SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

MARCH 2020

Constellation Close-up ARGO NAVIS

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THE ESSENTIAL GUIDE TO ASTRONOMY

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Hubble mosaic of the Carina Nebula's heart

PHOTO: NASA / ESA / N. SMITH (UC BERKELEY) / HUBBLE HERITAGE TEAM (STSCI / AURA)

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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. ©2020 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 420235, Palm Coast, FL 32142-0235. Printed in the USA.

A Mega Dilemma

A FEW YEARS AGO at a dark-sky site I was observing a deep-sky object with my 10×42 image-stabilized binoculars when two satellites crisscrossed each other through my field of view. It was a sobering reminder of just how much hardware we've put up there.

Yet as most of our readers are by now acutely aware, the total number of artificial satellites orbiting Earth — and potentially interfering with observations and astrophotography — will increase many times over in coming years. The aim of SpaceX and other companies entering the so-called *megaconstellation* arena is to provide broadband internet service around the globe.

As worthwhile a goal as that might be, its implementation will result in a paradigm shift to ground-based astronomy, and not just for amateurs. As News Editor Monica Young explains in her feature on page 14, professional astronomers are as wary of the planned megaconstellations as hobbyists are.

Whether this expanding type of light pollution will be as devastating to optical astronomy as some attest remains to be seen. What's clear is that astronomy conducted from Earth's surface will never be the same. Market forces are driving this development, and with billions of dollars in revenue at stake, it *will* go forward, juggernaut-like, no matter how vociferous astronomers get.

SpaceX Starlink satellites just prior to deployment on May 24, 2019

Alas, if you can't beat 'em, join 'em — or at least work with them. That's what our parent organization, the American Astronomical Society, and other astronomy groups are actively trying to do. After SpaceX's initial launch of 60 satellites last May, the AAS Public Policy staff, together with the AAS Committee on Light Pollution, Radio Interference, and Space Debris, formed a working group to scrutinize this mushrooming issue and seek ways to ameliorate its worst effects on astronomy.

Since then, the group has had eight telecons with SpaceX, and, according to an AAS post on December 5th, "things are moving in a hopeful direction." For starters, SpaceX is open to testing coatings to reduce future satellites' albedo. The AAS is also calling for observatories and SpaceX itself to develop simulations to fully assess the impact and to help observatories avoid interference from as many satellites in the company's Starlink megaconstellation as possible.

Altogether, the AAS has set a reasonable ad hoc bar for SpaceX and its competitors: satisfy the needs of the Large Synoptic Survey Telescope now being built in Chile. Set to begin in 2023, the LSST's deep, wide-field observations might well suffer most of all from megaconstellation glare. If SpaceX and others can meet that criterion, it would help all astronomers better come to terms with this turn of events. Especially, one might add, since we have no choice.

Peter

Editor in Chief

SPACEX

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Subscription Rates:
U.S. and possessions: $54.95 per year (12 issues)
Canada: $69.95 (including GST)
All other countries: $84.95, by expedited delivery
All prices are in U.S. dollars.

Newsstand and Retail Distribution:
Marisa Wojcik, mwojcik@i-cmg.com
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BIRTH OF TRULY BEAUTIFUL ASTROPHOTOGRAPHY

Photo: Phillipp Keltenich, sternenhimmel-fotografieren.de Taken with: Pro APO 71/450 Quadruplet

The beauty of excellent astrophotography is admired by everyone. Would you like to become one of the astrophotographers who create such images? You too can make this dream a reality with an Omegon premium apochromat, featuring an outstanding ED doublet, triplet or quadruplet lens and employing FPL-53 glass. With super-flat image fields and pin-sharp stars right up to the edge of the image. Of course the precision mechanics of the CNC-machined OTA are also impressive: all focusers are precision rack-and-pinion focusers with a high load capacity and 360° rotation for optimum image capture. This is the start of better astrophotography.

