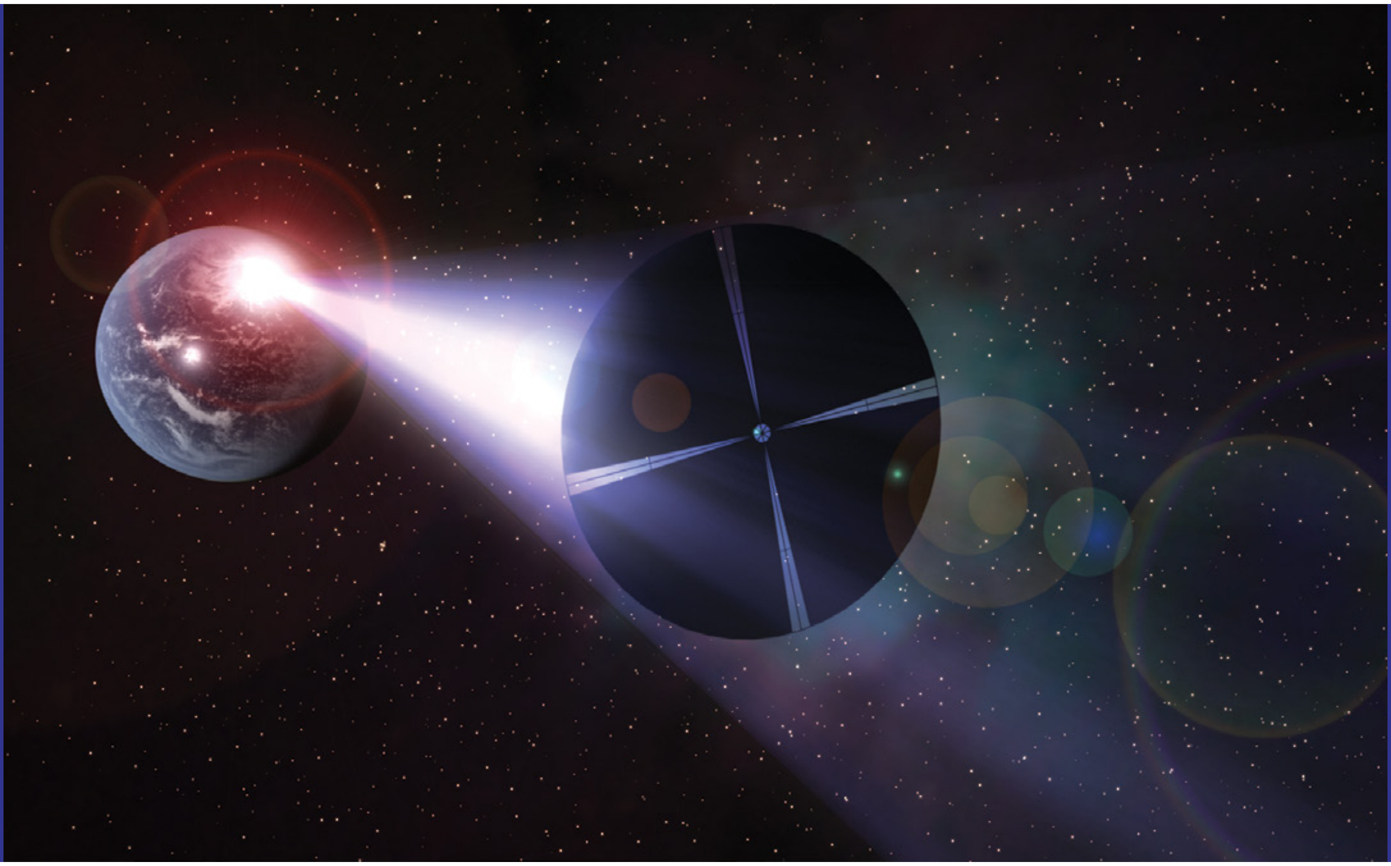
■ **WILLIAM SHEEHAN** co-authored (with Stephen James O'Meara) *Mars: The Lure of the Red Planet*. Among his recent books is *Saturn*, published in 2019.



▲ **THE SPOKES RETURN** After vanishing for several years, Saturn's ring spokes were recovered by the Cassini spacecraft in 2006. Although the formation mechanism of the spokes is still debated, their visibility seems to depend on the Sun's elevation above the ring plane. In this Cassini image from January 27, 2010, the spokes stretch from left to right across the finely pleated B ring.

ANTONIADI SKETCH: WILLIAM SHEEHAN / PUBLIC DOMAIN; CASSINI VIEW OF THE SPOKES: NASA / JPL / SPACE SCIENCE INSTITUTE

 by Jeff Hecht



SETI'S BIG BOOST

New instruments and data-analysis tools are opening more sky to the search for extraterrestrial intelligence.

The Kepler Space Telescope's haul of more than 100 potentially habitable planets has revolutionized our search for life in the universe. In the next decade, astronomers will pursue a step-by-step program to find and explore Earth-like exoplanets, which apparently not only exist but are plentiful. "The next thing we don't know is how many planets are able to support life," says Ian Crossfield (University of Kansas), a member of the decadal survey's panel on exoplanets, astrobiology, and the solar system.

One goal is to look for *biosignatures*, chemical fingerprints in a planet's atmosphere that indicate lifeforms (*S&T:* May 2021, p. 34). But beyond that, astronomers are also looking for *technosignatures*, signs of sophisticated technology that advanced civilizations might use, which we could detect light-years away. In other words: E.T.

The search for extraterrestrial intelligence, or SETI, began by seeking deliberate communications from other civilizations. Now, researchers are expanding their quest to include signals that intelligent life might send unintentionally, from sudden bursts of light from spacecraft-propelling lasers to anomalous spectra that might reveal a shell built around a star to capture its energy.

"The search for technosignatures — signs of advanced life — is very much complementary to the search for biosignatures of the basic forms of life," says Andrew Siemion

▲ **LASER LIGHT SAIL** One day, laser banks on Earth might power mini-spacecraft on a journey to Alpha Centauri, as imagined here in an artist's concept. Perhaps also one day, humans might detect errant light from an alien civilization using the same technology.

(University of California, Berkeley), director of the Berkeley SETI Research Center. Simple life appeared within Earth's first billion years, but uncovering definitive evidence of life from that time period has been difficult, even though we live here. Finding biosignatures on distant exoplanets will be even harder, he says.

We already know of one potentially habitable planet within 10 light-years and several more within 20. Even with the coming generation of 30-meter telescopes on the ground and 6-meter ones in space, we only expect to find a couple dozen potentially habitable planets close enough to detect biosignatures. In contrast, we could see a laser beam shot directly at us from a distance of up to thousands of light-years, and we might be able to register a powerful radar beam aimed at Earth from across the galaxy.

Thanks to recent exoplanet discoveries as well as fresh sources of funding, astronomers are doubling down on SETI. Thirteen white papers submitted to the astronomy decadal survey featured SETI work, says Siemion, a sharp rise from just two a decade ago. There are a growing number who wonder if gathering vast amounts of data from the galaxy could yield an unexpected signal so unnatural that only intelligent beings could have produced it.

A Long-term Quest

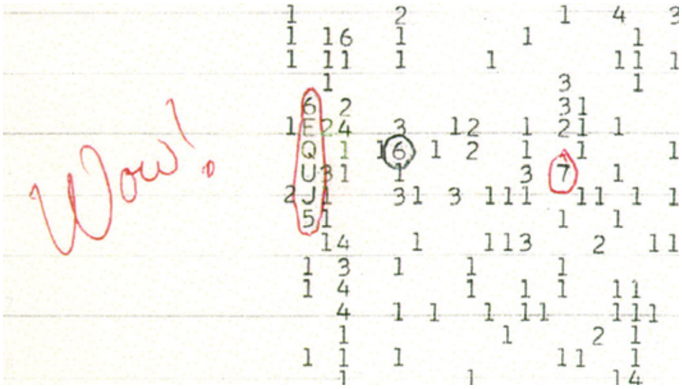
The term technosignature is new, but the basic idea remains what it has been for decades: a signal that, to our knowledge, nature cannot generate. Generally, such signals are either narrow in frequency or short in time. A laser beam, for example, would create a single-color signal spanning an unnaturally narrow range of wavelengths. A bright signal that lasts for only a nanosecond would also arouse suspicion. The shortest natural pulses we know come from pulsars and last 100,000 times longer: An outburst lasts at least as long as it takes light to travel across the source, which is 0.1 millisecond for a 30-kilometer object. Light can travel only 30 centimeters in a nanosecond, and no natural object that small could produce enough energy to be seen light-years away. Such a short signal might come from intelligent life.

Frank Drake began the first SETI experiment in the spring of 1960, when he turned the new 85-foot radio telescope at the National Radio Astronomy Observatory's site in West Virginia toward two nearby, Sun-like stars. Since then, SETI researchers have picked up some promising signals but no convincing evidence of extraterrestrials. Perhaps the most famous is the "Wow!" signal, a bright, narrowband radio burst that lasted 72 seconds, recorded in 1977 by the Big Ear radio telescope at Ohio State University. Its origin remains a mystery, and it has never repeated (*S&T:* May 2021, p. 84).

Over the years, the SETI quest has expanded to explore two regions of the electromagnetic spectrum in which cosmic noise is low and atmospheric transmission is high: radio frequencies from 1 to 10 gigahertz and visible/near-infrared wavelengths from 400 to 2300 nanometers. The biggest changes over the past decade have been in funding and

▼ **POTENTIALLY HABITABLE** An artist imagines the appearance of known Earth-size planets in their star's *habitable zone*, where water could conceivably remain liquid on a rocky surface. For comparison, on this scale Proxima Cen b is about the size of Earth. The planets are ordered by their distance from Earth, given in light-years (ly).

POTENTIALLY HABITABLE PLANETS: PLANETARY HABITABILITY LABORATORY / UNIVERSITY OF PUERTO RICO, ARECIBO; WATER TEXTURE: POLYGRAPHUS / SHUTTERSTOCK.COM



▲ **"WOW!"** The Big Ear Radio Observatory recorded incoming signals' brightness first using numbers and then, if the signal was bright enough, in letters. The letter "U" indicates a signal 30 times the background noise level; the signal as a whole lasted 72 seconds.

equipment, says Seth Shostak (SETI Institute). Shostak wrote this magazine's last report on SETI (*S&T:* Nov. 2010, p. 22). Back then, the premier SETI instrument was the Allen Telescope Array (ATA), a collection of 42 six-meter radio antennas that covers several square degrees of sky. Within that large field of view, back-end processing enabled SETI researchers to focus on one or two nearby star systems per pointing.

Built with more than $30 million from Microsoft cofounder Paul Allen in Hat Creek, California, and owned by the SETI Institute, the ATA was the world's first instrument dedicated to SETI when it began operation in 2007.

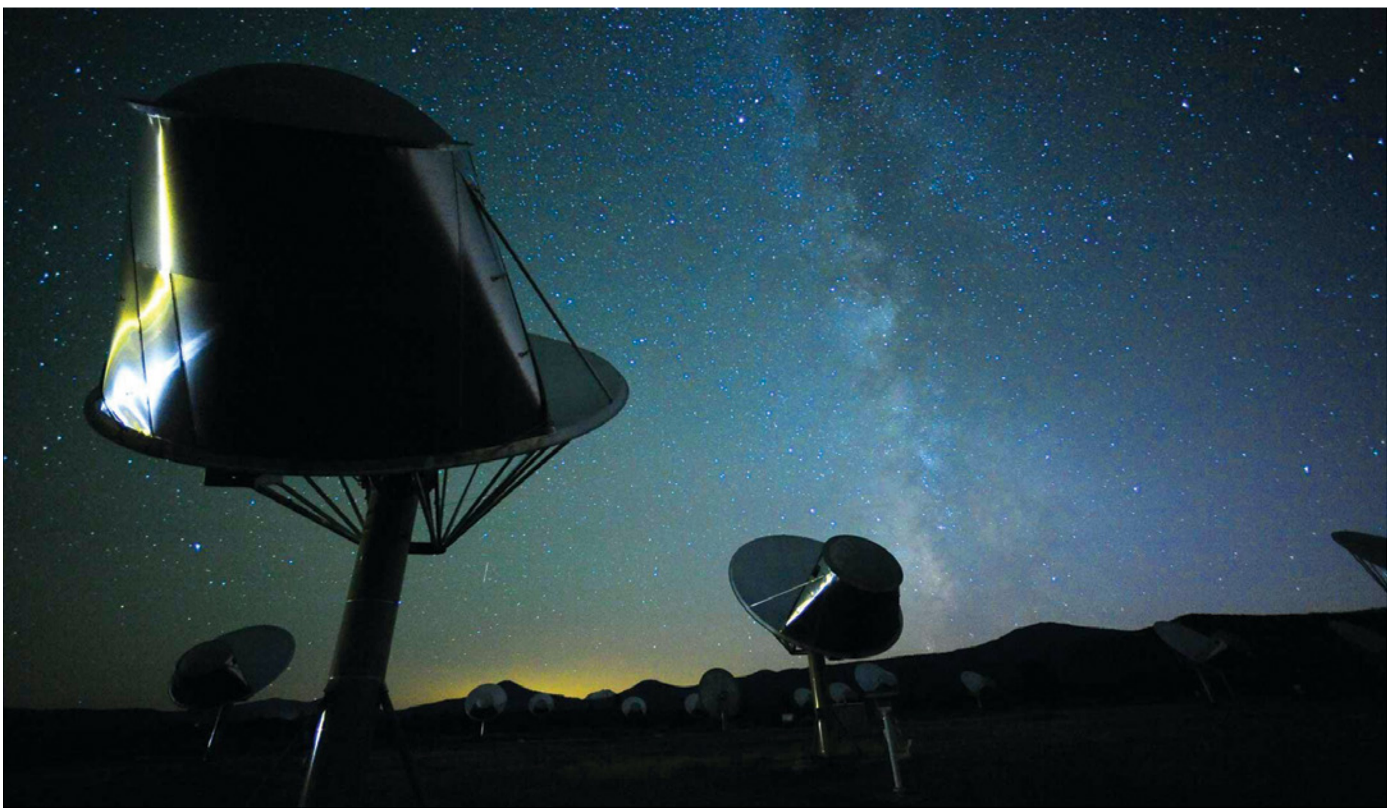
Meanwhile, the Kepler mission launched in 2009. While astronomers had already discovered 417 exoplanets, SETI astronomers were eagerly awaiting Kepler's haul — particularly the Earth-size worlds around Sun-like stars that the mission aimed to find.

However, funding issues plagued the array. Resources weren't available to realize the initial plans, which had called for a total of 350 dishes. Then the array shut down for several months in 2011, before the Berkeley Radio Astronomy Laboratory turned operations over to the nonprofit research institute SRI International. SRI used about a third of the array's time for projects such as tracking space junk, with the rest of the time available for the SETI Institute.

In 2020, the SETI Institute took over management from SRI, having already begun a major upgrade funded by Franklin Antonio, cofounder of Qualcomm. The improvements, to be completed this year, will enable the ATA to point at 16 star systems at any given time, speeding searches at frequencies from 1–15 gigahertz by a factor of 35. Upgrades will also improve the array's reliability and usefulness in collaborative searches. "It doesn't guarantee we're going to find E.T.," Shostak cautions, "but it will both speed up and increase the sensitivity of the search."

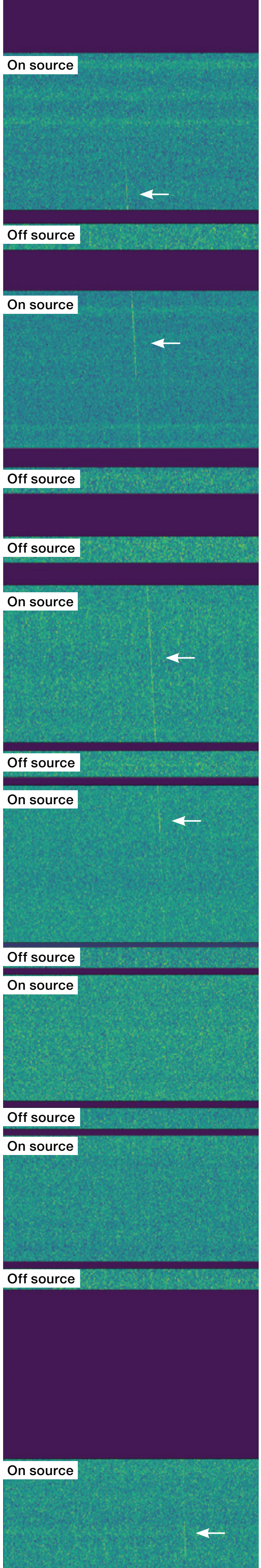
A Monetary Breakthrough

ATA is far from the only SETI enterprise, though, thanks to a recent increase in funding. In the early 2010s, Shostak received an email from Russian-Israeli billionaire Yuri Milner,



▲ **DEDICATED DISHES** The Allen Telescope Array surveys the sky above Hat Creek, California, for alien intelligence.

"WOW" SIGNAL: BIG EAR RADIO OBSERVATORY / NORTH AMERICAN ASTROPHYSICAL OBSERVATORY; ALLEN TELESCOPE ARRAY: SETI INSTITUTE



◀ **CANDIDATE 1** This plot shows what Breakthrough Listen found when pointed at Proxima Centauri ("on source"), a faint signal around 982 MHz that drifted in frequency (*x*-axis) over time (*y*-axis). The resulting faint yellow diagonal line is not visible in off-source pointings. Dark purple panels indicate time periods with no data, primarily telescope slews.

S. Z. SHEIKH ET AL. / *NATURE ASTRONOMY* 2021

a physicist by training who had turned his attention to business. Milner was initially interested in setting up a prize related to SETI research, but Kepler's trove of potentially habitable planets motivated him to instead launch the Breakthrough Initiatives, a set of programs to study the fundamental questions of life in the universe: "Are we alone? Are there habitable worlds in our galactic neighborhood? Can we make the great leap to the stars? And can we think and act together — as one world in the cosmos?"

The biggest of these efforts is Breakthrough Listen, which Milner and Stephen Hawking launched in 2015. It's providing $10 million annually for 10 years for radio and visible-light surveys of the 1 million closest stars, the galactic plane, and the 100 nearest galaxies. That big boost in funding is being spread around. Some goes to new equipment for the SETI Institute, and some goes to the Berkeley SETI Research Center headed by Siemion. Other money goes to acquire time for SETI research on major radio telescopes: the 100-meter Robert C. Byrd Green Bank Telescope in West Virginia, the 64-meter Parkes telescope in Australia, and the MeerKAT array in South Africa, as well as visible-light searches on the 2.4-meter Automated Planet Finder at Lick Observatory. All Breakthrough Listen data are stored in a public archive.

Parkes found the most interesting signal so far, dubbed Breakthrough Listen Candidate 1, a narrowband radio signal that appeared to emanate from Proxima Centauri over a period of five hours. It had "all the hallmarks of a technosignature," says Siemion. However, an exhaustive analysis published in November in *Nature Astronomy* found the cause was what he calls "pathological radio-frequency interference," the combination of multiple human-generated signals from near or inside the observatory.

Techno Leaks

A surge in backing has enabled SETI to expand its focus from detecting purposeful communications from advanced civilizations to unintentional technosignatures.

For example, physicists have envisioned that advanced civilizations might build vast megastructures around star systems. In 1960 at the Institute for Advanced Study in Princeton, Freeman Dyson suggested that aliens might surround their star with a shell to capture most of its energy. The star itself would thus be dark, only visible from the outside by the shell's heat emission.

Other evidence might arrive on our interplanetary doorstep. Some have suggested that the thin interstellar object 1I/'Oumuamua might be a derelict alien spaceship, much as Arthur C. Clarke described in his 1973 novel *Rendezvous with Rama*. That idea was part of the impetus behind the Galileo Project, an endeavor led by Abraham Loeb (Harvard) to build a dedicated array of instruments to search the skies not for electromagnetic signals from far-off systems, but for physical objects that might have originated in such systems and made their way here.

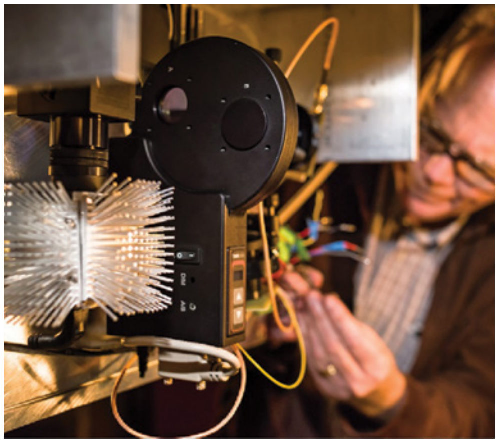
Advanced civilizations using laser propulsion on scales vaster than anything yet demonstrated by humans could lead to another class of technosignatures. "If you want to travel around the galaxy at a significant fraction of the speed of light, you have to use antimatter or a laser-powered light sail," says Eliot Gillum (SETI Institute).

Even humans are trying out the latter: The $100 million Breakthrough Starshot project plans to use high-power lasers to accelerate a fleet of stamp-size probes flying meter-scale light sails to the Alpha Centauri system. The trajectory would include a flyby of the potentially habitable planet Proxima Centauri b (*S&T:* Dec. 2016, p. 10).

Physicist James Benford (Microwave Sciences) suggested that astronomers could recognize glints of laser light reflected from or escaping around the edges of far-away light sails as coherent light. This idea also has a science-fiction connection: One of Benford's collaborators is his identical twin brother, Gregory, a well-known science fiction writer as well as retired professor of astrophysics from the University of California, Irvine.

LaserSETI

Detecting laser light, whether stray or intentional, will require searching vast swaths of both sky and time. While searches for visible flashes from other civilizations go back decades, those largely relied on focusing light onto a photomultiplier tube — the equivalent of a single-pixel camera. Last year, Gillum instead began installing a low-cost camera-based system named LaserSETI for what he calls the first "all-sky-all-the-time" search. He designed the instruments to seek short pulses of coherent light like those that James Benford envisioned. With it, he could capture the light from a propulsion beam as it sweeps across the sky, as both the beam and Earth move.