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- The optics of the four-lens quadruplet offer fully-apochromatic imaging
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- Your astrophotos will look as sharp and true in colour as with the triplet, but also show wonderful pin-point stars right out to the edges of the image
- Look forward to observations and images that will remain in your memory

	Article No.	Aperture	Design	Focuser	Price in USD
Pro APO 60/330 Doublet OTA					
Weight 1.7 kg | 3.7 lbs	60852	60mm f/5.5	doublet ED	2" focuser with 1:10 reduction	669
Pro APO 72/400 Doublet OTA					
Weight 2.0 kg | 4.4 lbs	60853	72mm f/5.6	doublet ED	2" focuser with 1:10 reduction	659
Pro APO 71/450 Quadruplet OTA					
Weight 2.5 kg | 5.5 lbs	60855	71mm f/6.3	quadruplet ED	2.5" focuser with 1:10 reduction	769
Pro APO 80/500 Triplet OTA					
Weight 3.7 kg | 8.2 lbs	60856	80mm f/6.3	triplet ED	2.5" focuser with 1:10 reduction	1199
Pro APO 80/500 Triplet Carbon OTA					
Weight 3.4 kg | 7.5 lbs	60857	80mm f/6.3	triplet ED	2.5" focuser with 1:10 reduction	1249
Pro APO 90/600 Triplet OTA					
Weight 3.8 kg | 8.4 lbs	60858	90mm f/6.7	triplet ED	2.5" focuser with 1:10 reduction	1249
Pro APO 107/700 Triplet OTA					
Weight 6.0 kg | 13.3 lbs	60859	107mm f/6.5	triplet ED	3" focuser with 1:10 reduction	2079

Order online at www.omegon.com

The Best "First" Telescope?

I enjoyed "Hobby Killers" (*S&T:* Dec. 2019, p. 36) and hope that everyone who put a telescope on their Christmas list read it! Years ago, cheap refractors were sold with a special "solar filter," a dark glass filter that screwed into the eyepiece for observing the Sun. The severe dangers of this are apparent — the filter can crack during use — and I wonder how many children back in the '60s or '70s had their eyesight permanently damaged by these. They've long since been discontinued, but if any old ones are lurking around, *do not use them* if you value your eyesight! This would make a hobby killer even worse: an "eyesight killer"!

Mark Puscas
Salem, Oregon

This piece was fantastic! I had a telescope 40 years ago as a child. Using it was a frustrating experience. Every possible thing that could go poorly did. After reading this article, I'm no longer fearful and jumping back into buying a telescope (a SkyQuest 8-inch Dobsonian). Thanks for this wonderful introduction!

Elihu Feustel
South Bend, Indiana

Regarding Jerry Oltion's comment on teeny-weeny eyepieces, specifically the 0.965-inch eyepieces that were once offered with most junk scopes, I agree that most are garbage. But some truly outstanding ones are out there, such as Zeiss and Pentax Orthoscopics. I have a complete set of the latter and consider these some of the finest planetary eyepieces ever made.

They are very sharp, with exceptionally low light scatter. These are no longer produced but can be obtained on the used market if one is patient. There are not many modern eyepieces that offer this level of performance.

Vahe Sahakian
Houston, Texas

Something I call the "big lie of amateur astronomy" relates to Jerry Oltion's fine article "Hobby Killers." The lie is that you're going to see stuff through the scope that looks like the photos from websites, books, magazines, and the telescope's box. I've never seen an ad or article for new folks explaining that they'll never see all the colors and details we get in photos when they use their scope visually and why there is such a difference. Such an explanation might reduce the hobby-killer syndrome.

Tim S. Jones
La Crescenta, California

Imagine my surprise when I turned the page to Jerry Oltion's article, "Revive a Hobby Killer" (*S&T:* Dec. 2019, p. 72) and saw the photo of an Edmund Scientific 4¼-inch reflector, poised purposefully on its gray pedestal mount. Fifty years ago, my parents drove me to the Edmund outlet, where I counted out $84.50 in saved-up coins for the instrument billed by the company as the "ideal telescope for quality-minded beginners." And so it proved to be.

Oltion's photo took me back to those frigid winter nights observing from the driveway of our suburban home. I swept up planets, double stars, and a host of Messier objects. The Edmund scope was the steppingstone to my decades-long professional career in astronomy.

While I've graduated to bigger instruments, the "Deluxe Space Conqueror" still sits in my office, a daily source of inspiration. The hobby killer in my case was not the Edmund scope but the rickety department-store refractor it replaced.

Alan Hirshfeld
University of Massachusetts
North Dartmouth, Massachusetts

I was dismayed to read Jerry Oltion's recommendation for beginners to avoid equatorial mounts. Flimsy mounts of *any* design aside, equatorial mounts are excellent at providing beginners a 3D, hands-on method to learn the motion of the celestial sphere.

My first telescope, a 4¼-inch Edmund Scientific Palomar Jr., came with a German equatorial mount. With the aid of the included well-illustrated and clearly written instructions by Sam Brown, it took me less than 15 minutes to learn how to operate and track the telescope with just one movement. The setup only required that I point the polar axis due north and set its altitude for my latitude. I was 10 years old at the time, and I learned it all on my own.

Howard Lester
Gansevoort, New York

Jerry Oltion replies: *While it's true that an equatorial mount will teach a person valuable skills if they later go on into advanced astronomy, my experience with dozens of newcomers to the field is that the initial learning curve for equatorial*

LEAH TISCIONE / *S&T*

mounts is too steep for most beginners to enjoy. Also, the awkward contortions you wind up making in order to see certain parts of the sky quickly become frustrating even for experienced users. If you're a gearhead and don't mind that steep learning curve — and if you're young and flexible — then you might like an equatorial mount. But based on what I've seen over the years, I'd say the odds are about 10-to-1 against it.

▲ Readers have weighed in on whether this vintage reflector and its equatorial mount would be a good choice for beginners.

The Farthest Visible Star

I'll admit it: I'm a little obsessed when it comes to seeing the farthest objects visible to me in the night sky. Knowing distances gives me not just the drive to attempt some really tough sightings, but also adds to my observing experience. So I really enjoyed reading Dave Tosteson's article "The Farthest Star" (*S&T:* Nov. 2019, p. 57) and comparing my accomplishments to his. For me and my 10-inch SCT, I'm proud to have seen several stars within M31 and M33!

But I'm really writing to inform Mr. Tosteson of the farthest star I know of, so that he can break his own record. It's a luminous blue variable known as NGC 2363-V1, in the galaxy NGC 2366, 11 million light-years distant. It shines around magnitude 18!

Scott N. Harrington
Evening Shade, Arkansas

S&T's New Ownership

Congratulations on the wonderful full-page announcement (*S&T:* Oct. 2019, p. 5) about your new ownership! Of the many hundreds of stargazers worldwide I correspond with, everyone is thrilled and happy about how this turned out. I'm sure Charlie and Helen Federer, and all the many wonderful editors and staffers of the past, are too! Thanks for making this happen — it's a pivotal event in the history of astronomy.

James Mullaney
Rehoboth Beach, Delaware

FOR THE RECORD

- The scale corresponding to Zeta Andromedae's surface temperature (*S&T:* Nov. 2019, p. 24) should have shown dark shades as the coolest and light shades the hottest. For a correct version, see **https://is.gd/ZetaAnd_temp**.

SUBMISSIONS: Write to *Sky & Telescope*, 1 Alewife Center, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1945

1970

1995

JERRY OLTION

◖ **March 1945**

Rocket or Meteor? "[C]oncerning the German V-2 rocket bomb . . . astronomers and meteorologists will find especially noteworthy the fact that [the] V-2 reaches the heights where meteors are generally observed. And, as would be expected, it is reported to glow a dull red, so the time may come when a meteor observer may have to distinguish between natural and man-made 'shooting stars.'

"The present range of the V-2 rocket is 200 miles from launching site to target, and its maximum altitude is 60 miles. Its speed is reported as about 4,500 miles an hour, or 1.25 miles per second, which is the same order of magnitude as that of the slowest meteors entering the earth's atmosphere."

◖ **March 1970**

Infrared Enigma "Last year [Caltech astronomers] published a preliminary catalogue of over 5,000 bright infrared sources of emission [observed with] a 62-inch f/1 epoxy-mirror telescope at Mount Wilson. [O]ne listed as IRC+10216 has turned out to be of exceptional interest. . . .

"This object is in Leo . . . and on a photograph taken with the 200-inch telescope appears as a tiny elliptical patch, about four seconds of arc long. Although visually fainter than magnitude 18, its observed 5-micron flux is greater than that of any known object outside the solar system. [Eric Becklin and colleagues] are inclined to interpret it as an evolved long-period variable star surrounded by an opaque shell of dust."