◀ **NIROSETI** The near-infrared/optical instrument mounted on the Nickel 1-meter telescope at Lick Observatory didn't find nanosecond-long pulses expected from far-off lasers, but its field of view was small.

To detect such technosignatures, Gillum points two pairs of wide-angle cameras at the same area of sky from widely separated spots. Each camera has a 75° field of view — nearly twice the height of Ursa Major — and is set at right angles to its partner. The initial observations have had one pair looking west from California and the other looking east from Hawai'i. The system, which uses transmission gratings to obtain spectra, looks for sources displaying only a narrow range of wavelengths, as you'd expect from a laser. A burst of laser-like light would leave a telltale signal in the data collected by the camera pair.

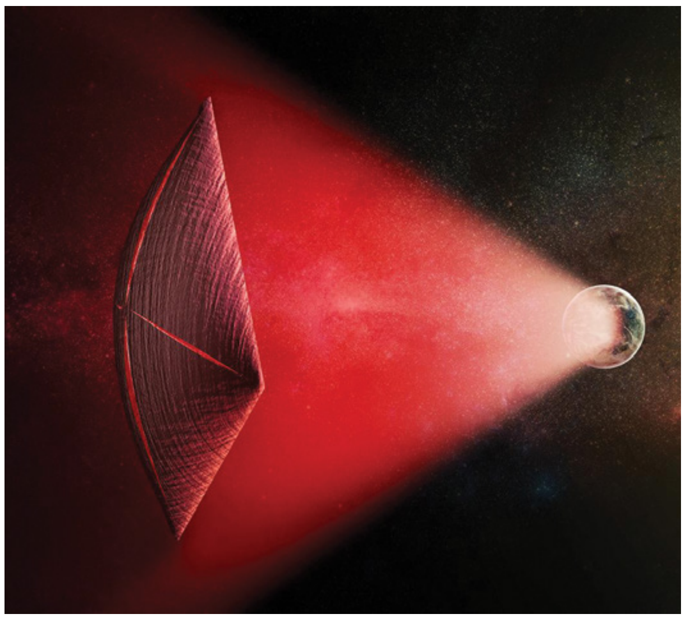
"Breakthrough Starshot is our ideal scenario," Gillum says, adding that a civilization using laser-powered satellites could be visible from far away. "Those lasers are extremely bright, and [detection] does not require anyone trying to communicate."

With two pairs of cameras monitoring the same region of sky simultaneously, combining data from the two can filter out errant detections. Observing from two locations also provides the source's parallax; Gillum says astronomers should be able to measure distances up to 25 times the distance of the Moon, so the system will not mistake a terrestrial spacecraft for E.T. In the long term, Gillum hopes to monitor the sky from about 70 sites.

Expanding the View

Another new thrust in search efforts is the doubling of the spectral range under study. SETI has long relied on silicon CCD detectors, which can record infrared light out to about 1,000 nanometers. Longer infrared wavelengths pass more successfully through interstellar dust than shorter wavelengths do; however, detecting them requires camera chips made from more exotic semiconductors, which have historically been beyond limited SETI budgets. More recently, though, mass production of indium-gallium-arsenide

▲ **MEGASTRUCTURE** The late futurist Freeman Dyson imagined that alien civilizations might need to utilize more energy from their host stars than we do. Such energy usage could ultimately come in the form of a "Dyson sphere," shown here in an artist's concept. Such a structure would block some or all of the visible light from the central star, but it would heat up and re-radiate that energy at infrared wavelengths.



▲ **STARSHOT** Lasers on Earth shining on light sails could power small spacecraft on interstellar journeys, as imagined here for the project Breakthrough Starshot. Alien civilizations might have thought of similar technology, from which we could detect laser "leaks." It's even possible that extraterrestrials might power such laser beacons as a means to communicate intentionally.

(InGaAs) detectors — sensitive at 900 to 1700 nanometers — has made them affordable.

Shelley Wright (University of California, San Diego) and others used InGaAs sensors to construct the Near-Infrared and Optical (NIRO) SETI instrument, now on the 1-meter Anna L. Nickel Telescope at Lick Observatory. Wright's team designed the system to spot nanosecond-long flashes, 100 million times shorter than the time it takes to blink an eye. So far, they haven't found any repeating pulses from 1,280 objects, each observed for at least 300 seconds.

Because the small field of view reduces the odds of looking at the right place at the right time, Wright is now working on a more ambitious project: Panoramic SETI. Called PanoSETI for short, the project will ultimately comprise a pair of observatories, each filled with half-meter telescopes searching the whole sky for flashes less than a second long.

To test the concept, the team installed two prototype telescopes at Lick, in the dome that houses the historic Carnegie Double Astrograph, and tested another two at a temporary site near Palomar Observatory. Installation at Lick finished in February 2020, but COVID-19 stalled first light; the group began testing in March 2021. Wright and her colleagues are now seeking additional funding and testing observing conditions at their preferred site on Palomar Mountain in southern California, the site of the 200-inch Hale Telescope.

In the full-scale installation at Palomar, the two domes, separated by 1 kilometer, would both contain 45 identical telescopes, each fixed in place with a 10° × 10° field of view. As Earth turns, the telescopes will scan 10,000 square degrees — the whole observable sky. The separation between the two domes will help rule out false alarms.

Piggybacking

Besides building its own equipment, the SETI Institute has long borrowed time on other instruments. "Sometimes we add new instruments, sometimes new sensors, sometimes a new detector, and sometimes new algorithms," says Siemion. With radio telescopes, he adds, "the main thing we need to do is to bring large computers to [analyze] the data to look for narrowband radio signals."

Two technological revolutions occurring in parallel are proving to be boons for SETI: the development of powerful radio arrays able to collect vast amounts of data, and the development of powerful computers able to process that data. The gigabytes and even terabytes collected daily by big arrays — including Australia's Murchison Widefield Array, the 27-dish Very Large Array (VLA) in the U.S., and MeerKAT, a 64-antenna South African precursor to the Square Kilometer Array — would have overwhelmed earlier generations of computers. But newer processors are capable of not only handling the data but piggybacking on other astronomical research to create additional search opportunities. After all, processing power comes cheaper than brand-new telescopes.

For example, a project called the Commensal Open-Source Multimode Interferometer Cluster (COSMIC) SETI aims to copy over signals gathered by the VLA for conventional radio astronomers. A splitter takes the feed from each radio dish and digitally copies the signals that astronomers are recording for other purposes. The data then go to SETI's processors, which can use them to examine other parts of the sky. "Even though the principal VLA observer might be studying galaxies or galactic nebulae," Shostak says, "the SETI scientists can be studying several nearby star systems as if they had a couple of large, single-dish antennas at their disposal."

Looking Forward

The odds against finding alien intelligence may be long, but that doesn't phase Shostak, Siemion, Wright, and others involved in SETI projects. They have an enormous universe to

Coming Up Empty

Ultimately, what SETI seeks is signals. So, what happens if we don't find any? Do we give up? Stop funding SETI?

Similar questions have arisen around other topics, such as dark matter. Ample indirect evidence suggests dark matter's presence in galaxies and clusters, yet the lack of direct detections troubles many. Nevertheless, progress continues as scientists conduct increasingly sensitive searches — and in that respect, SETI is no different.

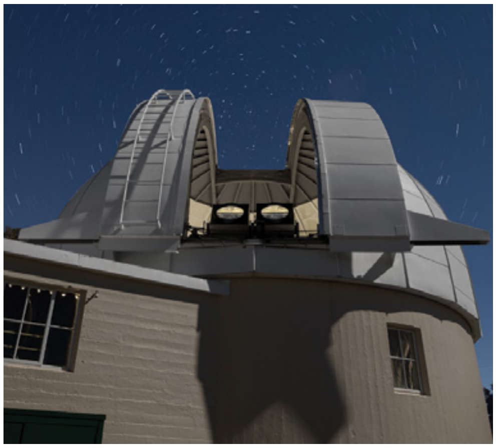
In fact, the lack of a signal can be informative in and of itself, ruling out certain stellar systems or types of technosignatures. As just one example, the Breakthrough Listen team has searched 1,327 nearby stars for the type of radio signals our own civilization can make — and found nothing. The survey eliminates the possibility of both an Earth-directed radio beacon as well as radio noise from a human-equivalent civilization. The upper limit that Danny Price (University of California, Berkeley) and colleagues derived from this non-detection? Less than 0.1% of the stellar systems within 160 light-years possess such transmitters.

Such experiments will guide future searches by setting ever more meaningful upper limits to what's out there. And maybe someday, they'll narrow the search enough to help snag a signal from E.T.

— MONICA YOUNG

search and a wealth of technology to bring to bear.

Breakthrough Listen plans to examine 1 million star systems in the next decade, up from the few thousand it has already covered. The SETI Institute aims to study red dwarf systems and other promising targets with the upgraded Allen Telescope Array. And LaserSETI, PanoSETI, and other programs will scan the whole night sky at visible and near-infrared wavelengths, looking for monochromatic sources.



◀ **PANOSETI PROTOTYPES** These two telescopes, in the same dome that houses the historic Carnegie Double Astrograph, served as a testbed for PanoSETI technology. Ultimately, plans call for 90 telescopes, housed in two domes separated by 1 km.

Complementary searches for technosignatures in astronomical data will occur via piggybacking programs such as COSMIC SETI. As of early April, the COSMIC team has installed amplifiers and splitters on all 27 VLA antennas, giving SETI scientists a full copy of the data streams. Siemion expects the most exciting results from these information troves as they're fed into powerful computers for analysis. By 2023, radio searches "will transition from a relatively small boutique endeavor to an integral part of the quest to understand the nature and distribution of life in the universe," says Siemion. "This isn't a hope — it is a fact.

"In my wildest dreams, we would detect convincing evidence of the existence of extraterrestrial intelligence," he adds. Less speculatively, though, he expects "clear and definitive constraints" on the distribution of technologically capable life in our part of the galaxy.

"In the next decade," he says, "I predict that we will, for the first time, have a robust ability to detect a modern-era, human-like technosphere, if it exists, among a handful of nearby extrasolar planets."

Shostak, for his part, thinks that by 2030 astronomers will either have found an intelligent signal or have discovered an unambiguous alien artifact, such as a Dyson sphere. But his wildest hopes are even grander than that: "We will have found more than one!"

He may seem overly optimistic, but then again, who a few decades ago would have expected to find the universe so full of planets?

■ **JEFF HECHT** writes about science and technology from the Boston suburbs. He has enjoyed reading *Sky & Telescope* since his teens, when he thought he would have needed a spaceship to see exoplanets.

▲ **SPLITTING THE FEED** The Very Large Array is a collection of 27 radio antennas in Socorro, New Mexico. Each antenna in the array measures 25 meters (82 feet) in diameter and weighs about 230 tons. In the COSMIC SETI initiative, feed splitters will copy the data that the VLA collects, enabling special correlators to analyze astronomical data for extraterrestrial intelligence.

PANOSETI: © LAURIE HATCH; VERY LARGE ARRAY: NRAO / AUI / NSF

OBSERVING
August 2022

1 DAWN: Early risers will be greeted by the sight of Venus, Mars, Jupiter, and Saturn in a long line stretching from the east to the southwest.

3 DUSK: Look to the southwest to see the waxing crescent Moon some 3° above Virgo's lucida, Spica. (See page 46 for more details on this and other events listed here.)

6 EVENING: The Moon, a day past first quarter, is in Scorpius, where it sits about 4½° right or upper right of Antares.

11 EVENING: The full Moon and Saturn grace the southeastern horizon after twilight ends; around 5° separates the pair. Both will be visible through dawn.

12–13 ALL NIGHT: This year's Perseid meteor shower peak coincides with the almost-full Moon, which will wash out all but the brightest meteors. However, this is a notoriously long shower, and you could see Perseids as early as mid-July and into the second half of August; seek out periods when the Moon interferes less. (See story on page 50.)

14 ALL NIGHT: Ringed wonder Saturn arrives at opposition and is visible from sundown to sunup. Turn to page 48 for more.

15 MORNING: The waning gibbous Moon hangs some 2° below Jupiter, high above the southern horizon before sunup.

18 DAWN: Brilliant Venus and the Beehive Cluster (M44) rise together in the east-northeast. Binoculars will tease out the dimmer lights of cluster members from the Morning Star's dazzle.

19 MORNING: The last-quarter Moon, Mars, and the Pleiades present a pretty sight high above the eastern horizon in the wee hours of the morning. The grouping spans a bit less than 6°.

20 MORNING: Face east to see the waning crescent Moon some 7° from Aldebaran, with Mars and the Pleiades nearby at upper right.

23 DAWN: The Moon is in Gemini and forms an attractive triangle with Castor and Pollux in the east-northeast before sunrise.

24 DAWN: The thin lunar crescent is now some 6° below Pollux. Castor anchors the line above the pair.

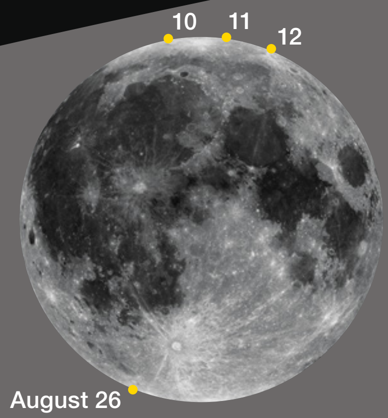
25 DAWN: The impossibly thin crescent Moon shepherds Venus as they rise above the east-northeastern horizon around 6° apart.

30 MORNING: Mars is pleasingly positioned halfway between Aldebaran and the Pleiades in Taurus. Look eastward to enjoy this sight.

30 DUSK: Back in Virgo, the waxing crescent Moon is a bit more than 4° upper right of Spica. Catch the pair before they set in the west.
— DIANA HANNIKAINEN

Glorious Saturn arrives at opposition this month. In October 2004, the orbiting Cassini spacecraft captured a series of images that were later assembled into the mosaic shown above. NASA / JPL / SPACE SCIENCE INSTITUTE

AUGUST 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
August 5
11:07 UT

FULL MOON
August 12
01:36 UT

LAST QUARTER
August 19
04:36 UT

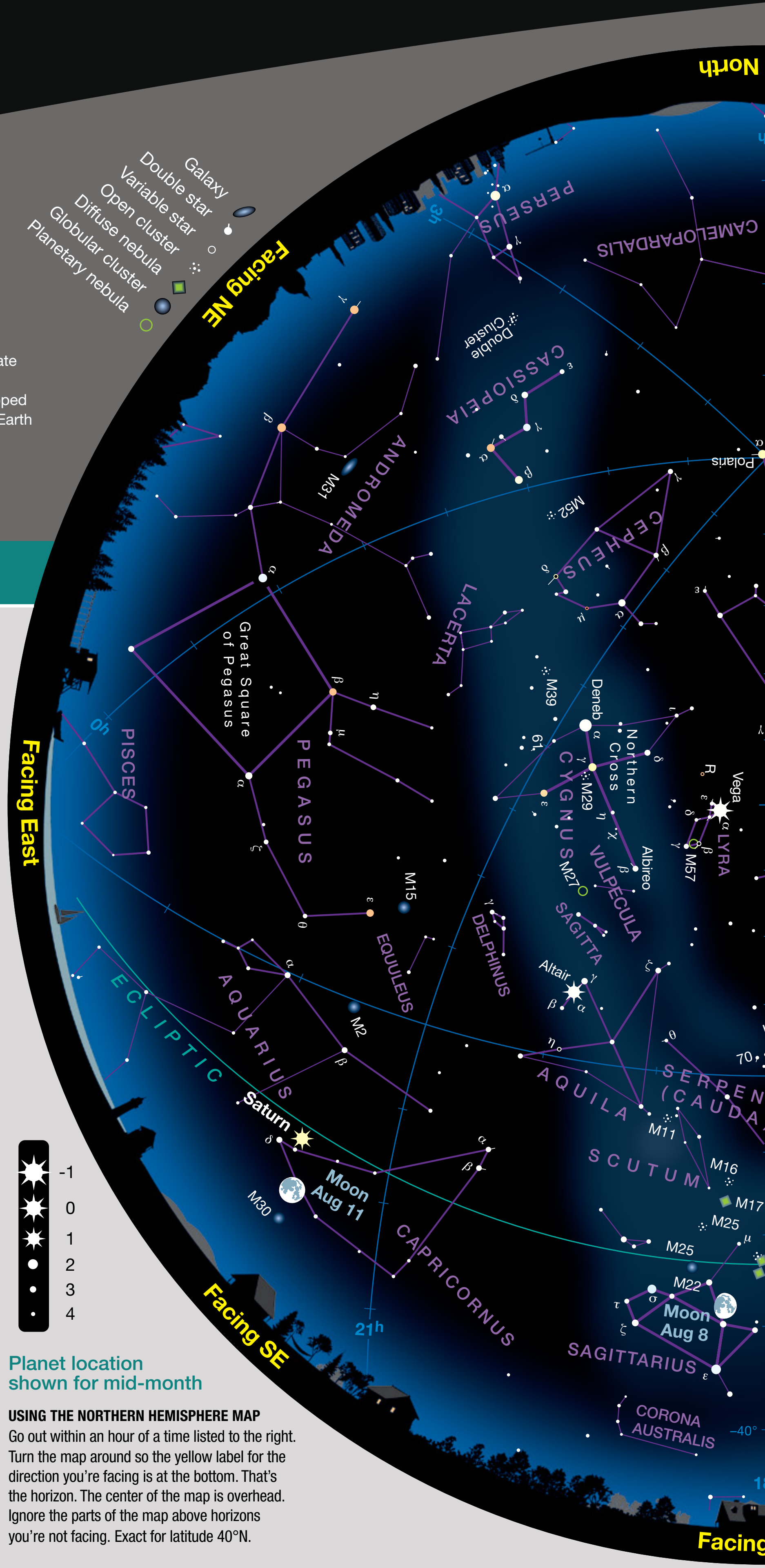
NEW MOON
August 27
08:17 UT

DISTANCES

Perigee	August 10, 17ʰ UT
359,830 km	Diameter 33′ 13″
Apogee	August 22, 22ʰ UT
405,417 km	Diameter 29′ 28″

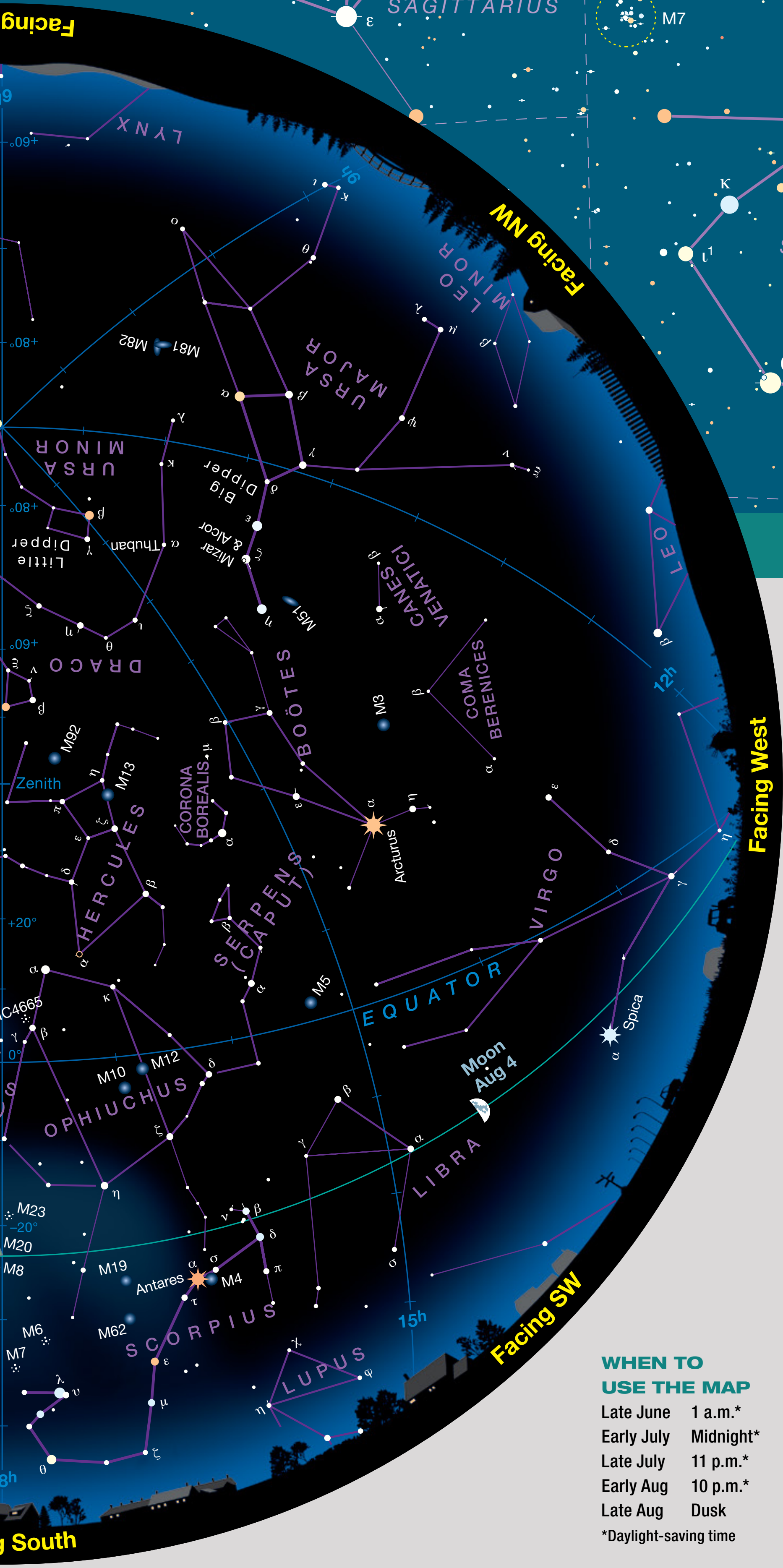
FAVORABLE LIBRATIONS

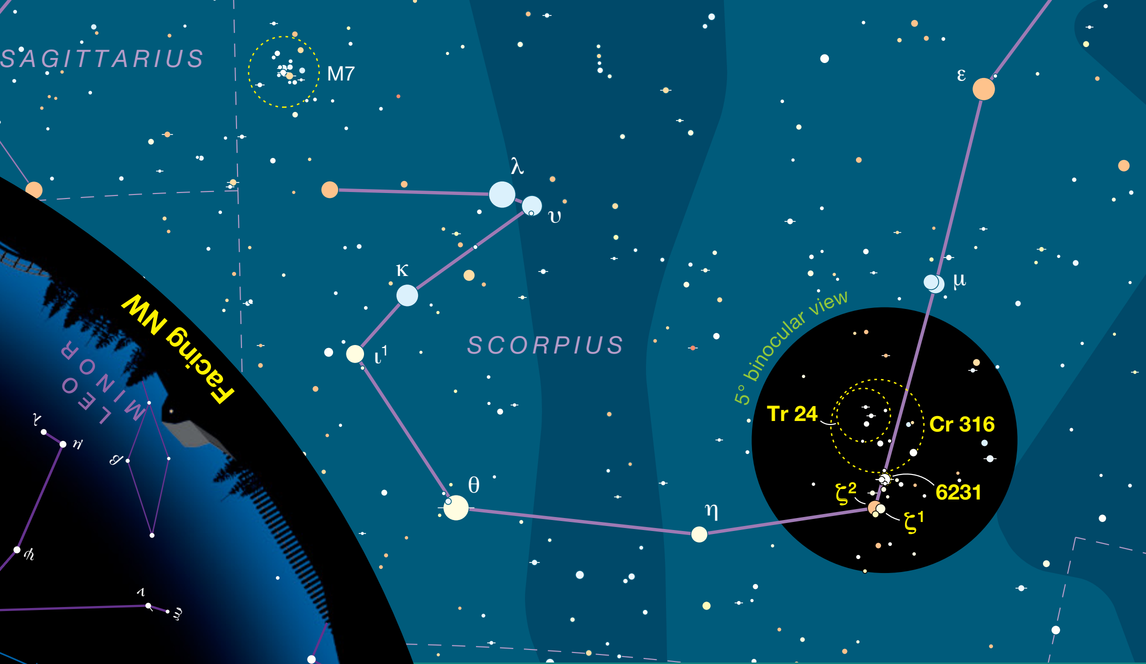
• Poncelet Crater	August 10
• De Sitter Crater	August 11
• Hayn F Crater	August 12
• Hausen Crater	August 26



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

The False Comet

Our target this month is a personal favorite, the False Comet in Scorpius. The False Comet is anchored by **Zeta^1 (ζ^1)** and **Zeta^2 (ζ^2)** Scorpii, where the Scorpion's tail arcs east, away from its back. North of those stars lies the compact open cluster **NGC 6231**, and farther north the superimposed clusters **Collinder 316** and **Trumpler 24**. To the naked eye, the stars and clusters can look remarkably like a comet, but binoculars of any magnification will explode that illusion into a wonderland of suns.