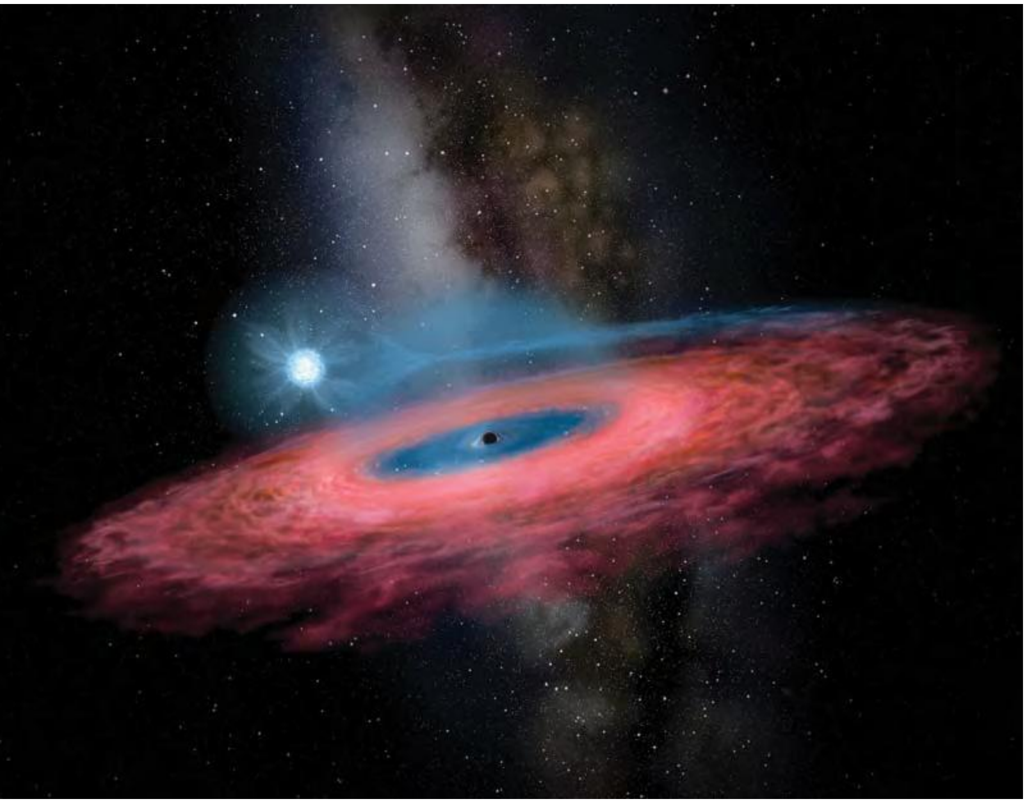
Today called CW Leonis, or the Peanut Nebula, it may be the nearest carbon star to our solar system at just 300 light-years.

◖ **March 1995**

Divine Julius "Throughout the history of astronomy great discoveries have been made from behind a veil of superstition. Astronomical events have often been interpreted as omens, then manipulated to suit the political needs of those in power. No culture excelled in that endeavor quite like that of the ancient Romans — their astronomical coins were true masterpieces of propaganda. . . .

"Shortly after Julius Caesar's assassination in 44 B.C., a comet was spotted and interpreted to be Caesar's soul ascending to heaven. In 17 B.C., with Augustus on the throne, another comet appeared and was believed to be Caesar's deified spirit returning to hail the beginning of a new age. Augustus deemed it politically expedient to commemorate the event on coins. One depicts a small comet above Caesar's head. Another has a full image of a multirayed comet with the inscription 'DIVVS IVLIVS' (Divine Julius. . . ."

Astro-numismatist Linda Zimmermann discussed other old coins believed to show planets, stars, and even meteorite falls.



▲ This artist's concept shows a hot, young star orbiting a black hole.

JINGCHUAN YU / BEIJING PLANETARIUM

BLACK HOLES

Black Hole Heavyweight Puzzles Astronomers

ASTRONOMERS MAY have found a seemingly "impossible" black hole 14,000 light-years away in Gemini. Their observations, published in the November 28th *Nature*, suggest that the object weighs in at a staggering 68 times the mass of the Sun.

Theories predict an upper limit around 50 solar masses for black holes forming from supernova explosions. So far, most of these stellar-mass black holes have been discovered via X-rays emitted by their hot accretion disks. LIGO and Virgo have also detected gravitational waves from the mergers of black holes with up to 50 solar masses.

But the new find didn't show up in Chandra X-ray Observatory observations or the LIGO ones. Instead, its existence was betrayed by the periodic wobble of a hot, young *B*-type subgiant star about eight times the Sun's mass.

Jifeng Liu (National Astronomical Observatories, China) and colleagues noted the star's motion during a survey carried out with the Chinese Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST). The star's orbit indicates that its unseen companion has at least six times the Sun's mass — massive enough to be seen if it were anything but a black hole — but it could be even more massive if we happen to be viewing the system from an angle other than edge-on.