Magnitude-3.6 Zeta^2 Scorpii is the odd object out here, a *K*-type orange giant less than 150 light-years away. Everything else — magnitude-4.8 Zeta^1 Scorpii and the aforementioned clusters — are part of the Scorpius OB 1 association, a sprawling field of bright young stars scattered from about 3,000 to 8,000 light-years distant.

My most memorable view of the False Comet was during my one trip south of the equator. I was at a conference in Punta del Este, Uruguay, and at night I'd slip down to the beach to cruise the southern skies. I was scanning along the Milky Way when I stumbled across a rich, complex cluster sprawling across nearly 3°. It didn't match any of the southern-sky highlights that I'd prepared for, so I double-checked my charts. For the first time in my life, I'd stumbled into Scorpius from the south, and was observing the False Comet near the zenith.

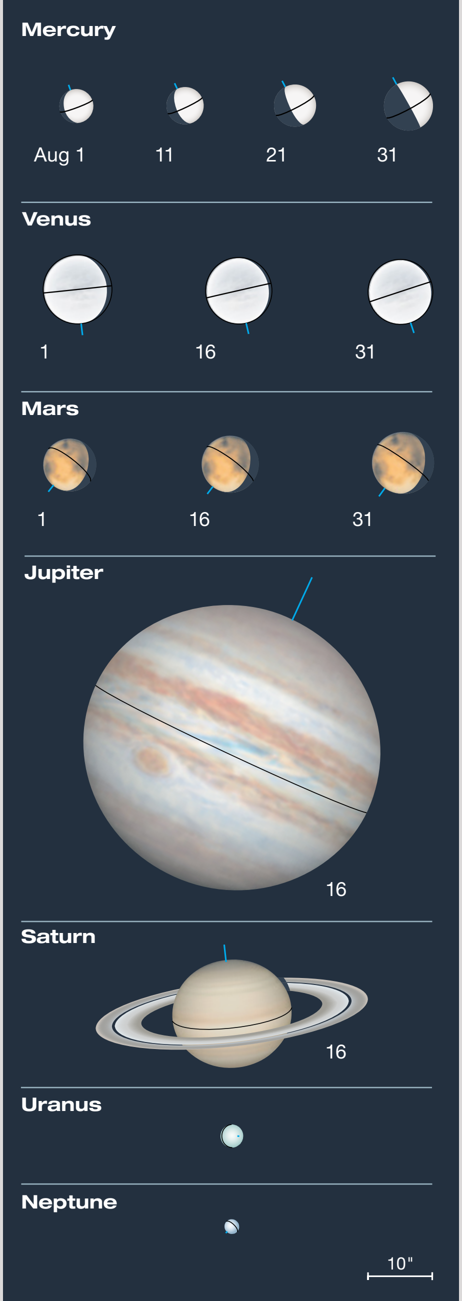
My favorite trick with the False Comet is to treat myself to the naked-eye view, and then to get out an array of binoculars and telescopes and observe the cluster at different magnifications. If you follow suit, I think you'll find enough to stay busy for quite a while.

■ **MATT WEDEL** gets lost in the sky fairly often but blundering into "southern" constellations when they were high in the sky remains particularly memorable.

WHEN TO USE THE MAP

Late June	1 a.m.*
Early July	Midnight*
Late July	11 p.m.*
Early Aug	10 p.m.*
Late Aug	Dusk

*Daylight-saving time



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

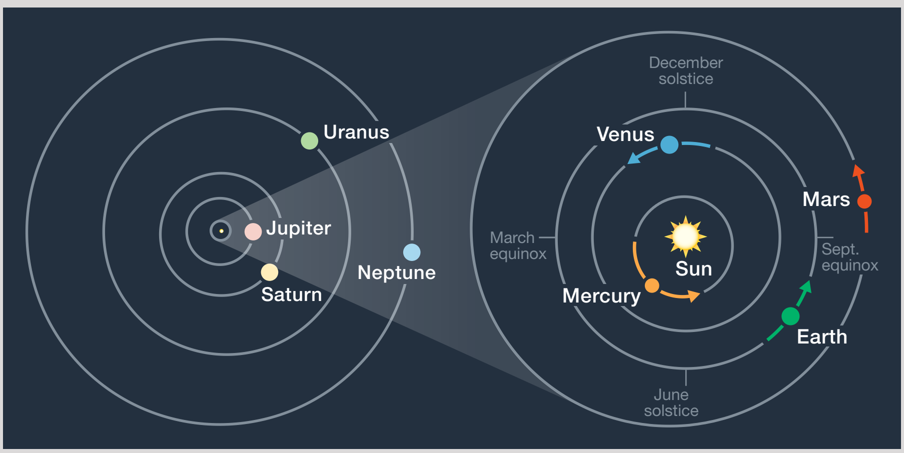
▶ **ORBITS OF THE PLANETS** The curved arrows show each planet's movement during August. The outer planets don't change position enough in a month to notice at this scale.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** visible at dust from the 7th to the 21st • **Venus** visible in the east-northeast at dawn all month • **Mars** visible at dawn all month • **Jupiter** and **Saturn** rise in the evening and are visible until dawn.

August Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$8^h 43.5^m$	+18° 09′	—	–26.8	31′ 31″	—	1.015
	31	$10^h 36.0^m$	+8° 50′	—	–26.8	31′ 41″	—	1.010
Mercury	1	$9^h 47.2^m$	+14° 53′	16° Ev	–0.6	5.3″	86%	1.267
	11	$10^h 48.2^m$	+8° 00′	22° Ev	–0.2	5.8″	75%	1.156
	21	$11^h 36.3^m$	+1° 19′	26° Ev	+0.1	6.6″	63%	1.024
	31	$12^h 11.1^m$	–4° 12′	27° Ev	+0.3	7.7″	48%	0.878
Venus	1	$7^h 11.8^m$	+22° 22′	22° Mo	–3.8	10.7″	93%	1.555
	11	$8^h 03.8^m$	+20° 47′	19° Mo	–3.8	10.5″	94%	1.594
	21	$8^h 54.7^m$	+18° 12′	17° Mo	–3.9	10.3″	96%	1.627
	31	$9^h 44.0^m$	+14° 46′	14° Mo	–3.9	10.1″	97%	1.655
Mars	1	$3^h 03.1^m$	+15° 30′	81° Mo	+0.2	8.3″	85%	1.132
	16	$3^h 40.8^m$	+18° 01′	86° Mo	+0.1	8.9″	85%	1.049
	31	$4^h 16.2^m$	+19° 57′	92° Mo	–0.1	9.7″	85%	0.964
Jupiter	1	$0^h 33.1^m$	+2° 00′	120° Mo	–2.7	45.1″	99%	4.373
	31	$0^h 26.9^m$	+1° 12′	151° Mo	–2.9	48.6″	100%	4.053
Saturn	1	$21^h 41.5^m$	–15° 12′	166° Mo	+0.4	18.7″	100%	8.886
	31	$21^h 32.9^m$	–15° 56′	163° Ev	+0.3	18.7″	100%	8.896
Uranus	16	$3^h 04.9^m$	+17° 00′	94° Mo	+5.7	3.6″	100%	19.589
Neptune	16	$23^h 41.9^m$	–3° 17′	148° Mo	+7.8	2.4″	100%	29.050

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**.



Vacationing in the Milky Way

Get ready for a starry summer tour of our home galaxy.

It's time to make your reservations for a vacation in the most grand and luxurious of all astronomical resorts: the summer Milky Way.

Some of us can still enjoy the full glory of our home galaxy from our own backyards — the ultimate "staycation." Sadly, however, due to light pollution the vast majority of people living in the United States and elsewhere have completely lost sight of this starry wonder. Most readers will have to travel many miles to escape city lights in order to fully enjoy the night sky.

In addition to choosing your viewing spot, the timing of a Milky Way "vacay" is also vital. Any bright moonlight can hinder your view, washing out the softly glowing band of light. You want to be sure to book your reservation for both the dark-of-the-Moon period and for when the Milky Way arches highest across the sky. This August, there are two good openings — a brief one at the start of the month, and a longer stretch in the second half. During August, you can view the Milky Way after moonset until around the 7th, but toward the end of that run you'll have to wait until after midnight for the Moon to set. The second, prime window opens on the evening of the 15th and lasts until the beginning of September, when the lunar crescent returns to the evening sky.

Of course, as with any vacation, we sometimes have to deal with poor weather, including summer haze. That haze is thickest near the horizon, where it can interfere with our views of the glorious Sagittarius and Scorpius Milky Way, which rides low in the south for observers at mid-northern latitudes.

Let's begin our travels near the zenith, in Cygnus. The Swan — also pictured as the Northern Cross — is enwreathed with one of the Milky Way's brightest sections, the Cygnus Star Cloud. This region is so bright that I can glimpse it with the naked eye even when the limiting stellar magnitude is as bright as 4.8 — typical for fairly small cities and many suburbs.

Under darker skies, we can begin to perceive some of the major dark indentations in the Milky Way caused by clouds of interstellar dust. The most famous of these is the Great Rift, which starts in Cygnus and splits the Milky Way, with the eastern arm of this luminous river extending southward toward the horizon and into Sagittarius, while the western channel comes to an end in northern Ophiuchus. About 7° north-northeast of Deneb is a lesser-known dark cloud, which nevertheless is pretty easy to see in good conditions. It cuts perpendicularly most of the way across the band of the Milky Way.

Midway up in the south on August evenings you'll find the roundish, bright glow of the Scutum Star Cloud. The great visual astronomer Edward Emerson Barnard called it "the gem of the Milky Way," and few would disagree.

Smaller, irregularly shaped patches of bright Milky Way stand out southwest of the Scutum Star Cloud. The Gamma Scuti Star Cloud is small but intense, and so, too, is the glowing knot of the Small Sagittarius Star Cloud, also known as M24.

At last, we arrive at the Large Sagittarius Star Cloud — the huge puff of steam rising from the spout of the Sagittarius Teapot. This wondrous region roughly marks the location of the physical center of the Milky Way Galaxy, though the actual galactic center is hidden by many thousands of light-years of interstellar dust. This swath of northwest Sagittarius and southeast Scorpius offers naked-eye wonders such as M8, the Lagoon Nebula, and the big open clusters M6 and M7, just above the Stinger of Scorpius. It's a satisfying place to wrap up our Milky Way holiday.

■ **FRED SCHAAF** enjoyed his best summer vacation 40 years ago when he saw a total lunar eclipse, sky-filling northern lights, and colorful volcanic twilights.

STAR ATTRACTION The most exciting Milky Way destination for stargazers is the rich swath found in the constellation Sagittarius, seen just above the treeline in this photo.

ALAN DYER

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

A "Double Transit" Night

Saturn reaches opposition as the Moon turns full.

WEDNESDAY, AUGUST 3

As the **Moon** makes its monthly journey eastward along the ecliptic, it passes by a handful of bright stars, and one of the brightest is 1st-magnitude **Spica**, in Virgo. Indeed, only Aldebaran, in Taurus, outshines it — and only by 0.1 magnitude. However, Spica is offset just 2° below that solar system superhighway known as the ecliptic, compared with 5½° for the Taurus luminary.

This evening the waxing lunar crescent is positioned 3° above Spica. This pairing is notable because it's the best one remaining in this year's dusk series. The twosome combines once again on the 30th, but on that occasion they'll be farther apart (4½°) and closer to the horizon. By the time the Moon revisits Spica in late September, the star will be just 20° from the Sun and lost in twilight's glare. You'll have to wait until November to see the Moon and Spica together again when the star re-emerges at dawn.

THURSDAY, AUGUST 11

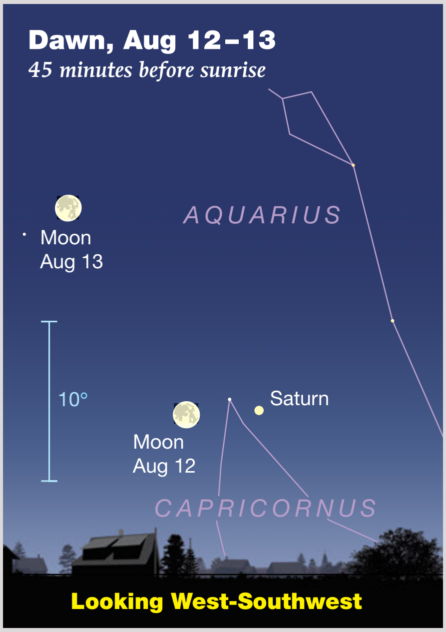
Tonight, we get a "double opposition." Sort of. Opposition occurs when a solar system body lies opposite the Sun's position in our sky. That happens (usually) once a month with the **Moon**, when it's full. With the outer planets, opposition typically occurs once a year. This year, **Saturn** reaches that milestone on August 14th, while this month's full Moon occurs late on the 11th — the two oppositions are separated by roughly 64 hours. You might expect that when two objects are opposite the Sun at the same time they'll be found in roughly the same region of sky — and you'd be right!

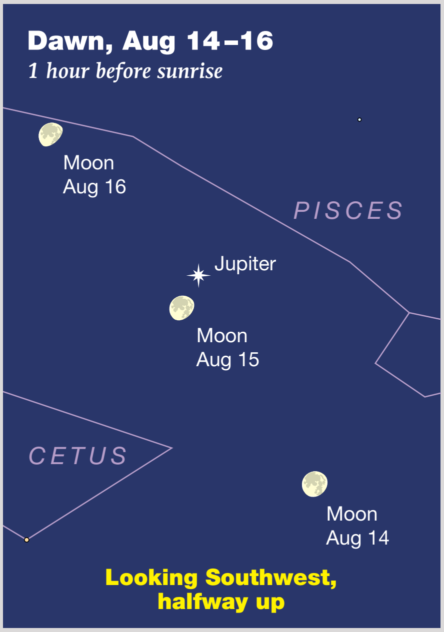
This evening +0.3-magnitude Saturn and the gloriously bright full Moon rise above the east-southeastern horizon in fading twilight, with just 5° separating them. As they arc across the sky, and the night of the 11th transitions into the morning of the 12th, the separation between the pair gradually diminishes until they're only 4° apart at around 4:30 a.m. EDT.

MONDAY, AUGUST 15

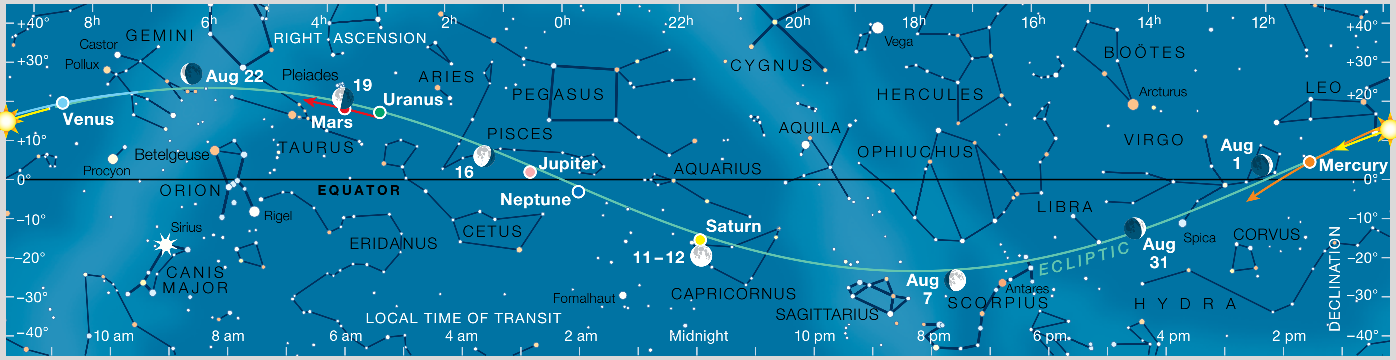
This morning the waning gibbous **Moon** sits only about 2° below left of brilliant **Jupiter**. It'll be a splendid naked-eye sight, but I encourage you to have your binoculars ready anyway. Thanks to the Moon's proximity to the –2.8-magnitude planet, you have a chance to see how late into twilight you can continue to hold Jupiter in view — first with your eyes alone, then with your binos. The Moon provides a handy signpost as twilight brightens and sunrise draws near.

I've observed Jupiter in a telescope in full daylight several times (with some careful hunting), but I don't recall ever seeing it in binoculars when the Sun is up. How about you? Jupiter and the Moon will be at their very closest at around 9 a.m. EDT, when they'll be slightly more than 1½° (three Moon diameters) apart. By then, it'll be daylight along the East Coast, but twilight will still be underway out West.





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

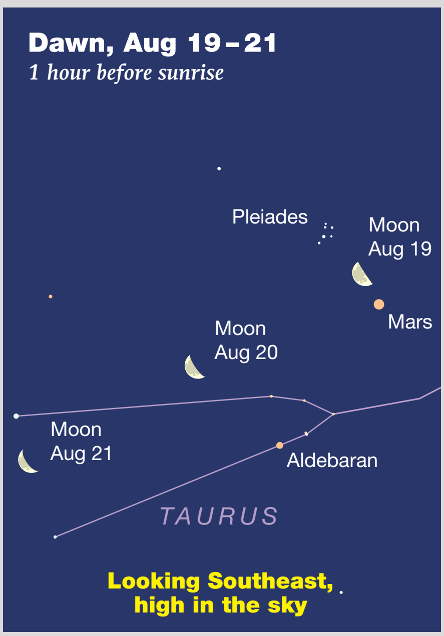


▲ The Sun and planets are positioned for mid-August; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

THURSDAY, AUGUST 18

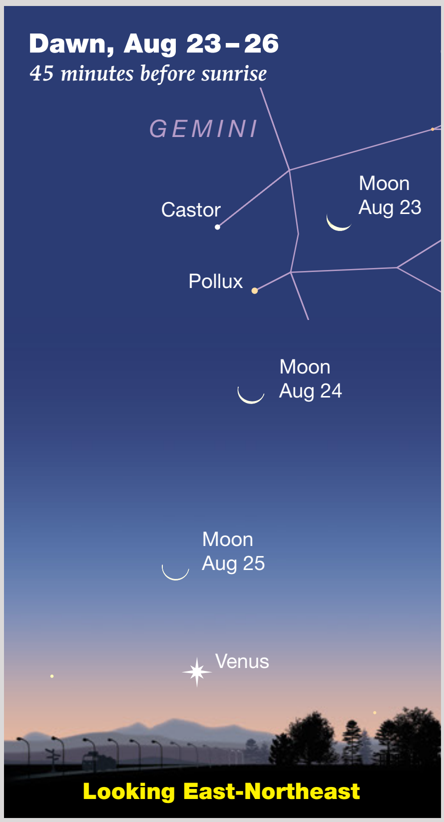
Venus is nearing the end of a long morning apparition that began back in January. Its reign as Morning Star still has another two months to go, but it's losing a little altitude with each passing morning.

At dawn today Venus is positioned just below the **Beehive Cluster** (M44), in Cancer. Here again, you'll be needing your binoculars since the Beehive stars aren't terribly bright, and right now they're competing with twilight, too. But with optics in hand, you'll be able to enjoy a very pretty sight as Venus temporarily becomes the brightest bee in the hive, albeit one buzzing around the cluster's outskirts. The brightness mismatch is extreme as the gleaming planet outshines the brightest cluster star by 10,000×! Venus and M44 rise 1½ hours before the Sun, so you won't have much time to take in the scene before twilight scares away the faint cluster bees.