A fingerprint in the spectra hints at a larger mass: a broad hydrogen-alpha emission line behaves in a manner contrary to the star's emission lines, moving toward Earth as the other lines from the star move away and vice versa. The authors argue that the hydrogen-alpha emission originates in a disk of hot gas orbiting the black hole, in which case its velocity (relative to the star's) indicates a whopping black hole with between 55 and 79 solar masses.

This result challenges our current understanding of massive star death. Even for a star equivalent to 200 Suns, stellar winds and mass loss during its supernova explosion would limit the mass of the resulting black hole. What's more, the companion star's spectrum suggests an environment rich in elements heavier than hydrogen and helium. Very massive black holes simply shouldn't form in such environments, says theorist Stan Woosley (University of California, Santa Cruz).

However, team member Stephen Justham (now at University of Amsterdam, The Netherlands) thinks the hydrogen-alpha measurements, on which everything hinges, justify excitement. The LAMOST observations are supported by higher-resolution data from the 10-meter Keck I telescope in Hawai'i and the Gran Telescopio Canarias in the Canary Islands.

Nevertheless, Justham agrees that such a massive black hole would be "shocking." For that reason, he suggests that the dark mass in the binary system might be not one black hole but a close pair of them.

Since the team's publication, other astronomers have argued that the changes in velocity seen for the hydrogen-alpha emission line are not real. While the star still appears to orbit an unseen companion, and it's massive enough to be a black hole, it wouldn't necessarily be a heavyweight.

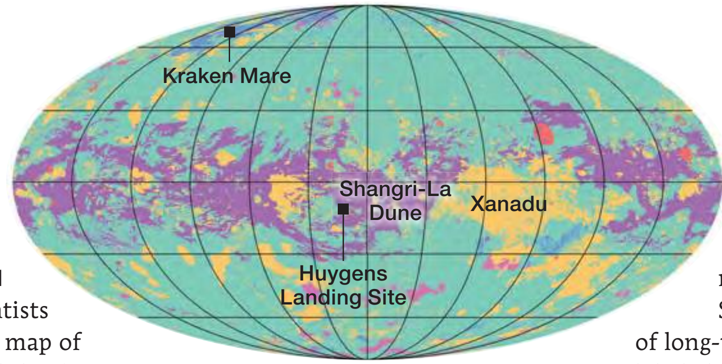
Moreover, parallax measurements by the Gaia spacecraft yield a distance of just 7,000 light-years to the star — half as far as assumed based on the star's spectrum and inferred true luminosity. If true, both the star and its invisible companion would be less massive, but astronomers would have to explain why the star is less luminous than expected from its spectrum. Follow-up observations would shed light on the system's distance and the companion's mass.

Meanwhile, Justham thinks that future radial-velocity surveys could turn up many more quiescent black holes in binary systems. "Whatever the exact mass of this one," he says, "it's a taste of a future black hole population we're only just starting to be able to discover."

■ GOVERT SCHILLING

SOLAR SYSTEM

New Map Shows Titan's Geological History



▲ This map shows Titan on a 1:20,000,000 scale, with six main geological features marked in color. NASA's Dragonfly mission, targeting a 2034 landing on the faraway moon, will investigate the Shangri-La Dune (*S&T:* Oct. 2019, p. 8), near the Huygens landing site.

WORKING WITH DATA FROM NASA's Cassini mission, scientists have produced the first global map of Titan's geological features. While it's not the first to portray these features, this map shows the evolution of geology on Saturn's largest moon.

Rosaly Lopes (Caltech) and colleagues combined more than 120 flybys' worth of data to create the map, as described November 18th in *Nature Astronomy*. In addition to high-resolution radar mapping that covered almost half of the moon's surface, Cassini also characterized the landscape using lower-resolution radar and near-infrared images and spectra.

The team identifies six main geological features and, based on mutual overlap, estimates their relative ages from newest to oldest: dunes, lakes, plains, labyrinths, craters, and hummocky regions. Plains and dunes dominate the surface, covering two-thirds and one-fifth of the surface, respectively.

The youngest features, dunes and lakes, don't overlap each other, so it's not yet possible to tell which feature is newer. Dunes are common at Titan's arid equatorial latitudes, while lakes dominate the more humid poles.

Some features are suggestive of long-term evolution. For example, global climate change might explain why the north pole hosts most of the wet lakes, while the south pole has more dried-out lakebeds and labyrinths. The latter likely formed when methane rain dissolved elevated terrain, creating steep channels, like karsts on Earth.

Spectra of the two oldest features — craters and hummocky regions — reveal the presence of water ice, hinting at even longer-term changes. Excavating impacts and the irregular mountainous terrain appear to expose an ancient icy crust that underlies the hydrocarbon-coated surface.