FRIDAY, AUGUST 19

Mars has been gradually picking up steam as it climbs out of morning twilight and progresses toward its December opposition. On this date, it's a zero-magnitude ember in Taurus and is one component in a striking early-morning conjunction that also includes the last-quarter **Moon** and the **Pleiades**. The Moon will be parked directly between the Red Planet and the cluster at around 4 a.m. PDT, when it's less than 2° from Mars and about 3° from Alcyone, the brightest Pleiad. Wide-angle binoculars, (such as 7×50s) will allow you to comfortably hold all three objects in a single view. Mars is drifting eastward at ½° per day, so it'll quickly leave the Seven Sisters behind.



TUESDAY, AUGUST 30

While binoculars really helped show **Mars** and the **Pleiades** together on the 19th, this morning's sight is pure, naked-eye pleasure as the Red Planet sits between the Pleiades and the **Hyades**. Selecting the 30th as *the* date is a bit arbitrary since Mars is between the two open clusters for several days — on the 30th it just happens to be most precisely aligned with Aldebaran and Alcyone. But the truth is, the sight is no less appealing on the 29th or 31st. So, if weather interferes, you'll have a few backup dates to work with. Mars continues its eastward trek until the end of October, when it pauses, reverses course, and begins drifting westward.

■ Consulting Editor **GARY SERONIK** periodically treks eastward from his British Columbia home to visit the magazine's Cambridge offices.

Saturn at Opposition

August presents a fine opportunity to view the planet, its rings, and a handful of its brightest moons.

Spectacular Saturn comes to opposition on August 14th to the stridulations of summer crickets and katydids. Shining at magnitude +0.3 and presenting rings spanning 42″, the planet sits in eastern Capricornus. With the Sun setting earlier each evening and generally favorable late-summer weather, there's no better time for some public astronomy. If you own a telescope, I encourage you to share Saturn with everyone you can. More than a few lifelong skywatchers got their first spark of interest from a telescopic view of the ringed wonder.

After narrowing to 12.3° in June, the ring tilt increases to 13.9° in mid-August with the north face exposed. At low magnifications, telescopes show only a single ring, but 100× or more will subdivide it into three. (See the illustration presented on page 29.) Cassini's Division, a dark gap 0.8″ wide (at opposition), separates the outer A ring from the wider, brighter B ring. The innermost C ring (also known as the crepe ring) appears translucent. It's most easily seen where it crosses in front of Saturn's globe and looks deceptively like a shadow or cloud belt. The C ring also appears as a filmy, gray wedge in the space between the inner edge of the B ring and the planet's limb.

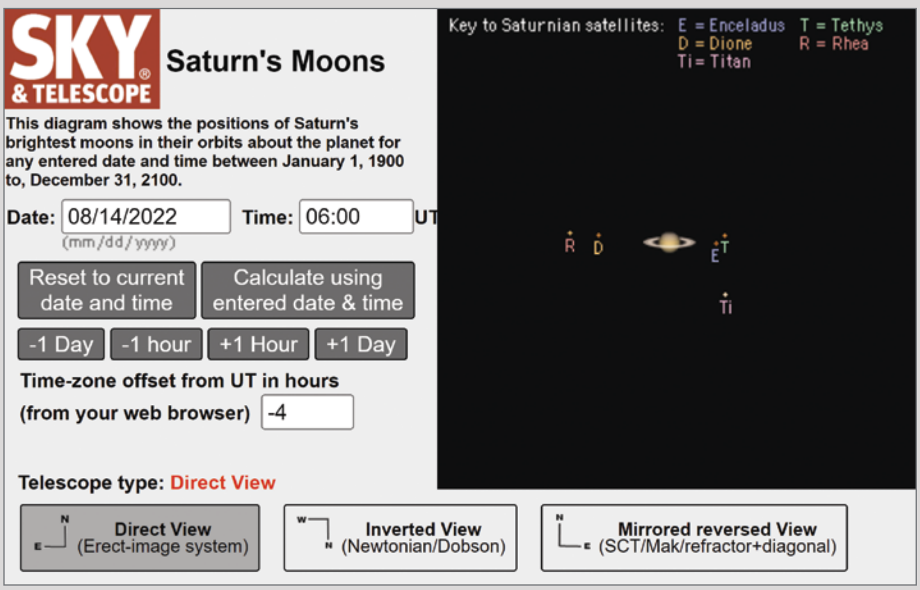
If you have a 10-inch or larger telescope and rock-solid seeing conditions, crank up the magnification to at least 400× and try for the much narrower Encke Gap, located within the outer edge of the A ring. The tiny moon Pan, just 35 kilometers (22 miles) across, orbits within the gap and clears it of material. You might also glimpse the broader but low-contrast Encke Minima, an ever-so-slightly darker band located midway in the A ring. Photographs often show the feature well, but it's a serious challenge for observers. Large scopes used under ideal seeing conditions also sometimes reveal tantalizing hints of dark spokes streaking radially across the broad B ring. See the feature on page 28 for more on this aspect of the rings.

Saturn's rings comprise billions of pieces of mostly water ice that range in size from sand grains to boulders as big as houses. A ring form may symbolize eternity, but astronomers have identified a steady flow of *ring rain* — water ice precipitating from the rings into the planet's atmosphere — that will drain away Saturn's signature feature within the next 300 million years or less. So much for eternity!

On nights of steady seeing, a 4-inch telescope used at magnifications of 100× or greater should reveal the brownish North Equatorial Belt and the gray "beanie cap" of the North Polar Region. The South Equatorial Belt remains hidden this apparition, but patient observers may spy the pale, gray band of the South Temperate Zone, south of the ring plane.

Saturn is attended by (at last count) 83 moons, most of which are tiny. However, eight of them are visible in amateur telescopes, including Titan (magnitude 8.4), Rhea (9.8), Tethys (10.3), Dione (10.5), Iapetus (10.2 to 11.9), Enceladus (11.8), Mimas (13.0),

▲ Saturn shows off its rings, Equatorial Zone, North Equatorial Belt, and North Polar Region in this photo taken on April 18, 2022. The dark band below the ring plane is the shadow of the rings on the planet's cloudtops. The lighter gray "shadow" just above the ring plane is the C ring, also known as the crepe ring.



▶ *Sky & Telescope*'s interactive online tool allows observers to identify which of the five brightest Saturnian moons is which. Alternatively, the tool can be used as a planning aid to show the arrangement of moons for a specific time and date in the future.

SATURN: CHRISTOPHER GO; TOOL: *S&T*

and Hyperion (14.3).

With a diameter of 5,150 kilometers, Titan is slightly larger than the planet Mercury and big enough to show a disk (0.8″ wide) at opposition. It's also one of the few moons to show a distinctive color — an unmistakable sunset-orange. Hyperion, the faintest of the eight, is actually easier to see than brighter Mimas because it orbits far from the planet's glare.

Iapetus has a split personality, with bright and dark hemispheres. During the eastern half of its 79.3-day orbit, the moon fades to 12th magnitude as we view its coal-dark side. West of the planet, it presents its reflective, icy face and shines nearly two magnitudes brighter. Iapetus reaches greatest western elongation around August 8th, making the first half of the month an ideal time to catch it.

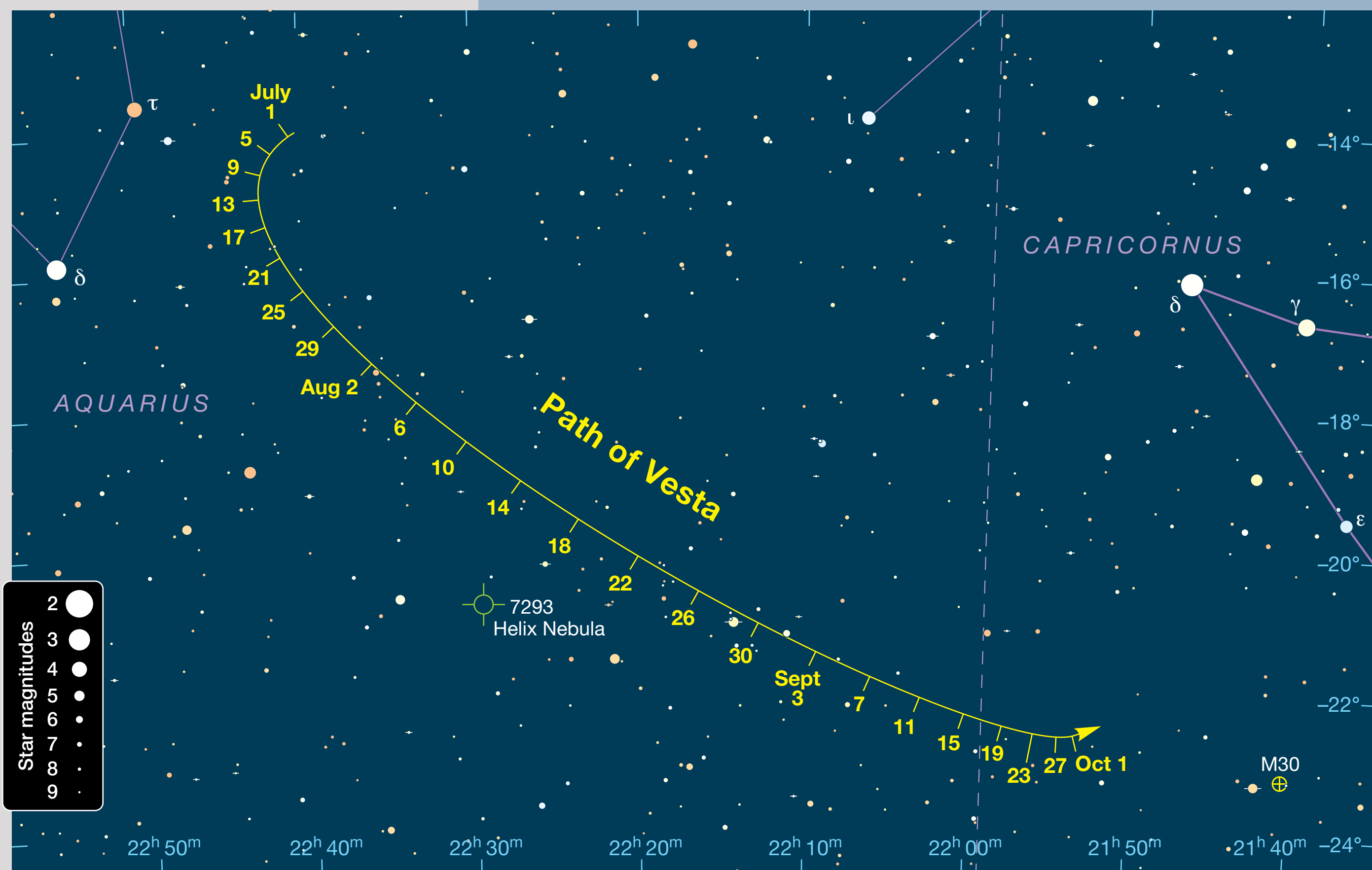
To keep track of the five brightest moons, use the interactive Saturn's Moons app, found on the Tools page at **skyandtelescope.org**.

Bright Vesta and a Double Shadow Transit at Jupiter

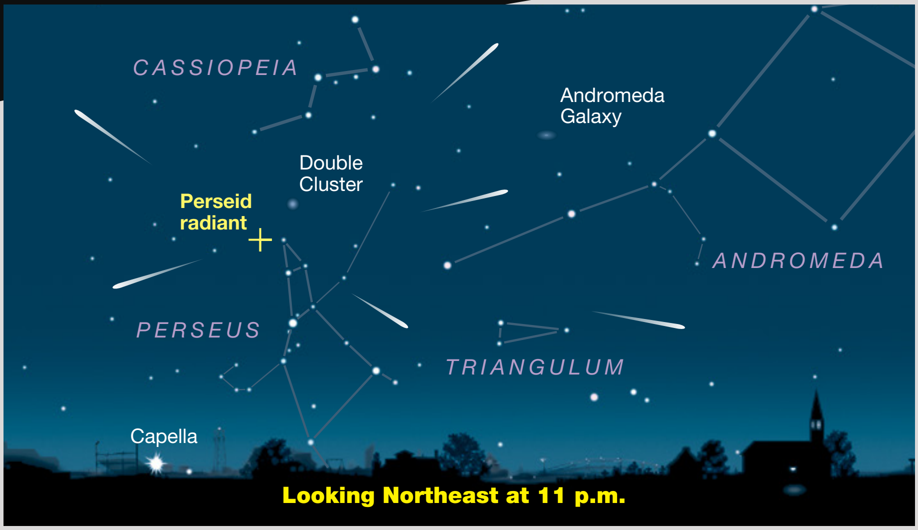
VESTA, THE SECOND LARGEST main belt asteroid, comes to opposition on August 23rd, when it brightens to magnitude 6.0. For much of the month, the 525-kilometer-wide object will be an easy binocular target as it treks westward across Aquarius. On the nights of August 14–16, Vesta passes 1.7° north of the large and ghostly Helix Nebula (NGC 7293).

If you're out tracking Vesta a week before its opposition, make a note to look in on Jupiter on the night of August 15–16 to see the double shadow transit of Io and Ganymede. As the table on page 51 lists, Io's shadow enters the planet's disk on August 16th at 3:24 UT (11:24 EDT, August 15) and is joined by Ganymede's shadow a few minutes later at 3:59 UT. The two inky dots will drift across the planet's disk from 3:59–5:38 UT (11:59 p.m. to 1:38 a.m. EDT). Jupiter will be well placed for viewing across the eastern two-thirds of the Americas during the transits.

Because the black Jovian moon shadows contrast strongly with the planet's cloudtops, they can be picked up with a surprisingly modest telescope. The key to observing shadow transits is moderate magnification (in the range of 100×) and steady seeing conditions.



▼ Vesta plies star-poor southern Aquarius this month and comes to opposition on August 23rd, just a few days after Saturn. Observers can hone their naked-eye skills by attempting to find the 6.0-magnitude asteroid without optical aid. (Vesta's position is plotted for 0^h UT.)



▲ The annual Perseid meteor shower reaches maximum on the night of August 12–13 but with reduced numbers due to light from the nearly full Moon. The meteors will stream from the radiant, which stands about 20° high at nightfall but climbs to more than 60° by the start of dawn, when you'll see the most activity.

Perseids Versus the Moon

THIS IS AN OFF-YEAR for the annual Perseid meteor shower as it peaks on the night of August 12–13, just one day after full Moon. Before you completely give up hope, though, remember that the display produces plenty of bright meteors and many spectacular fireballs. Moreover, the stream is broad, so we can expect at least a few Perseids darting about on clear nights from mid-July through the end of August.

During the shower's peak under moonless skies, 90 meteors per hour streak across the sky from a radiant in Perseus, below the familiar W of Cassiopeia in the northeastern sky (see the chart above). However, moonlight will reduce that number by about half. Although this year's peak occurs around 1 UT on August 13th (9 p.m. EDT on the 12th), you'll likely spot more meteors from 2 a.m. till dawn local daylight-saving time on the 13th, when the shower's radiant stands at its highest.

The Perseids are famous for outbursts, in which the counts can briefly double or even triple. Last year during the small hours of August 14th, a day after the predicted maximum, only about 45 meteors per hour were anticipated. Instead, skywatchers got a big surprise, with more than two streaks per minute. The reason? Earth ran into an unexpectedly dense filament of dust deposited by the shower's parent comet, 109P/Swift-Tuttle. What will happen this year? Moonlight or not, I'll be checking and encourage you to do the same.

Minima of Algol

Aug.	UT
3	4:33
6	1:21
8	22:10
11	18:59
14	15:47
17	12:36
20	9:25
23	6:13
26	3:02
28	23:50
31	0:39

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.

Action at Jupiter

AUGUST IS A BIG MONTH for Jupiter. On the 8th, it reaches the meridian before the start of morning astronomical twilight for the first time this apparition for observers at 40° north. On that morning, Jupiter will shine at magnitude –2.7, present a disk 46″ across, and attain an altitude of 52° just as twilight begins. You may want to continue observing Jupiter into twilight, however, since the planet's pastel hues become more apparent against a deep-blue sky. The giant planet spends the entire month in Cetus, near the border with the zodiacal constellation Pisces. Jupiter slips into Pisces on September 1st.

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

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.)

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

August 1: 8:47, 18:43; **2**: 4:39, 14:34; **3**: 0:30, 10:25, 20:21; **4**: 6:17, 16:12; **5**:

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

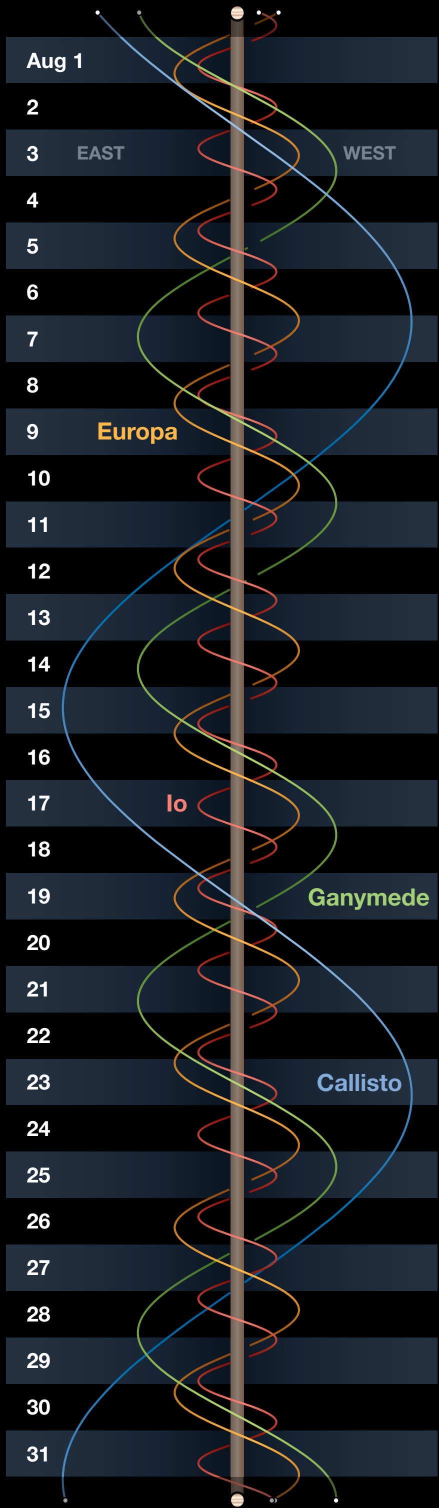
These times assume that the spot will be centered at System II longitude 23° on August 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 23° and 1⅔ minutes later for each degree more than 23°.

Phenomena of Jupiter's Moons, August 2022

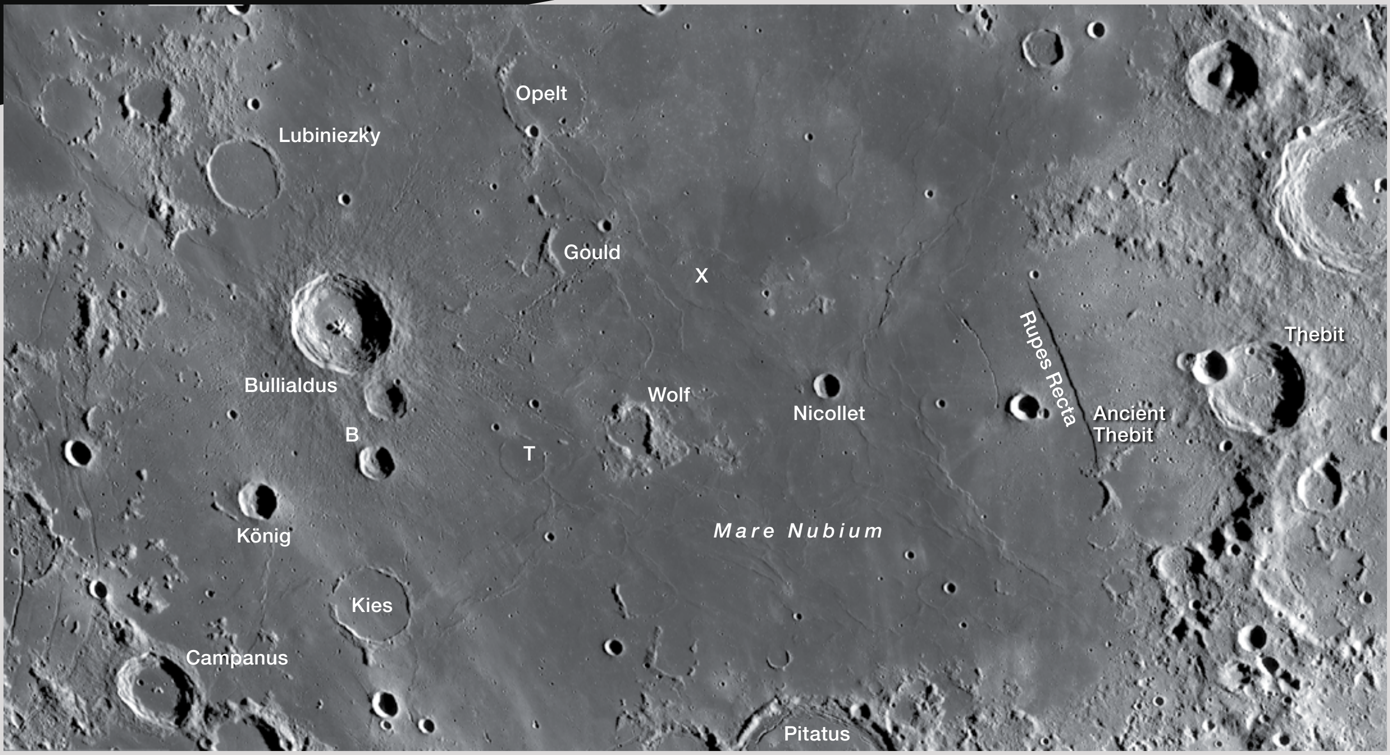
Aug. 1	2:27	I.Ec.D
	5:52	I.Oc.R
	19:57	III.Sh.I
	22:58	III.Sh.E
	23:36	I.Sh.I
Aug. 2	0:47	I.Tr.I
	0:59	III.Tr.I
	1:49	I.Sh.E
	2:59	I.Tr.E
	3:32	III.Tr.E
	11:13	IV.Sh.I
	12:03	IV.Sh.E
	12:50	II.Sh.I
	15:15	II.Tr.I
	15:25	II.Sh.E
	17:41	II.Tr.E
	20:55	I.Ec.D
Aug. 3	0:19	I.Oc.R
	18:04	I.Sh.I
	19:14	I.Tr.I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



NASA / JSC / ARIZONA STATE UNIVERSITY

Of Ghosts and Graveyards

Scan the lunar seas for rim islands and buried craters.

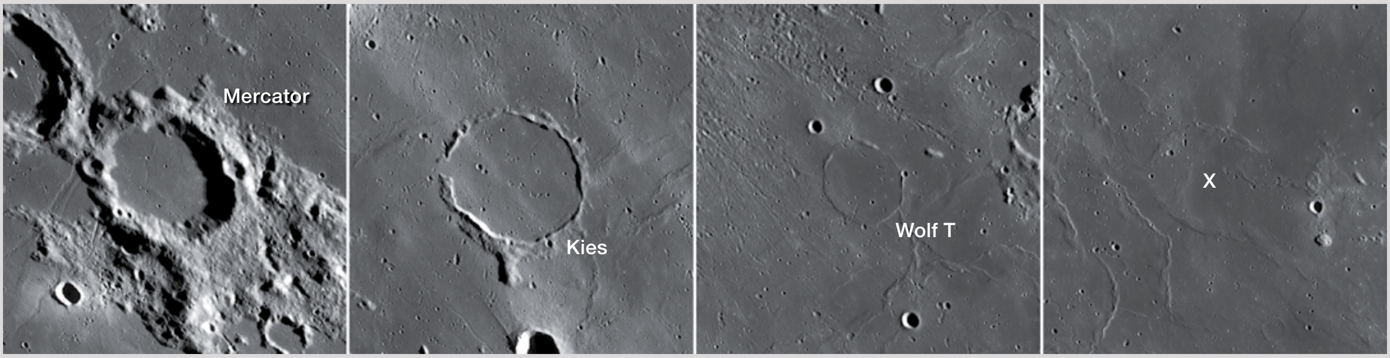
Innumerable impact craters formed throughout the Moon's 4.6-billion-year history. The creation of subsequent craters and basins obliterated many previously existing impact craters, while lava flows surrounded, flooded, or completely buried others. Eroded craters are shallow structures with rounded rims and are morphologically less dramatic than those that lava flows affect. Mare lavas breach crater rims, fill many large craters, cover ejecta deposits, nearly bury some craters, and totally erase others from the geological record.

One of the best places to observe the various stages of lava inundation is **Mare Nubium**. Unlike typical maria, this 700-km-wide (450-mile-wide) expanse isn't surrounded by rim remnants and lacks the gravitational anomalies found in other basins. The only hint that this particular mare fills an impact basin is that its center is roughly 400 meters deeper than its edges. Nubium probably was an ancient basin that exists now only as a shallow pond of lava. This thin veneer of basalt is what makes it an ideal crater graveyard, with all the stages of crater/lava interaction on display.

Let's start with **Bullialdus**, a 61-km-wide, complex crater with terraced walls and an uplifted central peak. Its ejecta of nearby radial ridges and more distant secondary craters clearly lie atop Nubium lavas. Bullialdus is the only large, morphologically fresh crater on Nubium; all others are affected by older lava flows. To the east, 15-km **Nicollet** is relatively new, though it's completely encircled by lavas and only the highest parts of its near rim ejecta remain. Slightly thicker piles of lava south of Bullialdus blanket the hilly outer-rim flanks of the 23-km-wide craters **König** and **Bullialdus B**.

The craters described so far are surrounded by lava flows originating outside the craters' rims. But along the southwest edge of Mare Nubium are two 47-km-wide craters — **Campanus** and **Mercator** — that have unbreached rims yet also feature mare-covered floors. The impacts that produced these two craters must have deeply penetrated the target rock, creating sub-floor fractures where magma erupted to fill the newly excavated depressions. A closer look reveals that the lava-covered floor of Campanus is about 1.4 km deeper than the neighboring mare, whereas Mercator's floor has the same elevation as Mare Nubium. The complex rim of Campanus is relatively crisp, suggesting that it's younger than Mercator, whose eroded rim lacks the terracing common to younger craters. Perhaps both Mercator and the neighboring mare were fed by the same magma source, and the lavas rose to the same level in both locations. A reasonable interpretation is that when Campanus formed later, less magma was available, producing a shallower flood.

At the southern edge of Nubium is another lava-flooded crater, 101-km-



▲ Several features in southern Mare Nubium illustrate the various states of mare lava inundation of pre-existing craters, culminating in the unnamed ghost crater seen at right.

diameter **Pitatus**. Its unbroken rim indicates that lava rose up from below its floor.

A more complicated crater is 26-km-wide **Wolf**, situated on a remnant of even older, rugged, pre-mare terrain. Its rim is broken, so some lava may have entered, though its floor is lower than the surrounding mare.

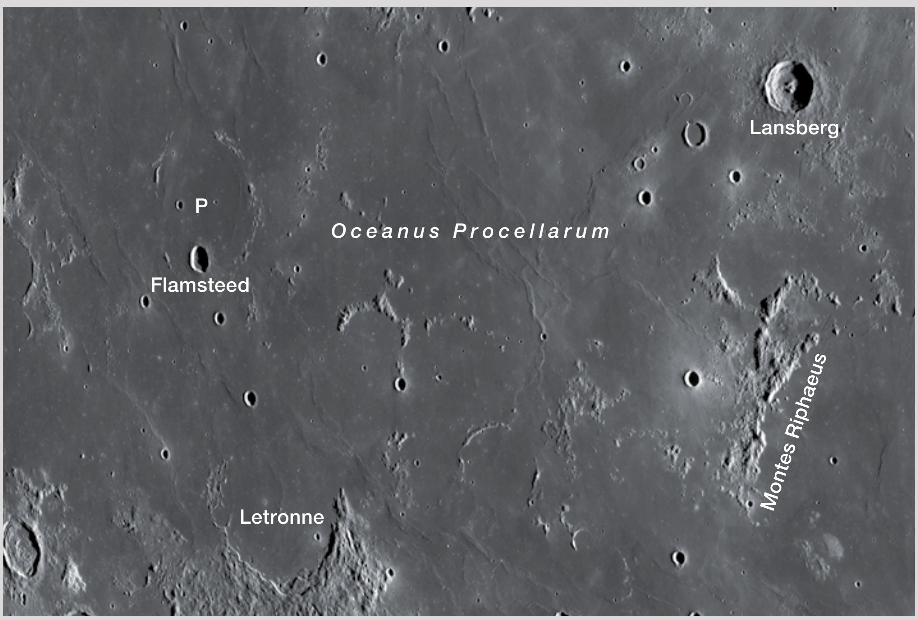
Typically, when mare lava flows encircle a crater and penetrate its rim, the entire floor becomes flooded to about the same elevation as the surrounding mare. Both 46-km-diameter **Kies** and similarly sized **Lubiniezky** are easy-to-find examples. The amount of a rim that's left exposed depends on the original rim height as well as the thickness of the abutting lava. A thicker pile of lava must surround 49-km-wide crater **Opelt** than encircles Kies and Lubiniezky, as only short arcs of Opelt's rim remain visible. Most interesting is a thin mare ridge where the western segment of the crater's rim would be, presumably caused by lava draping over the buried rim. To the south, **Wolf T** lies within a thicker pile of lava, converting its western half into a "ghost crater" delineated by mare ridges, while only pieces of the eastern rim crest remain. East of Gould is a complete, 35-km-wide, nameless ghost crater with a 250-meter-deep central sag. However, no remnants of its original rim are visible — only mare ridges. The feature's center is marked by an X in the images on the top of these pages. While observing Nubium, try to spot several other nearby lava-modified craters, especially the line of severely eroded and flooded examples south of Opelt.

Shifting our gaze northwest to **Mare Cognitum**, we find the arc of **Montes Riphaeus** — the remains of a flooded crater that must have originally been some 200 km wide. Continuing west across southern **Oceanus Procellarum**, we come to the battered ring of **Flamsteed P** spanning 112 km, and 118-km-wide **Letronne**, as well as other large, partial-rimmed, lava-filled circles. Because southern Procellarum has many flooded craters, its extensive lava plains must not be very thick.

Did you notice the one crater most dramatically altered by mare lavas? At the eastern edge of Mare Nubium, when the Sun is low, you may have spotted the 200-km-wide circular formation informally named Ancient Thebit. Its eastern rim is the half circle of mountains that 57-km-wide **Thebit** cuts, and whose western rim is represented by a half-circle of mare ridges. This western rim is usually overlooked due to eye-catching **Rupes Recta** (the Straight Wall), which cuts across the center of Ancient Thebit. The Straight Wall is a fault resulting from the western half of Ancient Thebit dropping down more than 600 meters sometime after the Nubium lavas filled the big depression.

As you explore these rimmed islands and wrinkly ridges with your telescope, keep in mind that piles of lava must have so thickly engulfed some craters that not even a circle of ridges exist to mark their existence. Rest in peace, you ghost craters.

■ Contributing Editor **CHUCK WOOD** doesn't wait for Halloween to search for ghost craters.



NASA / JSC / ARIZONA STATE UNIVERSITY (2)

Understanding Focal Ratios

This important optical parameter can help you produce better astrophotos.

◀ This deep exposure of the Sagittarius Milky Way features the Lagoon (bottom) and Trifid Nebulae. It was taken with a 200-mm f/4 camera lens. Fast glass gathers more light than slower optics, for cleaner, noise-free images.

RICHARD WRIGHT

One of the most fundamental principles of photography is that the more light you collect, the less image noise you'll have. This is especially relevant when it comes to photographing the night sky, in which a good signal-to-noise ratio is vital for pleasing results. The bottom line is simple: More light ("signal") is *good*.

You may think that boosting your camera's ISO setting is an easy way improve the situation, but doing so only makes the image *appear* brighter and does nothing to increase the amount of recorded signal. This is not the solution you are looking for — see "Understanding ISO" (*S&T:* Dec. 2021, p. 54).

Let There Be Light

There are a number of ways to get more light to your camera's sensor. The most obvious and intuitive approach is to increase the exposure length. You can accomplish this either by taking longer individual exposures or by capturing many shorter exposures and combining them afterwards with software. I discussed this topic in detail in the April issue (page 54).

A second way to gather more light is to use a larger imaging scope or camera lens. That makes sense — a bigger lens will collect more light than a smaller one. However, there's a second, less-obvious parameter that governs how bright your images appear: the *focal length* of the lens. While *aperture* governs the total amount of light the lens collects, the focal length affects both the image scale and brightness. As the focal length increases, the image becomes larger or more "zoomed in."

This sounds great until you realize that for a given aperture, the same amount of light is being spread more and more thinly as the image scale goes up. In other words, a 50-mm aperture lens with a focal length of 100 mm produces a brighter and smaller image of your target than a 50-mm lens of 200-mm focal length. A highly magnified nebula can become too faint to photograph well without a great deal of exposure time. To compensate, that 200-mm-focal-length lens would need twice the aperture (100-mm) to produce as bright an image as the smaller, shorter-focal-length lens.

To understand why, we have to consider the *focal ratio* (f/ratio) — the relationship between a lens's aperture and its focal length. To calculate the f/ratio, simply divide the focal length by the aperture. For example, a 100-mm aperture lens with a 400-mm focal length is an f/4 optic (400 ÷ 100). Camera lenses have the ability to vary their f/ratio with an iris that can constrict or open up in order to let more or less light in. "Opening up a lens" to let more light in is a standard operating procedure in low-light situations. It shortens the exposure time, which is why lenses with wide apertures are referred to as "fast," while those with smaller apertures are called "slow."

Telescopes and astrographs are built for a specific, fixed f/ratio and don't have adjustable f-stops. A 200-mm telescope with a 2,000-mm focal length (like a typical 8-inch Schmidt-Cassegrain) has a focal ratio of f/10. By contrast, a 200-mm astrograph with a focal length of 400-mm has an f/ratio of f/2. Both telescopes collect the same amount of light, yet the latter presents a much brighter image for your camera to record.

How is this possible? Very simply, you are trading the scale of a larger, faint image for a smaller, bright one in which the light gathered by the objective is more tightly concentrated. The net result is an astrophoto with less apparent noise.

Devilish Details

All this might strike you as counterintuitive. After all, if the amount of light collected is determined solely by the aperture of the lens, how can one optic produce a brighter image than the other? There are two reasons. First, more light is being delivered per pixel. In the f/2 system, much more of that 200 mm of light-gathering capacity is concentrated on your camera's sensor compared with the f/10 instrument.

Because faster optics deliver a brighter image, a popular accessory for astrophotography is something called a *focal reducer*. This is a lens that goes between your camera and telescope (or camera lens) and concentrates the light gathered by your optics into a smaller area — effectively reducing the focal length of the entire optical train and speeding up the f/ratio. For a typical Schmidt-Cassegrain telescope

▶ Changing the f/ratio of a camera lens is as simple as opening and closing a diaphragm to let either more or less light into the camera. Stopping down the aperture a bit from maximum usually results in sharper stars, particularly in the corners of the frame, but at the cost of less light reaching the camera's sensor.

▲ A telescope or camera lens can only produce a fully illuminated circle of a specific size. A focal reducer will yield a brighter image, but it may also shrink the image circle so much that your camera's entire sensor (indicated by the gold box, above) isn't being fully illuminated, resulting in the dark corners shown here.

VIGNETTING EXAMPLE: RICHARD WRIGHT; LENS APERTURE SERIES: GARY SERONIK

▲ Optics with the same f/ratio produce images of the same brightness regardless of the lens aperture. This pair of Andromeda Galaxy photos illustrates the concept. Both images are equally bright, but the left frame is cropped to appear more "zoomed in" to mimic the results of an instrument that has greater focal length than the one used for the full-frame portrait on the right.

with a native focal ratio of f/10, you can purchase a focal reducer that will transform the scope into an f/7 or f/6.3 system, depending on the model of reducer used.

Many refractors also have matching reducers available to accomplish the same optical trick. However, there are limits to this seemingly magical device. So far, there's nothing on the market that can convert an f/10 optic into an f/2 (leaving aside the HyperStar system that makes use of the native f/2 focal ratio of a Schmidt-Cassegrain's primary mirror). There are many factors involved, but suffice it to say, the best fast optics for photography are designed to perform that way from the start.

Another limitation when it comes to focal reducers is the size of the *fully illuminated field* — the diameter of the image circle. Your camera's sensor should completely fit inside this circle in order to capture all the light your optics can deliver. A focal reducer can recover light falling outside your camera's field of view, but if the new image circle is too small, you're going to end up with a photo with ugly dark corners. This can't be corrected in post processing. Your only option is to crop out the corners of the image.

The opposite of a focal reducer is a Barlow lens (for telescopes) or a teleconverter (for camera lenses). Most observers are familiar with the advantages of a Barlow lens for viewing small targets — such a device typically doubles (or more) the magnification of a given eyepiece. Barlows and teleconverters work the same way for photography and are handy for increasing the image scale. The downside is a slower f/ratio. For example, a 2× teleconverter used with a 100-mm f/2 lens yields a 200-mm lens, but with a maximum focal ratio of f/4. Our f/10 Schmidt-Cassegrain telescope fitted with a 2× Barlow would have a focal length of 4,000 mm, but with a focal ratio f/20! This would be prohibitively slow for photographing most deep-sky objects, but the Moon and planets are bright enough to make this combination practical.

▲ A telescope's effective focal length can be shortened with a focal reducer (bottom right) or lengthened with a Barlow lens (top). A teleconverter (bottom left) is used with a camera lens to increase its focal length.

With digital manipulation in post-processing, we can make an image as bright as we want. However, there's no question that fast focal ratios deliver more light to our camera's sensor — and more light always means a cleaner, smoother, more attractive final result.

■ **RICHARD WRIGHT** likes to shoot through both camera lenses and telescopes, and is always in search of faster glass for his astrophotography.

ANDROMEDA GALAXY PAIR: RICHARD WRIGHT; OPTICAL ACCESSORIES: GARY SERONIK

More Than Just a Pretty Crescent

NGC 6888 is a faint but seductive deep-sky wonder.

◀ **GORGEOUS WRECKAGE** Adrift roughly 5,000 light-years from Earth, the emission nebula NGC 6888 is a vast shell of gas sculpted by high-velocity winds from 7.5-magnitude WR 136. The exceedingly hot, massive Wolf-Rayet star shines some 600,000 times brighter than our Sun and is doomed to die in a supernova explosion. NGC 6888 is a subtle target for observers, who know it as the Crescent Nebula for its visual appearance in telescopes.

OLEG BOUEVITCH

First, the bare-bones truth: **NGC 6888** is no showstopper.

The pale object in central Cygnus known as the Crescent Nebula is barely visible without narrowband filters. But amateur astronomers embrace challenges, and NGC 6888 rewards those who scrutinize it in dark skies with large telescopes — in my case, Mount Kobau (sounds like "oboe") with an 18-inch f/4.5 Dobsonian. The ghostly Crescent doesn't repel us, it *attracts* us.

NGC 6888 certainly intrigues professional astronomers. They've designated this expanding cloud an emission nebula that's being excited by an enormous, decaying sun with the cryptic name **WR 136**. The WR stands for Wolf-Rayet. First noted in 1867 by French astronomers Charles Wolf and Georges Rayet, the spectra of Wolf-Rayet stars are characterized by broad emission lines predominantly of helium. Massive, luminous, and hot (likely descended from stars of spectral class O), they develop intense radiation pressure and winds. A Wolf-Rayet's violent behavior results in tremendous mass loss. In short, the star becomes unstable.

WR 136 is a classic case. Originally a star of perhaps 20 solar masses, its hydrogen-rich atmosphere has been stripped away. Intense radiation from the exposed helium core has since expelled gas in a high-velocity wind that has collided into a previously ejected envelope to create an elliptical shell about 25 by 16 light-years in extent, tilted roughly 45° to our line of sight.

Getting There

NGC 6888 lies 2¾° southwest of 2nd-magnitude Gamma (γ) Cygni, also known as Sadr. To get there, I enjoy a scenic Gamma-to-Crescent star-hop down the Cygnus Milky Way. My most recent ramble occurred on an exceptional night in August 2019 atop 6,100-foot (1,860-meter) Mount Kobau in southern British Columbia. Kobau's zenith sky can be described in a single word: black.

Gamma is enwreathed in an especially rich swath of stars and nebulosity several degrees across. Amid the Gamma glitter are four tiny clusters. The best of the bunch, 35′ north of Gamma, is **NGC 6910**. Starting the 18-inch at 64× that night, I saw two 7th-magnitude stars, 3¼′ apart, connected by a wavy string of 10th-magnitude pinpoints. Two more jutting from the middle of the string turned NGC 6910 into a squished letter Y. Cute!

The other three clusters are less appealing, but they promised double-star bonuses, so I hit 'em. A bit less than 55′ west-northwest of Gamma is **Collinder 419**, a compact clump obliterated by a 6.0-magnitude star. This beacon is **Struve (Σ) 2666**, which harbors an 8.2-magnitude secondary sun 2.8″ away. Around 40′ on the other side of Gamma, the cluster **Dolidze 10** is basically a minute rectangle. On its northernmost corner is **Dembowski 22**, a double comprising 8.2- and 9.5-magnitude stars 2.9″ apart. And 58′ south-southwest of Gamma, **Dolidze 5** yields five or six dim dots enveloping a teeny triangle. North of the triangle, **Σ2668** presents 6.3- and 8.5-magnitude elements separated by 3.5″. The three clusters and their embedded binaries were a snap at 128×.

After Σ2668, I returned to low power and swept southwestward 1½° to a lovely, north-south star pair, 2.2′ apart. The 7.1-magnitude northern component

▲ **CRESCENT IN THE SWAN** Spend some time in Cygnus this summer exploring the area around Gamma Cygni (Sadr, upper left), which includes NGC 6888, the Crescent Nebula (lower right). The carbon star RS Cygni is visible above left of the nebula.

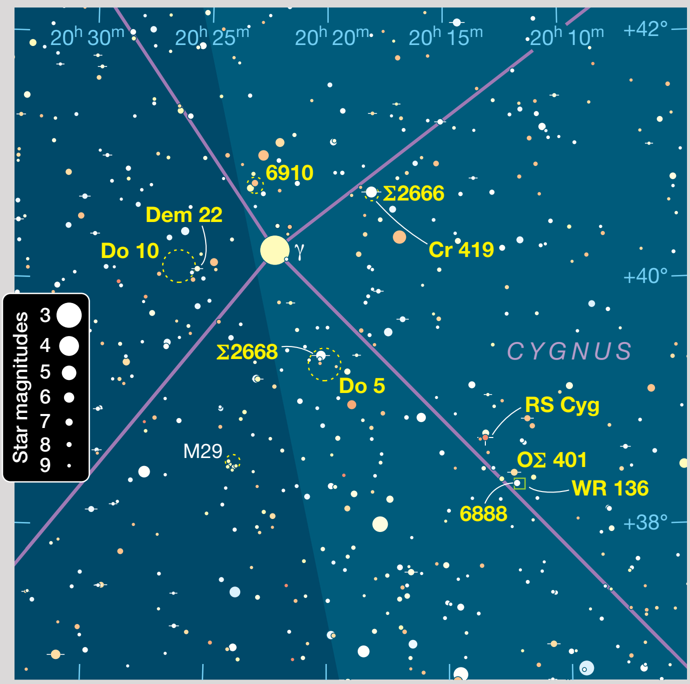
ALAN DYER

is bluish-white; the southern one is **RS Cygni**, a ruby carbon star (the color contrast varies as RS Cygni meanders between magnitude 6.5 and 9.5). Nudging the scope so that the blue-red tandem hugged the northeastern edge of my 1°-wide eyepiece field placed NGC 6888 in the center.

Really? I couldn't see it — at least not at first.

Initial Impressions

Fear not, Crescent-seekers. The field contains a ¼°-long, east-west, diamond-shaped asterism outlined by four 7th- and 8th-magnitude stars. The eastern half of the diamond overlays the top half of NGC 6888. Indeed, the diamond's second-brightest glint is the nebula's 7.5-magnitude progenitor, WR 136. The gossamer oval cloud, 18′ × 13′ in extent, lies on a northeast-southwest slant. Get that diamond and you've got your Crescent.



◀ **GAMMA-TO-CRESCENT** The Crescent Nebula, NGC 6888, lies less than 3° southwest of Gamma Cygni. Second-magnitude Gamma lies at the center of the Northern Cross. Four small open clusters located within a few degrees of Gamma are plotted and labeled here. Very few star atlases label all four clusters (Dolidze 5 is nearly always missing).

Or maybe not.

During my initial low-power examination of NGC 6888, all I saw was a mere wisp delineating the cloud's northwestern edge. The streak issued southwestward from the 7.3-magnitude double star **ΟΣ 401** (the shiniest member of the diamond). ΟΣ 401's yellowish primary hosts a 10.6-magnitude companion 12.8″ eastward. The star/streak combo resembled a comet sporting a split nucleus and slender tail.

The "slender tail" became more distinct with the aid of a doubly ionized oxygen (O III) filter. The O III extended my ersatz comet in both directions. From the "split nucleus," tendrils of cirrus at the nebula's northeastern end curve southeastward to terminate at an 8.2-magnitude star (it's the eastern point of the diamond). On the opposite side of NGC 6888, the comet's "tail" merges into fainter, feathery stuff that angles southward toward the southwestern end, where it re-intensifies and curls southeastward. However, the nebula's vanishingly thin eastern perimeter eluded detection. My perception of NGC 6888 was limited to an incredibly delicate celestial crescent.

Ah, but it's more than just a pretty crescent!

Seduced

My trusty voice recorder captured my reactions to several subtle features studied via three ultra-wide-angle oculars — all filtered. First up was a Pentax XW 30-mm coupled to a Lumicon O III. "I have 69× here, and I say wow! Lots of dark sky around the nebula. Still no eastern rim, but averted vision suggests a dusky interior. I'm seeing a small, roundish patch inside the curve at the southwest end, and a bit of fluff on either side of WR 136."

The "bit of fluff" was part of a bridge of material connecting the sharp western rim to the tenuous eastern fringe. The bisecting bridge passes WR 136 to morph the Crescent from a backwards letter C into a ragged numeral 3. But unless conditions are good, that's a bridge too far. Ace deep-sky observer Steve Gottlieb has detected some of the span in his 18-inch scope. In a recent article (*S&T:* Aug. 2019, p. 31), Steve noted that from the western rim, "a filamentary triangular wedge forms a diffuse bridge to the central WR star." The portion trending farther southeastward from WR 136 is more difficult.

Next, I threaded the O III into an Ethos 13-mm eyepiece: "Oh, nice. 158×, yet the 100° field surrounds the nebula with plenty of dark sky. The western border becomes discontinuous and splotchy south of where the 'comet tail' fades out. The patch just inside the southwest end is quite obvious. The rest of the interior is featureless, though, and that bridge is a tough sell. Alongside the southwest end is a short arc of four faint stars. They're fuzzed by the filter, yet they accentuate the curving rim. Cool effect!"

And finally, I tried a friend's 21-mm Ethos and a Tele Vue Bandmate O III. The result was total satisfaction. "This is one fine combination. It's 98×, and the contrast is better. Lots of surrounding dark sky. The patch at the southern end is prominent, the interior is now slightly greyish; even the bridge is fleetingly visible. The view is ethereal and seductive."

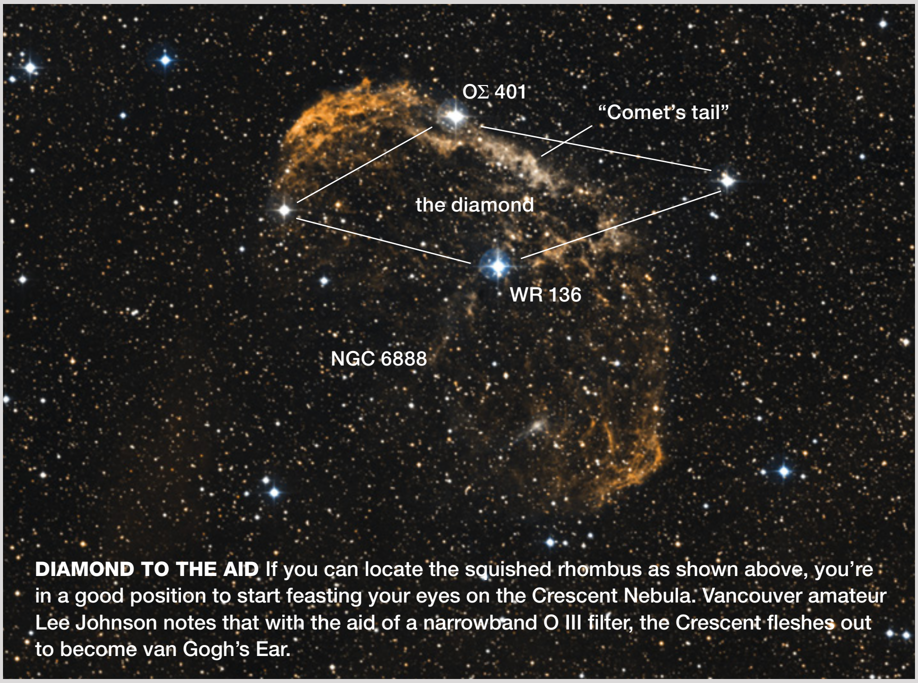
The friend cited above, Vancouver amateur Lee Johnson, capped our session on an artistic note. Lee, eyeing a pallid, oval mist, bright along one edge, calmly stated: "I call it van Gogh's Ear. Remember 19th-century Dutch master Vincent van Gogh, who cut off his left ear in a fit of rage? Well, this is his disembodied ear adrift in space."

So much for ethereal!

Final Impressions

After studying NGC 6888 through those eyepiece/filter combinations, I knew it better than ever. So, the inevitable question remained: Could I trace the Crescent *without* filters? The answer surprised me.

Shuttling between 98× and 158×, I couldn't miss the "comet" streak, nor the strong curves delineating both ends of the oval. NGC 6888 in natural light reminded me of the Veil Nebula (western component) glimpsed in a small scope. With patient staring, I ultimately perceived an elliptical "egg shell" enveloping a filmy, essentially translucent interior. Satisfying!



DIAMOND TO THE AID If you can locate the squished rhombus as shown above, you're in a good position to start feasting your eyes on the Crescent Nebula. Vancouver amateur Lee Johnson notes that with the aid of a narrowband O III filter, the Crescent fleshes out to become van Gogh's Ear.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

Yet, I wanted more. I'd been intrigued about something former *S&T* Contributing Editor Sue French mentioned in her excellent book *Deep-Sky Wonders* (Firefly). Sue commented that "Observers with large scopes report ripples of material adorning the entire nebula." Those "large" scopes must dwarf my Dob because I've never witnessed ripples (they do show in photos, though).

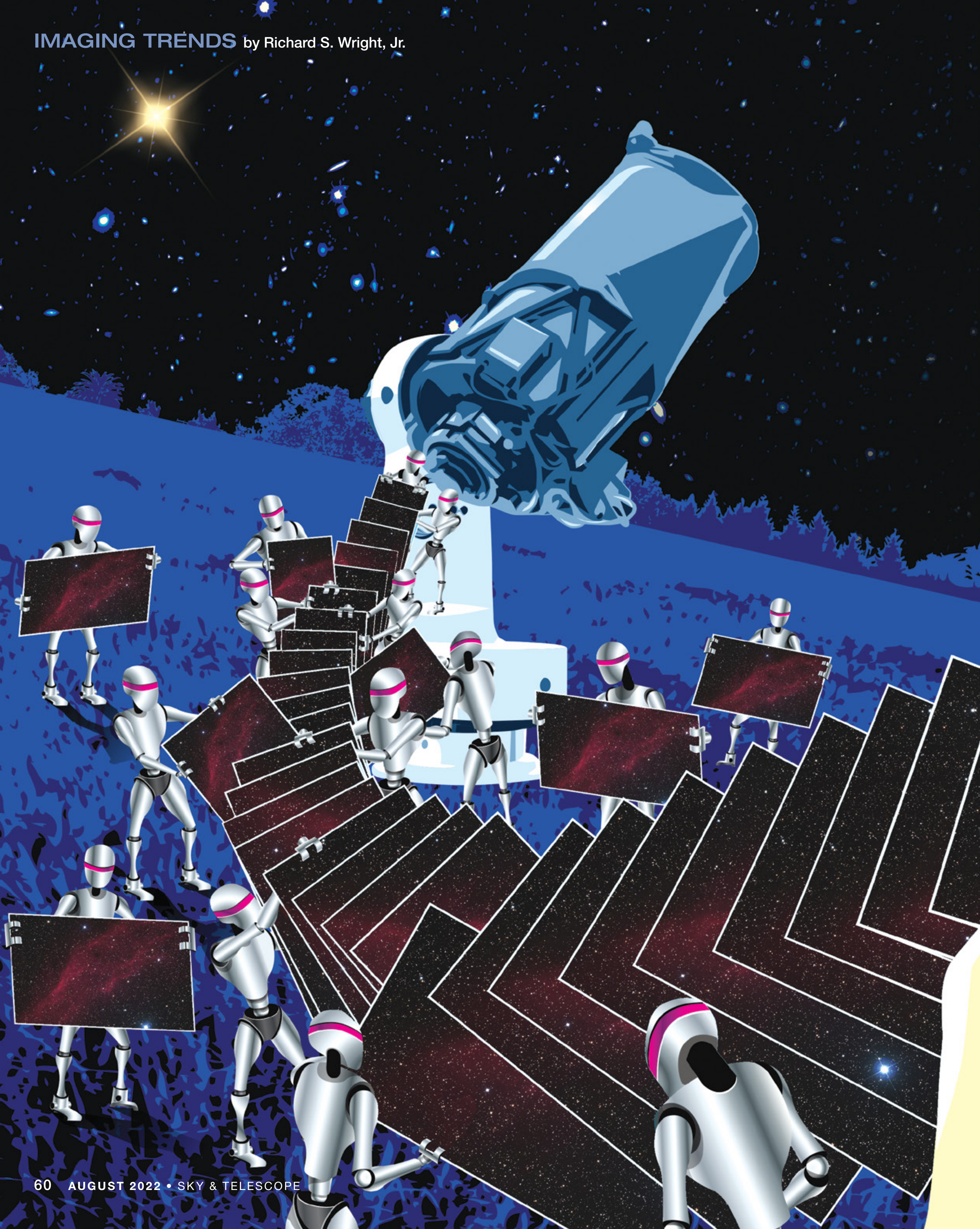
Since that pristine night, I've wanted to revisit NGC 6888 to probe its softly textured interior. Alas, my attempts have been thwarted — first by lousy weather later in 2019, then by pandemic restrictions (2020), and raging wildfires (2021). My longing for another look continues.

■ Contributing Editor **KEN HEWITT-WHITE** conducted the fieldwork for this article on a single August night during the 2019 Mount Kobau Star Party.

Celestial Crescent

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 6888	Bright nebula	—	18′ × 13′	20^h 12.0^m	+38° 21′
WR 136	Wolf-Rayet star	7.5	—	20^h 12.1^m	+38° 21′
NGC 6910	Open cluster	7.4	10′	20^h 23.2^m	+40° 47′
Collinder 419	Open cluster	5.4	4.5′	20^h 18.1^m	+40° 44′
Struve 2666	Double star	6.0, 8.2	2.8″	20^h 18.1^m	+40° 44′
Dolidze 10	Open cluster	—	15′	20^h 26.3^m	+40° 07′
Dembowski 22	Double star	8.2, 9.5	2.9″	20^h 25.5^m	+40° 06′
Dolidze 5	Open cluster	—	10′	20^h 20.5^m	+39° 22′
Struve 2668	Double star	6.3, 8.5	3.5″	20^h 20.3^m	+39° 24′
RS Cygni	Carbon star	6.5–9.5	—	20^h 13.4^m	+38° 35′
ΟΣ 401	Double star	7.3, 10.6	12.8″	20^h 12.2^m	+38° 27′

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



THE NEXT BIG THING

Deep-sky astrophotography is rapidly evolving, and in some ways the future is already here.

It seems that every few years someone states, "We are in the golden age of astrophotography!" This is usually followed by a string of examples explaining why they believe it to be so. Here we are again at a crossroads, with astro-imaging gaining traction in popular culture beyond the amateur astronomy community. And much of this is driven by smartphones, microcomputers, CMOS detectors, and even gaming consoles.

Deep-sky astrophotography is again at the cusp of a revolution. It's an amazing time to be sure, and we're seeing things we never thought would be possible — mounts so accurate they don't require guiding corrections during long exposures, cameras more sensitive than ever, and tiny computers that ride along with the telescope while orchestrating the tasks of a host of accessories. Astrophotography has an amazing journey ahead. Here's where I see it going next.

DANIEL HERTZBERG

The Times They Are A-changin'

We saw one revolution already at the close of the 20th century. Film astrophotography, with its chemical processes, darkroom artistry, and gas-hypering alchemy, gave way to the environment of digital cameras, specialized computer software, and the virtual darkroom. But even that familiar scenario will eventually become the exception rather than the rule.

Everything having to do with astrophotography is changing, including the optics we use. Commercially produced telescopes and camera lenses are better than ever, thanks both to advances in computer-formulated optical designs and the addition of new materials such as extra-low-dispersion glasses. Fast, high-quality optics are easily accessible and more affordable than ever. For example, with a mirrorless camera with a tripod and an f/1.4 lens, you can now record a Milky Way image in under 10 seconds with equipment that doesn't cost a small fortune. An f/7 telescope, once considered photographically "fast" by deep-sky imagers, is now passed by unless it's paired with a reducer/flattener. Scopes with focal ratios of f/5 and f/4 are now the norm, with even f/2 instruments available from several manufacturers. I currently own three telescopes that produce sharp, round stars across a full-frame camera sensor at f/3 and faster — a feat that was until recently considered prohibitively expensive.

The same goes with the detectors in our cameras. CMOS chips today exceed the performance of CCDs. Some CMOS camera manufacturers are closing in on the effective elimination of read noise and achieving the maximum quantum efficiencies possible for digital detectors. What's next? I have some ideas, and I'm not the only one.

◀ **AI FOR YOUR DSLR** Products like the Arsenal 2 add a Graphics Processing Unit (GPU) to your camera for remote-controlled computational photography assistance. This device adds new capabilities to your camera, including focus stacking, high-dynamic-range compositing, and even accurate auto-focusing on star fields.

▼ **FAST AND DEEP** This image of the Milky Way was recorded with a single, 10-second exposure made with a Canon EOS Ra operating at ISO 3200 and an f/1.4 Sigma Art lens on a stationary tripod. The same photograph taken with a DSLR a dozen years ago would have been riddled with noise and would have barely shown our galaxy at all.

RICHARD S. WRIGHT, JR. (2)

Computational Photography

When a process can't be improved, the only thing left to do is to change the process. Any student of modern history understands that today's amazing, leading-edge, expensive technology is only a few years away from being cheaper and small enough to fit in your pocket or strapped to your wrist. A good example is my Apple Watch. It can monitor my heart rate, read my blood-oxygen level, make international phone calls for free, and, if I ask it to, find all the dog photos on my paired smartphone. We already live in the future!

The next big buzzword creeping into the conversation about astro-imaging is *computational photography*. In fact, computational photography is already revolutionizing photography. You're most likely already taking it for granted.

Computational photography is when computer processing is used to aid or improve photography in-camera. We already have handheld cameras (in your smartphone) that combine multiple exposures of varying lengths to create high-dynamic-range (HDR) images. That same smartphone camera will take as many as a dozen or more very short images in low light, then align and combine them to make a single, low-noise image — all happening automatically in your device while you watch. Today I can take a 5-second, handheld exposure in low light without a tripod, and it won't be a smeared mess. These are all examples of computer processing being applied while the image is recorded to dramatically improve the capabilities of our cameras and the quality of our photos.

This technology is still in its infancy, as improving computational power continues to increase the capabilities of image- and graphics-processing technologies. In every case, industries outside of astrophotography are driving these technologies forward. You're probably familiar with a Central Processing Unit (CPU) — the "brain" at the heart of most computer systems. Another acronym you may be less familiar with is GPU, or Graphics Processing Unit, a term coined by the hardware graphics accelerator company NVIDIA in 1999. Today, GPUs power 3D simulations and games in computer and gaming consoles, and the performance improvements they've made possible are staggering. Computer images are simply numbers, and a modern GPU can perform trillions of numeric calculations every second, making those 3D-rendered games run smoothly. Many of the latest advances in our smartphone-camera capabilities have arisen because your smartphone, just like your laptop or desktop computer, now comes with an integrated GPU.

Live Stacking

Sure, this technology is amazing, but what does it have to do with astrophotography?

Nearly all astrophotographers are familiar with the term *stacking*, in which many exposures are combined to increase the resulting image's signal-to-noise ratio. (See my recent article "Image Stacking Demystified" in the April 2022 issue, page 54.) Some astronomy-specific, camera-control software packages for planetary imaging have added a new feature called *live stacking*. In this computational process, your camera takes a batch of very short exposures — perhaps only a few seconds each — and your computer aligns and combines them in real time, just as in your smartphone. Santa Barbara Imaging Group (SBIG) implemented the earliest incarnation of live stacking for astrophotography way back in the 1990s. SBIG's program simply accumulated the images as they downloaded from the camera, but the action was limited by the accuracy of the telescope's tracking capabilities — periodic error in the tracking mount would produce oblong stars in the resulting stack. Today's new live-stacking algorithms take advantage of faster computers equipped with powerful CPUs and GPUs to align and stack your image sequence. This means the telescope only needs to track flawlessly for several seconds at a time for the stars to remain round in each image. In fact, equatorial tracking isn't necessary at all, because field rotation won't be visible in such short exposures.

A few years ago, ATIK (**atik-cameras.com**) introduced the Infinity, a camera/software combination that performs live stacking. However, any camera can be used for live stacking with a computer and the right software. MallinCam's control software also does live stacking with its cameras (**mallincam.net**). *SharpCap* (**sharpcap.co.uk**) is another inexpensive option with live stacking that can control products from a growing number of manufacturers. I wrote the alignment routine that can do this with Software Bisque's *TheSkyX Imaging Edition* (**bisque.com**), and it runs fast enough to be used on a small, ride-along computer.

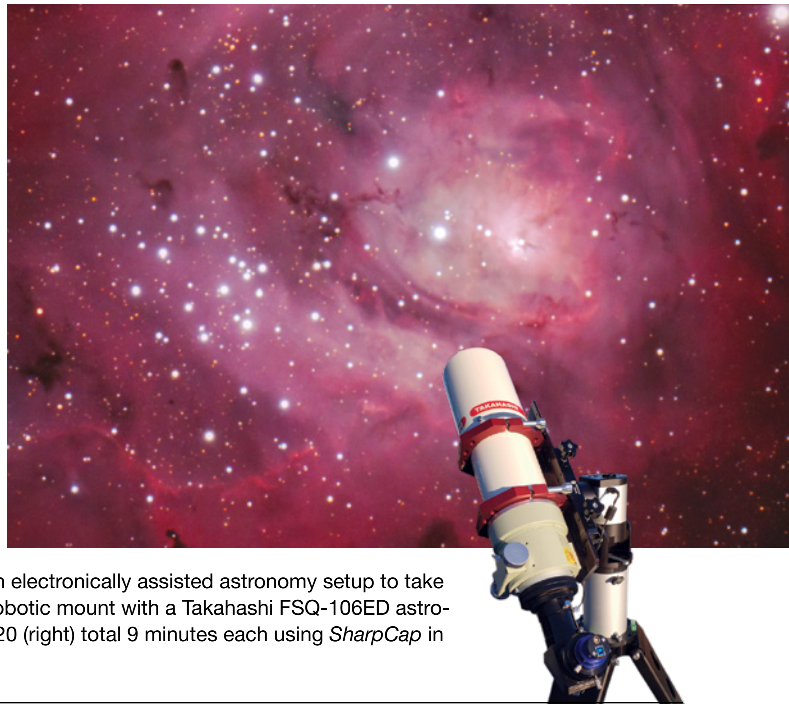
◀ **SHRINKING COMPUTERS** Tiny, power-efficient computers like this PrimaLuceLab Eagle 4 will be taking the place of your laptop at the telescope soon. An integrated GPU is also a standard feature of these devices and one day will be doing much of the heavy lifting as your images download from the camera.

A few commercial products on the market today combine all these capabilities. The Vaonis Stellina and Unistellar eVscope (reviewed in *S&T:* Mar. 2020, p. 68 and *S&T:* Dec. 2020, p. 66, respectively) are completely integrated telescope systems that incorporate live stacking, autonomous alignment, and *plate solving* (matching star patterns to identify field coordinates) to make imaging easier than ever before. Such "observation stations" can send their images to several connected smartphones or tablets simultaneously and let multiple people image with the same scope.

Many accomplished astrophotographers I've chatted with discount these products as insufficient for their needs. Well, of course, they're not going to work for everyone, for the same reason a wedding photographer wouldn't give up a medium-format camera if given a choice to use a smartphone camera, would they? The barrier to entering the hobby of astrophotography has historically been prohibitively high, both in terms of monetary cost and in the steep learning curve needed to attain the skill necessary to effectively use highly sophisti-

▼ **AUTOMATED IMAGING** This is the future: completely integrated imaging systems like the Unistellar eVscope 2 (left) and Vaonis Stellina (middle) that perform live stacking and image processing while you watch. Results like the image of the Running Man Nebula (right) excite beginners, and eventually these systems will deliver extremely high-quality results.

RIDE-ALONG COMPUTER: JOHNNY HORNE / *S&T*; OBSERVING STATIONS: SEAN WALKER / *S&T* (2); RUNNING MAN NEBULA: RICHARD BERRY



▲ **HIGH-END ASSIST** Astrophotographer John Gleason assembled his own electronically assisted astronomy setup to take high-quality, live-stacked images. He combined a Rainbow Astro RST-150 robotic mount with a Takahashi FSQ-106ED astrograph with a QHY5III-462C color camera. These images of M20 (left) and M20 (right) total 9 minutes each using *SharpCap* in Livestack mode. Gleason then processed the images in *Adobe Photoshop*.

cated gear and complex processing techniques. Products like the Stellina and eVscope may seem pricey to some, but they are cutting-edge technology bringing astrophotography into the mainstream. New, disruptive technologies that upend entire industries almost always seem crude and expensive at first, but it rarely stays that way for long.

Live stacking is the future. How short an exposure can be for it to be useful for stacking a deep-sky image is limited only by the camera's read and pattern noise. As mentioned, these noise sources are already on a trajectory towards insignificance. The day is coming when there will be virtually no effective limit to how short exposures can be, or how many frames can be combined to produce results equivalent to the lengthy exposures we need today.

Capturing, storing, and processing thousands or even tens of thousands of 30-megapixel deep-sky images may seem like an insurmountable hurdle today, but this is just a temporary situation. My first hard drive stored 20 megabytes of information, which isn't enough room to save a single raw image from my Canon EOS Ra mirrorless camera. Hard drives, CPUs, and GPUs are improving all the time. You can pick up a 10-terabyte hard drive for about $150 on Amazon right now. And then there's "cloud storage," which is entirely online. Imagine what will happen when we can upload massive amounts of data without needing large hard drives at all.

Always Room for Improvement

Until fast and plentiful cloud storage becomes a reality, there are other ways live stacking can improve that won't require massive storage space. Arthur C. Clarke's Law of Revolutionary Ideas states that every important new idea evokes three stages of reaction:

1: "It's completely impossible — don't waste my time."
2: "It's possible, but it's not worth doing."
3: "I said it was a good idea all along."

Many are still at the second stage, though I'd count myself as fully embracing stage three. I think the next step in live stacking deep-sky images may be to simply save the intermediate results every 5 minutes or so. Then you'll have a folder full of 5-minute (effective) exposures that you can process later.

All common post-processing routines will eventually be done by an artificial intelligence computer algorithm: Subexposures will be calibrated on the fly and have advanced noise-reduction techniques applied as they are saved. Airplane and satellite trails will be detected and rejected immediately. Sophisticated histogram-stretching operations will be performed on images before you even see them. Lucky imaging will also be revolutionized by faster computers that can evaluate and discard sub-par frames in real time, reducing data storage requirements tremendously.

Making eye-catching astrophotos is more than collecting and assembling data — and that part of the process, the "art," will never go away. But make no mistake — live stacking is the future, astrophotography is going mainstream, and getting impressive results will not take nearly as much work as it does now.

Until then, we'll keep moving forward. We can't really see what the future holds entirely, but I'm sure it will be amazing when we get there.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** is a Senior Graphics Software Engineer at LunarG, Inc., where he specializes in high-performance GPU technologies.

JOHN GLEASON (3)

Solar Everything

SOLAR ASTRONOMY: *Observing, Imaging, and Studying the Sun*

Edited by Christian Viladrich
Axilone, 2021
solar-astronomy-book.com
480 pages, ISBN 979-10-92974-08-9
US$75, softcover

IF YOU'RE AN AMATEUR astronomer with a particular fixation on our star, then this book is for you. *Solar Astronomy: Observing, Imaging, and Studying the Sun* is a (quite possibly *the*) compendium of information about solar astronomy with an emphasis on modern equipment and imaging techniques. That said, it's a lot to take in, so be prepared.

Solar Astronomy is an update and English-language translation of *Astronomie Solaire*, published in France in 2018. The book's stated goal is to be a comprehensive guide to solar-observing techniques, and its cast of 14 authors helps make it such. Each contributor has his (yes, they're all male) own area of expertise. Some are telescope makers and engineers; others are historians or specialize in imaging and data analysis.

This lavishly illustrated book begins with a short history of solar observing, from pre-telescopic times through the current epoch of space-based solar observatories. Chapters on understanding the Sun and on safely observing it follow.

> *Solar Astronomy* comes loaded with useful information for practicing amateurs, exploring its subjects in a way that will give readers lots of ideas for their own future projects.

Solar Astronomy dives more deeply beginning with Chapter 4's discussion of observing conditions. Christian Viladrich breaks down how your surroundings can strongly influence local seeing conditions and how to plan your observing location to take advantage of its more positive aspects. For example, it's generally better to observe in the morning when the ground temperature is cooler than the air. Seeing can also be improved by surface wind, which can disperse heat radiating from the ground that would normally degrade the view.

Chapter 5 begins the book's main course with discussions of telescopes for solar observing. Viladrich thoroughly considers each principal type of device: refractors (from singlets to triplets), reflectors, and catadioptric instruments. He ponders the pros and cons of each and how they differ for solar work.

The next three chapters (encompassing a full third of *Solar Astronomy*) detail how to observe different regions of the solar atmosphere and what equipment is specialized for each task. The focus here is on the photosphere and chromosphere, and the authors include cutaway diagrams of the filters and custom instruments best suited to observing these solar zones. The lion's share of the space is dedicated to the calcium II and hydrogen-alpha regions of the solar spectrum.

The authors take an impartial approach to discussing the commercial equipment. It's fascinating to learn the inner workings of complex solar filters like the Fabry-Perot etalon, or the actual benefits of stacking multiple filters.

Altogether, this book covers everything you'd ever want to know about solar observing and imaging. Readers will find tips on focusing as well as subsections on digital sensors, image acquisition, and processing routines for popular planetary-imaging software.

Interested in sketching the Sun? Chapter 10 describes how this activity improves your observing skills and offers pointers on how to get the most from quickly evolving solar features. How about solar radio astronomy? Chapter 13 explains what you can do with amateur equipment, including instructions on how to build a radio telescope to investigate our star yourself. Is your special interest observing and photographing total solar eclipses? Chapter 14 has those subjects covered.

In sum, *Solar Astronomy* comes loaded with useful information for practicing amateurs, often exploring the minutiae of equipment, image processing, and custom telescopes in a way that will give readers lots of ideas for their own future projects. Ken Harrison and Peter Zetner did an excellent job translating from the French, though many odd sentence structures and curious punctuation remain. These aspects, however, won't deter the serious reader of this tome, which should be on the bookshelf of every solar aficionado.

■ Associate Editor **SEAN WALKER** is excited to try some new solar-imaging techniques he picked up in the process of reviewing this book.

Nightscaping with Sequator

This handy software adds the power of image stacking to landscape astrophotography and more.

▲ The free PC program *Sequator* enables users to stack dozens of short exposures to produce deep, noise-free images of the Milky Way over a stationary landscape. It also works for the occasional bright comet, as this image of Comet NEOWISE (C/2020 F3) demonstrates. It was recorded on July 21, 2020, from the author's light-polluted backyard and comprises one hundred 6-second exposures recorded with a Nikon D3300 and a 50-mm lens at f/2.8.

Sequator

U.S. Price: free

https://sites.google.com/view/sequator

What We Like

Freeware

Automatic alignment and stacking

Accepts RAW camera files

What We Don't Like

Occasionally fails to align images accurately

Auto brightness sometimes overly aggressive

PHOTOGRAPHING THE STARRY SKY over a picturesque landscape can be challenging. The best results tend to come from photographers using the latest digital cameras and fast lenses. In addition, exposures lasting more than 10 seconds or so also require a camera mounted on star tracker in order to record stars as pinpoints of light rather than elongated streaks. That's a significant piece of extra equipment if you're travelling to a scenic vista to capture the star-filled sky.

But what if the only gear needed to take deep nightscapes were your camera, lens, and tripod? And what if none of the equipment needed to be top-of-the-line? As for many of today's problems, there's a software solution to make life easier. The free PC program *Sequator* makes imaging easy, only requiring you to change your technique slightly to get great results.

Written by Taiwanese software engineer and landscape photographer Yi-Ruei Wu, *Sequator* is a powerful stacking program that lets users combine many short nightscape-type exposures into a single photo with round stars and the signal-to-noise quality of a long exposure. We tried it out to see how well it works.

Limited Exposures

Sequator allows users to photograph with the bare minimum of equipment — a digital camera, a good-quality lens, a tripod, and a shutter-release cable. The only requirements are to keep the individual exposures short enough to avoid trailed stars, and to capture a dozen or so shots of each scene. The software does the rest.

You can quickly determine the maximum length of the individual exposures by using the handy "500 rule." Simply divide 500 by the focal length of your lens (in millimeters) to get an approximate maximum exposure length before stars become dashes instead of dots. For example, the exposure limit for a 24-mm lens is 21 seconds (500 ÷ 24 = 20.8). Because the actual time it takes for a star to appear trailed will vary depending how far from the celestial pole you're targeting, some imagers use a more conservative "400 rule," dividing 400 by the focal length of the lens.

After you've recorded your nightscape frames, the program has only a few controls, so it's easy to master. *Sequator* accepts RAW-format digital camera files from all the major manufacturers, as well as both 16- and 8-bit TIF files, and JPEGs.

You begin by opening *Sequator* and simply dragging and dropping the files into the program window. The software then asks which "file category" the images are: ***Star images*** (light frames), ***Noise images*** (dark calibration frames), or ***Vignetting images*** (also known as flat-field frames). Select *Star images*, and, in a moment, *Sequator* will determine the middle exposure in the series and display it. All the imported images will then appear in the *Star images* section on the left side of the screen, with the middle exposure chosen as the ***Base image***. If you've recorded either dark or flat-field calibration frames, you can drag-and-drop them into the program and be sure to assign them to their proper sections. These noise and vignetting images are optional and can be skipped if you prefer, at least with camera-lens shots.

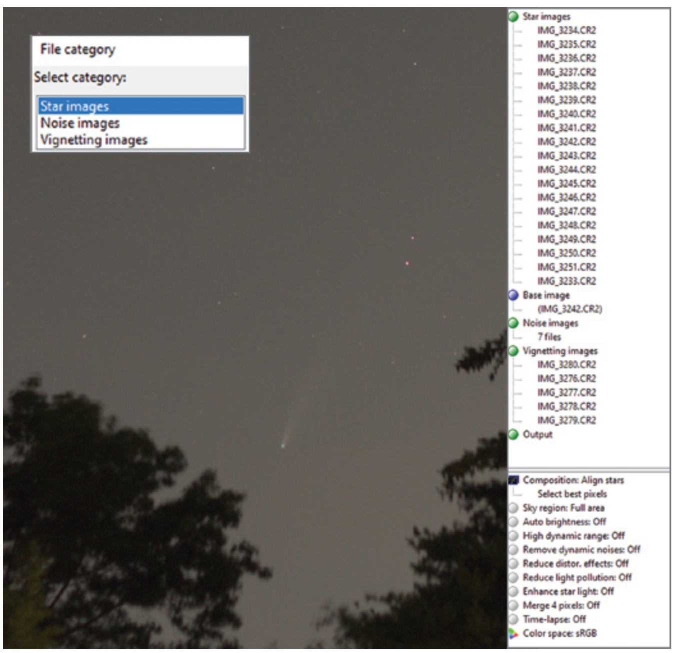
The next task is to tell the program how you'd like to combine the exposures by clicking ***Composition*** in the bottom left of the screen. This offers you a few options. The default setting is ***Align stars***, though you can also select ***Trails***, which skips the alignment stage and assembles a star-trails photo from your individual exposures.

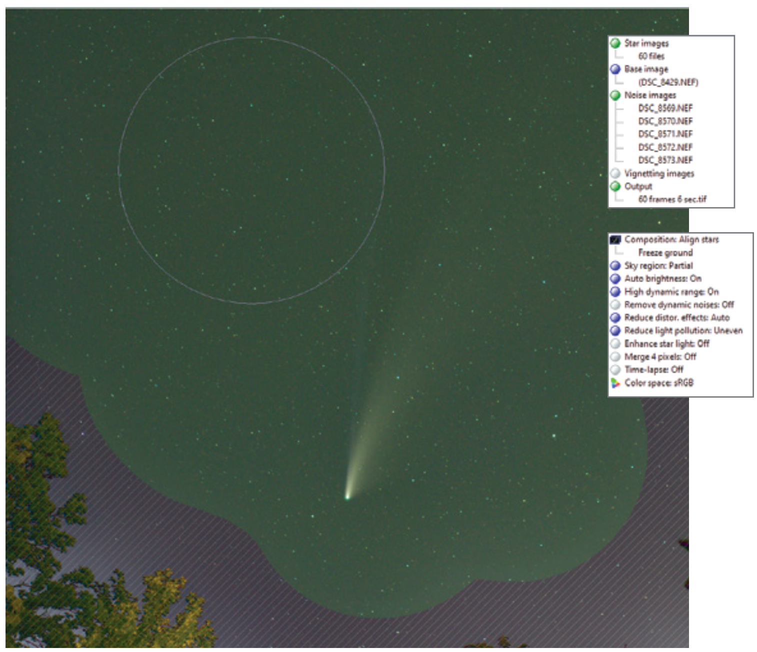
Choosing *Align stars* brings up additional choices. Selecting ***Accumulation*** aligns the images based on the stars and stacks the result using a sum routine, which works well but doesn't produce a stationary foreground. Choosing ***Select best pixels*** combines the images using a sigma pixel-rejection algorithm that analyzes the image and rejects pixel values that deviate from the median level of each image, producing a low-noise image, though it still permits the foreground to smear.

Determining Land and Sky

If your images contain a landscape, click ***Freeze ground***. This sets up the next step in the process. Clicking ***Sky region*** opens up a few new options. The first is ***Boundary line***, which lets you choose a point in your composition that defines a straight

▼ *Left:* Users import files into the program by either dragging and dropping them into the open program or by using the File pulldown menu at top left. Sequator automatically detects if you are adding *Star images*, *Noise images* (dark frames), or *Vignetting images* (flat-field calibration files). *Right:* Key to *Sequator*'s success when stacking starscapes with a stationary foreground is for you to help the program determine which part of the image is sky. You perform this in the *Sky region* section, where you mask the sky area using one of three options: *Boundary line*, *Gradient*, or *Irregular mask* (pictured). A resizable, circular brush lets you paint a mask over the sky area in the base image.





border between the sky and foreground. This option works well if you don't have a complex foreground with tall trees or buildings of varying height. You can click and hold your mouse to adjust the angle of this boundary to match your composition. The next option, ***Gradient***, allows you to set an area between the foreground and sky that will include a transition zone between the two areas. This is also useful if you're shooting over a field with a low horizon, for example.

For images with a complex foreground, the best choice is the ***Irregular mask***. Clicking this option immediately brings up the directions to "Fill the sky with brush," meaning you paint a mask that covers the sky area in your photo. You drag the brush tool around the sky area you'd like aligned while carefully avoiding having the mask cover any of the foreground you want to remain stationary. The brush size is adjustable with your mouse wheel. You don't want to paint your mask too close to the foreground objects; if the mask covers any of the foreground, the stacked result will display an unnatural glow around the foreground edges.

After painting the sky mask, there are a few more options to consider before stacking can commence. The next two selections are ***Auto brightness*** and ***High dynamic range***. The first is intended to avoid blowing out the highlights when stacking many frames. It often produces good results. However, I found the tool to sometimes be overly aggressive, particularly when I only had a few images to combine. The *High dynamic range* setting is intended to keep the brightness of the final result within the range that can be represented in a 16-bit file. It's best used if you intend to do additional processing to the final stacked image in another program.

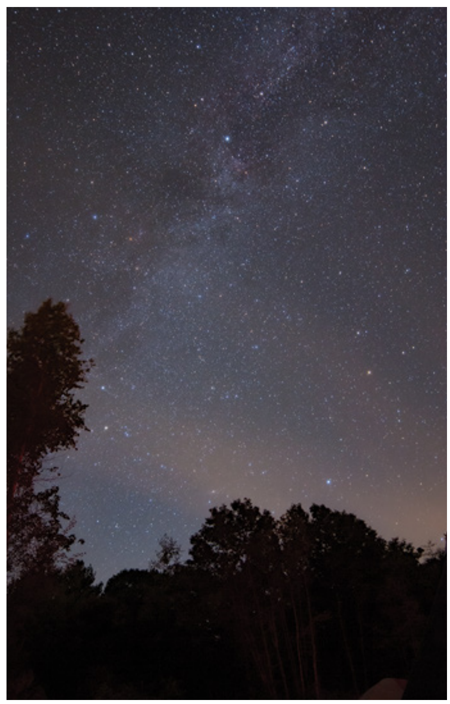
If you didn't include dark frames

▲ The stacked result above includes sixty 6-second exposures to achieve the noise characteristics similar to a 10-minute exposure.

(*Noise images*) when adding all your files, select ***Reduce dynamic noises***. This does a very good job eliminating hot pixels, which grow into red-, green-, and blue-colored lines in the composited result. It's also useful when imaging on warm nights and your dark frames aren't the same temperature as your light frames.

Reduce distor[tion] effects is particularly useful when you stack a lot of frames and the star positions change greatly throughout the series. This option will analyze the stars near the horizon and edges of the frame and try to make them appear round rather than elongated. There are two options here: ***Lens*** and ***Complex***. Selecting *Lens* will correct minor distortions due to lens design and some distortion when shooting through telescopes (more on this later). *Complex* is best suited for photos recorded through extremely wide-angle lenses, though the software's author recommends only stacking up to 5 minutes total exposure when shot this way.

At this point you can apply the ***Reduce light pollution*** command, which does an impressive job of detecting and suppressing image gradients. There are two options in this tool: ***Deep sky*** or ***Uneven***. The *Deep sky* light-pollution filter corrects simple linear gradients and works best with telephoto images or photos taken with a telescope. Most nightscape photos taken under less-than-pristine skies will benefit from the *Uneven* option, and the aggressiveness slider below it allows you to adjust how strong this filter is applied. Additionally, there's an ***Intelligently-aggressive*** check box, which, when selected, analyzes the



▶ *Sequator* isn't always successful when processing RAW camera files. The image at right includes 12 RAW frames with the *Auto brightness* and *High dynamic range* options activated, producing a noisy, over-processed result. The photo at far right stacks the same 12 frames that were first processed in *Adobe Camera Raw* and saved as 16-bit TIF files before being imported into *Sequator*.

color and tone of the light pollution to produce a more natural result.

A few additional options are available. First of these is ***Enhance star light***, which will boost the brightness of stars in the stack. Activating this made the stars slightly brighter in the resulting image but only when its slider was moved to the "Strong" setting. Next is ***Merge 4 pixels***, an action that is analogous to binning, in which groups of 4 pixels are combined into a single pixel. Selecting this adds the signal of every 4 pixels to produce a brighter image, but the resulting picture is ¼ the size of your original files.

The ***Time-lapse*** function will combine a predetermined number of images to produce low-noise frames that can then be assembled into a time-lapse movie. Note that *Sequator* doesn't generate a video file; instead it saves modified image stacks that can be imported into another program to make a movie. *Startrails* (**startrails.de**) is one popular option for making video sequences.

The final option is ***Color space***, which sets the color profile of the resulting image. There are two choices: sRGB or Adobe RGB.

Once you've made all your selections, the last step is to assign the name of your output file. Selecting ***Output*** opens the default location where the results will be saved. Enter the filename, and you're ready to go. Clicking ***Start*** opens a window that shows the progress as each image combined. Once completed, click the ***Close*** button at the bottom right of the window, and your stacked image is displayed. If you're unhappy with the result, you can go back and change settings then run the program again until you're satisfied.

Sequator produced a good result with my untracked, RAW-format nightscape photos. However, I often got better color and a more natural result if I processed my RAW images using *Adobe Camera Raw* and saved them as 16-bit TIF files before importing those files into *Sequator*. Another option is to stack the RAW files in Sequator but skip the *Auto brightness* command. The resulting 16-bit TIF appears dark but is suitable for processing in another program.

There are some practical limits to how many frames the program can handle, at least when combining wide-field images. I had excellent results stacking up to 10 minutes of total exposure taken with a 50-mm lens on a crop-sensor camera. Much more than that, the program would introduce artifacts particularly along the border between the sky and the foreground. Sometimes the software would simply produce a bad result, particularly when stacking very wide-angle images taken with my 14-mm lens. But retrying the same data would eventually produce an acceptable result when turning on different options.

Not Just for Nightscapes

As mentioned earlier, *Sequator* can automatically align and stack images taken through telephoto lenses and even telescopes. In fact, the program did an excellent job stacking DSLR images captured with a 10-inch classical Cassegrain telescope.

Sequator is an astro-imaging program that I find highly useful for lightening my load when I'm on the go. It eliminates the need to bring a tracking mount, particularly when shooting with the latest, highly sensitive digital detectors and fast lenses. And it's helpful for those using DSLR or Mirrorless cameras who want to produce nice results quickly and with a minimum of user input. The price is certainly tough to beat.

■ Associate Editor **SEAN WALKER** is always looking for ways to make astrophotography easier.

▼ *Left:* About 5 minutes of total exposure appears to be the limit for stacking very wide-angle images in *Sequator*. More than that causes the program to fail, producing some odd results like the one shown below. It's a stack of roughly 20 minutes total, made with a 14-mm lens. Also note the red, green, and blue streaks that are the result of not applying *Noise images* or activating the *Reduce dynamic noises* option. *Right:* By limiting the stack to fifteen 20-second exposures from the same series as the image seen at left, *Sequator* was able to generate an attractive photo of Comet NEOWISE rising above Lake Massabesic in southern New Hampshire on the morning of June 10, 2020.

▲ BEEFY BINOCULARS

Orion Telescopes & Binoculars announces a new, hefty pair of binoculars. The Orion GiantView ED 20×100 Waterproof Astronomy Binoculars ($1,099.99) feature 100-mm extra-low-dispersion-glass objectives to provide clear, bright views of the night sky. These big binoculars have a rubberized exterior coating to ensure a firm grip and include eyepieces with 20 mm of eye relief, which permits users to observe with or without glasses. The binoculars use BAK-4 Porro prisms and have well-baffled interiors to provide extremely high-contrast images. The binoculars weigh 4.2 kilograms (9.3 lb) and can be attached to a tripod or other solid mount via an integrated ¼-20 threaded adapter that slides along the central axis rod. A heavy-duty, foam-lined carry case and a limited 1-year warranty are included.

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

▲ QUAD ASTROGRAPH

Orion Telescopes & Binoculars now offers a compact astrograph for wide-field imaging. The Orion EON 70-mm ED Quadruplet Astrograph Refractor Telescope ($1,799.99) is an f/5 astrograph weighing just 3.9 kg (8.6 lb) — perfect for photographing large nebulae and star fields. The telescope uses four elements in a pair of Hoya FCD-100 ED lenses to provide pinpoint stars across a 43-mm image circle. The scope measures 32.4 centimeters (12.75 inches) with its dew shield retracted and is equipped with a dual-speed, 3-inch rack-and-pinion focuser and two step-down adapters to directly connect your camera. The telescope comes with hinged tube rings, a Vixen-style dovetail mounting bar, and metal lens caps, and it accepts a Synta-style quick-release finderscope (not included).

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

◀ HARMONIC MOUNT

Astronomical-camera manufacturer ZWO makes its first foray into the world of telescope mounts with its new ZWO AM5 Mount (starting at $1,999). It features ZWO's newly developed strain-wave gear drive to produce excellent guiding in a small package. The mount weighs just 5.5 kg (12 lb) yet boasts a load capacity of 13 kg without counterweights, and a 20-kg payload after installing an optional counterweight and shaft. The mount's innovative gear-and-belt system is driven with Nema stepper motors on both axes and is fitted with a built-in brake that engages immediately in the event of unexpected power loss. The mount can operate in either equatorial or alt-azimuth modes from any latitude. It's controlled with a joystick and is plug-and-play-compatible with the company's AsiAIR telescope-control computers, thanks to a built-in Wi-Fi adapter. The AM5 includes an ST-4-compatible autoguider port, and its dual-compatibility saddle plate accepts both Vixen- and Losmandy-style dovetails. The base model includes a joystick controller and DC power cable to supply the required 12V power at 3 amps.

ZWO
astronomy-imaging-camera.com

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

Over-Under Binoculars

You don't need prisms to make a great pair of binoculars.

BACK IN APRIL 2019, I wrote about Frank Szczepanski's unique approach to making a binocular telescope using only four mirrors instead of the traditional six. Frank has since reduced the number of mirrors required to two.

Of course, that requires a set of objective lenses up front instead of primary mirrors in back, but there's plenty of innovation in between.

One of the biggest problems with any large binocular telescope is that the distance between the centers of the primary light-gathering elements — be they mirrors or lenses — is wider than the spacing between the observer's eyes. That means the light must be bounced off matching sets of mirrors to bring the optical axes closer together.

A Clever Solution

Except it doesn't, really. With his Newtonian telescope design, Frank sends the light from one scope *through* the light path of the other one, using unequal-diameter secondary mirrors to bring the two optical axes together as tight as you'd please.

He does a similar thing with his 80-mm refractor binos. Because the light paths are cone-shaped, they don't actually intersect the way they do in a Newtonian of the same design, but the principle is the same: Run the light path of one telescope beneath the light path of the other one and put the eyepieces as close together as you want.

Using a pair of the same 80-mm doublet objectives that I wrote about in our November 2021 issue, Frank built the telescope you see here. One objective is slung beneath the other one and off to the side by the interpupillary distance required for Frank's eyes and mounted quite a way behind the other. A diagonal mirror interrupts the light path from that objective and sends it upward to an eyepiece.

The upper scope uses the same arrangement, but the lens is positioned well forward of the other, and the diagonal bends the light path much farther down the cone than the lower scope does. That light path reaches the other eyepiece at just the right spot for the two eyepieces to be perfectly spaced for Frank's eyes. This scope doesn't have the capability to adjust the interpupillary distance, but with a pair of 2-inch, wide-field eyepieces it accommodates a pretty good portion of the average human eye spacing.

The diagonals are just front-surface mirrors from a copy machine. Adjusting screws allow Frank to tip one from side to side and the other up and down to merge the images, and once they're set, they seldom need re-adjustment.

The scope is made from scrap plywood, and the focusers are simply friction-fit tubes where adjustments are performed by sliding the eyepieces inward and outward. But the view through it is nothing short of stunning.

◀ Frank Szczepanski's binocular scope uses offset objective lenses to bring the interpupillary distance closer together than the objective lens diameter. It's mounted on an extendable umbrella stand that can be cranked up and down to the perfect height for observing any part of the sky.

ALL IMAGES COURTESY OF AUTHOR UNLESS OTHERWISE NOTED

High-quality eyepieces paired with these 80-mm binoculars will blow your socks off so fast your boots will be shredded.

Deluxe Model

Robert Asumendi, of 3D-printed binoscope fame (*S&T:* June 2019, p. 74), saw Frank's scope and ran with it. Well, in a matter of speaking. He was so impressed with the view through it that he went home and designed a version of his own that he could 3D-print. Because he modified the design on a computer before building anything, he was able to experiment digitally. That allowed him to figure out how to slide one light path left and right to allow for interpupillary spacing adjustment, plus build in interchangeable filter holders, helical focusers, an internally mounted laser finder, and space for future upgrades like an embedded plate-solving camera or sky quality meter.

His first version was a great success, but 3D-printing large parts is time-consuming and expensive. So he went back to the drawing board and came up with a more robust version using a laser-cut aluminum frame. That turned out to be lighter than the printed version, plus it's much more durable and provides sturdy mounting points for all components.

▲ Robert Asumendi's binoscope uses the same optical design as Frank's, with some nifty refinements.

Interocular Adjustments

Inside the frame, the upper lens/mirror/focuser assembly is mounted on a small, 3D-printed, rack-and-pinion setup with gears at both front and rear, tied together with a solid drive shaft. That keeps its optical path paired precisely with the other one even when shifting from side to side. The rack allows for 12 mm of interpupillary adjustment, from 58 to 70 mm, which seems to fit just about everyone. Robert says, "I've tested it successfully with an entire Girl Scout troop."

Frank pivots his scope in altitude on side bearings at the scopes' center of gravity, allowing views from horizon to zenith without balance issues. The eyepiece height does vary, so he mounted the scope on a patio umbrella post with a crank that lets him raise and lower it quickly and easily. Robert mounts his scope on a camera tripod with a gear-driven center shaft, or on a tabletop fork mount.

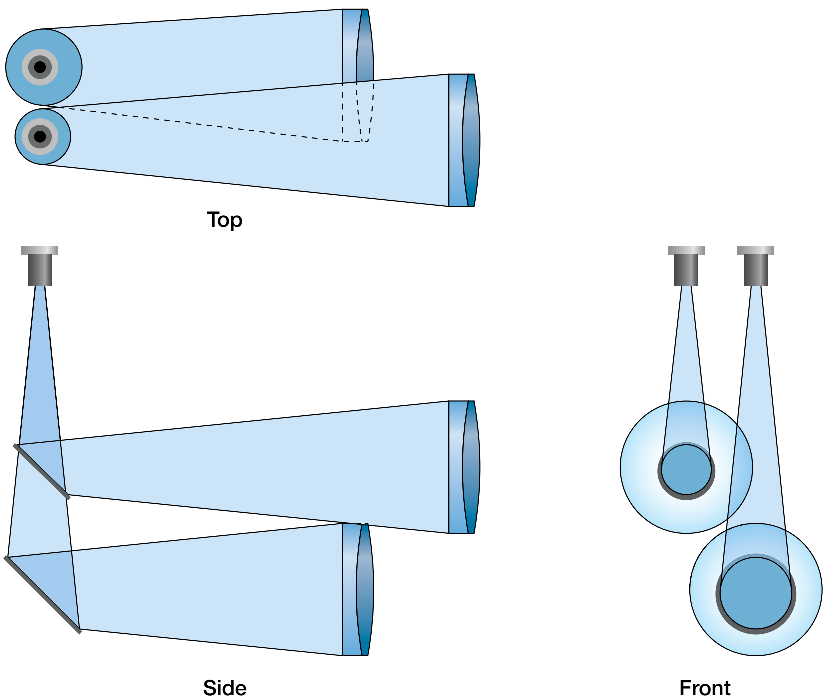
Frank's scope is a solid wooden box. Robert wraps his framework with EVA foam, for its insulating value but also for light weight and its soft feel.

Both scopes use green lasers for finders. Frank also put an optical finder on his but soon realized he didn't need it. At low power, the field of view in these scopes is a whopping 6° to 7° depending upon the eyepieces used. Both scopes can accommodate 2-inch eyepieces, so the only limitation is the diameter of the eyepiece barrels.

And holy cow, what an incredible view these scopes provide! The Double Cluster (NGC 869 and NGC 884) easily fit in

▶ The light path of one side passes right beside the light path of the other, bringing them close enough together to fit the observer's eyes.

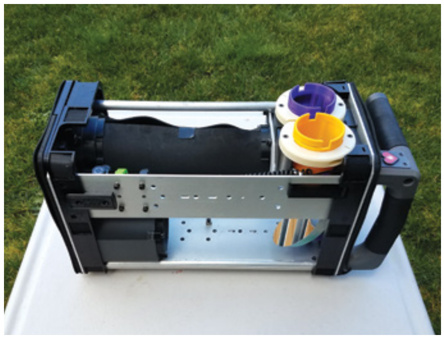
▼ As seen from behind, the light paths are staggered both horizontally and vertically, bouncing off mirrors that direct the light to the eyepieces.



SCOPE INTERIOR: FRANK SZCZEPANSKI; LIGHT-PATH DIAGRAMS: GREGG DINDERMAN / S&T

▲ The controls for image merging and interpupillary distance are easily accessible on the back of Robert's binoscope.

▲ Filters slide in beneath the eyepieces for quick insertion and removal.



▲ The interior of the binoscope reveals its 3D-printed and laser-cut aluminum parts.

the field, along with nearby open cluster Stock 2, which is too large to see even by itself in most optics. The North America (NGC 7000) and Pelican nebulae (IC 5067 and IC 5070) are also framed comfortably with room to provide context. And with both eyes involved, the effect is simply stunning. The crispness and clarity feels like the Hubble — a Hubble with over 100 times the field of view. Objects that require study to see in my 20-inch scope stand out easily in these scopes. Have you ever seen the Heart and Soul nebulae (IC 1805 and IC 1848) at all, much less together in one field looking as bold as the Lagoon and Trifid (M8 and M20, respectively)? I have now. And I've seen the Witch Head Nebula (IC 2118) for the first time ever . . . in a pair of 80-mm binoculars. Aperture doesn't always rule — it's aperture, field of view, and stereo vision all working together.

Of course, nebula filters help. While Frank uses screw-on filters on each eyepiece, Robert designed removable filter cartridges that slide into place below the eyepieces. Either setup provides enhancement of faint nebulae almost beyond belief. Remember Howard Banich's article on the Cygnus Loop (*S&T:* Sept. 2021, p. 28), beautifully sketched as seen piecemeal through a 28-inch scope? In these scopes it's all there in one glorious field.

But the real joy with these binoculars is to simply sweep them around the sky and see what you encounter. What's in that stretch of Milky Way above Aquila? Why, look, it's Barnard's E! Plus, a couple million background stars that not only glow like a fireworks blast but also reveal the texture of the galaxy's mottled spiral arms.

Comfort and Versatility

What makes these telescopes so amazingly different from a regular pair of 80-mm binoculars? Ease of use, for one. You can sit in a comfortable chair with your eyes aimed downward to look into the eyepieces, not craning your head back and getting a crick in your neck. Field of view, for another. With interchangeable eyepieces you can go from 7° to as tight as you want (and add nebula filters). And, of course, steadiness. Without having to hold onto anything, you can simply look into the eyepieces and lose yourself in the view.

Robert mounts a laser finder inside the frame and provides a button on the back of the scope to activate it. He made the button heart-shaped, and he calls his telescope the "Heart." Why? Robert says, "On my binoculars you push the heart button to shoot a laser at something you like, something wondrous, hopefully in good company, and feel genuinely a little closer to everyone and everything. That's what I want to inspire."

I have to say, these binoculars are the right way to do it.

■ Contributing Editor **JERRY OLTION** is building one of these amazing binoscopes himself.

Plans Available

When I publish a column about a particularly nifty telescope design, I'm often asked if the designer would consider making kits available for people who don't have the shop capabilities to build one themselves. My usual response is "Alas, no," but this time around I can anticipate those requests with a happy "Yes, indeedy." Robert isn't selling kits, per se, so much as providing plans, building instructions, 3D-print files, and sources for the aluminum parts, lenses, mirrors, etc. ATMs can 3D-print many of the parts for themselves or source them online, and a video series of assembly instructions will lead builders through the process of creating their own "Heart" binoscope. In the videos, you'll watch an 8-year-old girl assemble one at a desk; I'm pretty sure you can do it, too.

For more information, visit: **http://analogsky.co/heart.**

▷ PORTRAIT OF A BUSY SKY

Soumyadeep Mukherjee

Ice crystals in the atmosphere caused a double lunar halo to form over Kolkata, India, on September 25, 2021. Perseus peeks out from the Moon's light on the left, while a contrail slices through the right side of the smaller ring.

DETAILS: *Nikon D5600 camera and Tokina 11-to-16-mm zoom lens. Stack of 30 exposures, each 13 seconds long at f/3.2, ISO 160, and several 6-second exposures at f/4, ISO 800.*

▽ RIVER OF DUST

Gregg Ruppel

NGC 6559 in Sagittarius is a complex of reddish emission nebulae and smaller patches of bluish reflection nebulae. Meandering tendrils of dark gas and dust cut across its center like a braided river.

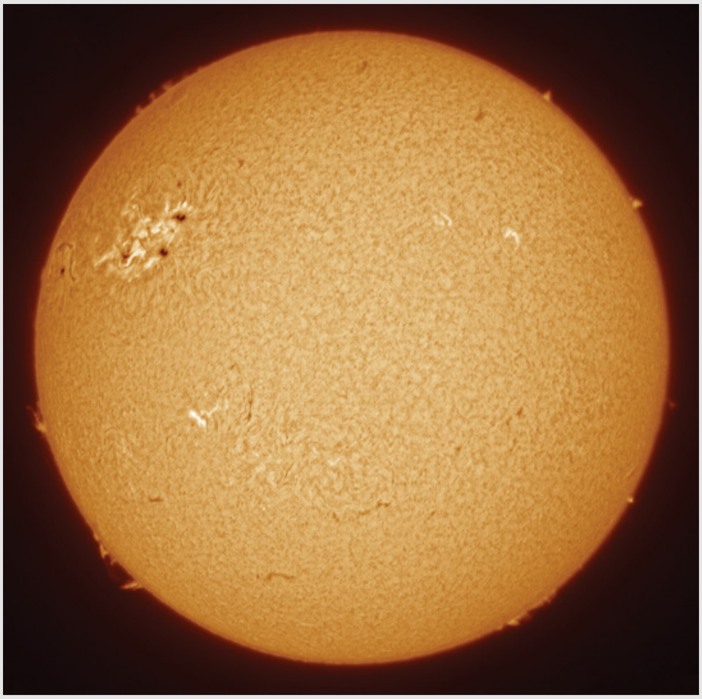
DETAILS: *Astrosysteme Austria ASA10N Newtonian astrograph and SBIG STL-11000M camera. Total exposure: 14 hours through Hα and LRGB filters.*

WAXING GIBBOUS

Jamie Cooper

In this high-resolution mosaic of the Moon, bright rays shooting out from the craters Tycho (bottom) and Copernicus (left) stand out against the dark seas Mare Nubium (lower left), Oceanus Procellarum (middle left), and Mare Imbrium (upper left). Several interesting craters are visible in stark relief along the sunrise terminator, including Philolaus (top), Aristarchus (upper middle left), and Schickard (bottom left, with its far rim partially in darkness).

DETAILS: *SkyWatcher Explorer 250PDS Newtonian and ZWO ASI290MM video camera. Mosaic of 70 images, each a stack of multiple video frames recorded through a near-infrared filter.*



◁ SOLAR ACTIVITY RAMPS UP

Damien Cannane

Bright plage surrounds three dark sunspot groups at upper left in this image of the solar disk taken on April 19th. Several smaller active regions pepper the chromosphere, while dancing prominences litter the solar limb.

DETAILS: *Coronado SolarMax II 60 Hα solar telescope and ZWO ASI178MM camera. Stack of 400 video frames.*

▽ MAGICAL MOMENT

Majid Ghohroodi

The peaked shadow of Mount Damavand in northern Iran almost perfectly aligns with the rising full Moon as seen from the summit just before sunset on June 5, 2020.

DETAILS: *Canon EOS 6D DSLR camera with Canon EF 24-to-70-mm zoom lens. Total exposure: 1⁄500 second at f/5, ISO 400.*

Gallery showcases the finest astronomical images that our readers submit to us. Send your best shots to gallery@skyandtelescope.org. See **skyandtelescope.org/aboutsky/guidelines**. Visit **skyandtelescope.org/gallery** for more of our readers' astrophotos.

SKY&TELESCOPE

Market Place

Your essential source for astronomical products

ACCESSORIES

ORGANIZATIONS

TELESCOPES

CLASSIFIEDS

- **FOR RENT:** 3BR/2BA furnished home in ARIZONA SKY VILLAGE PORTAL, AZ. Spectacular observing/birding! irkitzman@gmail.com www.arizona-dreaming.com 520-203-8500
- **SOUTHWEST NEW MEXICO:** Casitas de Gila Guesthouses. Dark skies, great accommodations; power, wifi, and pads available. casitasdegila.com/astronomy.html. 575-535-4455.

Classified ads are for the sale of noncommercial merchandise or for job offerings. The rate is $1.75 per word; minimum charge of $28.00; payment must accompany order. Closing date is 10th of third month before publication date. Send ads to: Ad Dept., Sky & Telescope, Suite 300B, One Alewife Center, Cambridge, MA 02140.

skyandtelescope.org

Ad Index

The Loon Alarm

Rising to the call, the author enjoys a memorable viewing of the Perseids on an Adirondack lake.

With the Pleiades in attendance, Perseids streak across a New England sky in August.

SEAN WALKER / S&T

ON THAT AUGUST NIGHT last year, I had decided to let Nature awaken me. Or perhaps my determination to see what I hoped to see in the wee hours would subconsciously propel me out of bed, without the need for electronics. It turns out that it was a loon, its wild cry entering through the window, that roused me.

My eyes still closed, I slowly drifted into consciousness. *Yay, it's 3:37 a.m.*, I thought — the loon chose a good time. My heavy eyelids wanted to close again, but I forced them open and rose, lest the "loon alarm" had no snooze button.

I grabbed a flashlight and departed the Adirondack cabin into utter darkness. Thoughts of early-stirring bears foraging for the season's abundant blueberries haunted me, and I switched on the light. As I made my way to the lake, pine needles cushioned my footfalls and bracken ferns brushed against my legs. I descended the steps to the dock, then extinguished my light, letting my eyes adjust to the darkness as I gazed up at the glittering heavens.

Usually, I'm setting as Perseus is rising, but not that morning. I had done the hardest thing of all for me — risen with Orion in August. There he was, his belt of three stars winking in a vertical line as they rose in the east. But where was Perseus? *Ah, there*, I thought, elevated higher and shining more brightly than I'd ever been up to observe. He resembled an upside-down, fancy letter "V", and his oval shield sparkled more clearly than I'd ever seen it.

It was from Perseus where the celestial transients I sought would radiate. In mid-August every year, Earth crosses the orbital path of Comet 109P/Swift-Tuttle, whose remnants treat us Earthlings to a scintillating display. Between about 2 a.m. and dawn on August 12, 2021, as Bob King noted in his piece on the Perseids (*S&T:* Aug. 2021, p. 48), one could witness the peak, with up to 100 shooting stars per hour at a dark site.

I own a 1910 edition of Camille Flammarion's book *Astronomy for Amateurs*, which features a drawing of the 1799 Leonid meteor shower that has intrigued me for years. The drawing depicts, above a ship at sea, a night sky shot through with dozens of shooting-star trails. Would I see something similar with the Perseids? My excitement grew as I scanned the sky.

While I waited, I wondered, how much do I miss in life by not rising early? One can't burn the candle at both ends, yet if I could, I'd stay awake all night to witness not only meteor showers but the stars in their nightly sojourn across the great black bowl.

That morning's pre-dawn extraterrestrial parade was not as spectacular as shown in the Leonids drawing. But it did provide 15 meteors in 25 minutes — a decent haul — so I declared my meteor bag full and slowly picked my way back to the cabin. Stepping quietly inside, I returned to bed. With sweet-scented breezes wafting through my window, I smiled with satisfaction that I'd heeded the loon alarm.

■ **ROSEMARIE BUGENIS** is a retired Earth science teacher who takes time to enjoy bird-listening by day and stargazing by night, both of which are possible from her home in Brooklyn, New York.


UNISTELLAR
THE UNIVERSE AWAITS
M42 - NEBULA IN ORION
M51 - WHIRPOOL GALAXY
M57 - RING NEBULA
Nikon EYEPIECE TECHNOLOGY
UNISTELLAR
eVscope 2
UNCOMPROMISED OPTICS FOR
A STUNNING VISUAL EXPERIENCE
Power, speed and optical expertise come together to deliver the most immersive space exploration experience.
• Best-in-class electronic eyepiece designed by Nikon
• Transport Backpack
• Enhanced Vision Technology
• Autonomous Field Detection
• Light Pollution Reduction
• 5000+ objects catalogue
• Motorised Alt-Az mount
UNISTELLAR
unistellar.com