■ MONICA YOUNG

GALAXIES

Three Black Holes May Merge in Nearby Galaxy

NEW OBSERVATIONS OF a galactic crash site show that there are not just two but three black holes on the verge of union in the butterfly-shaped galaxy NGC 6240. Two of them are the tightest supermassive pair known.

Astronomers have long known that there were two black holes in the galaxy. Images taken by the Chandra space telescope in 2001 had revealed X-rays from hot gas swirling into the twin maws.

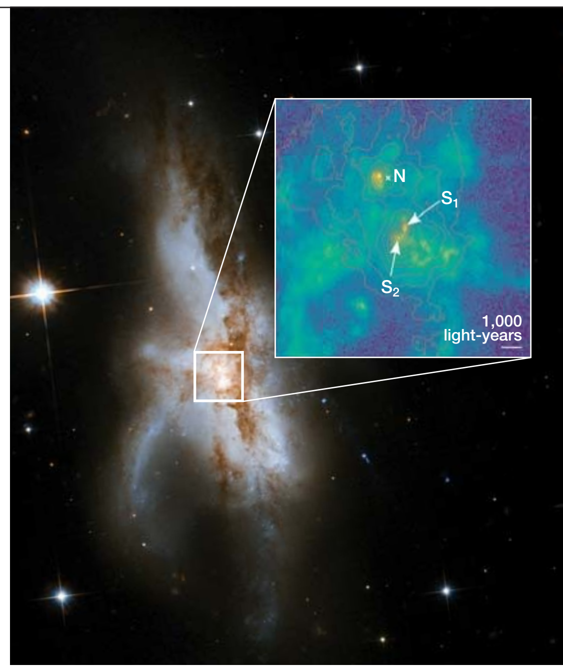
Using the Multi Unit Spectroscopic Explorer (MUSE) on the European Southern Observatory's Very Large Telescope in Chile, Wolfram Kollatschny (University of Göttingen, Germany) and colleagues examined light emitted by ionized elements, such as hydrogen, nitrogen, and sulfur, across the galaxy. Spotting two peaks of emission within one of the radio knots, they realized that one of the black holes is actually two, a close pair separated by only 650 light-years. The discovery will appear in *Astronomy & Astrophysics*.

By measuring the speeds of stars whirling around each black hole, Kollatschny's team estimates that the northern black hole has 360 million Suns' worth of mass; the southern duo has 710 million and 90 million solar masses, respectively. The whole trio is contained within a volume less than 3,000 light-years across.

"Such a concentration of three supermassive black holes has so far never been discovered in the universe," says team member Peter Weilbacher (Leibniz Institute for Astrophysics Potsdam, Germany).

With three black holes in its core, NGC 6240 is probably the remnant of a three-galaxy merger. Theoretical calculations have shown that such multiple mergers should be rare in the present-day universe, so this multiple-merger system represents an opportunity to study something that usually only occurs in the distant universe.

■ MONICA YOUNG



▲ The relatively nearby galaxy NGC 6240 harbors three supermassive black holes at its core: The northern black hole (N) is active and was known before. New observations show that the southern component actually consists of two black holes (S_1 and S_2). The green color indicates gas ionized by radiation surrounding the black holes, and the red lines show the contours of the galaxy's starlight.

TITAN GEOLOGY MAP: NASA / JPL-CALTECH / ASU; GALAXY: NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) / HUBBLE COLLABORATION / A. EVANS (UNIV. OF VIRGINIA, CHARLOTTESVILLE / NRAO / STONY BROOK UNIV.); INSET: P. WEILBACHER (AIP)

STARS

Extreme Photons from Collapsing Massive Stars

ACCORDING TO THEORY *long-duration gamma-ray bursts* (GRBs) unleash most of their energy via twin jets springing from opposite sides of a collapsing massive star. These jets then ram into surrounding material to produce extremely high-energy photons — but until now, astronomers hadn't seen them.

The shock wave from the collapsing star accelerates electrons, which whirl around magnetic field lines and emit gamma rays. Theorists had long predicted that in dense environments, such as where the shock collides with material around the star, these gamma rays could bump into other fleet electrons, stealing their energy to catapult into the trillion-electron-volt (TeV) range.

Astronomers had previously only seen hints of such photons, but within a minute of the flash known as GRB 190114C, TeV photons began raining down above the Major Atmospheric Gamma Imaging Cherenkov (MAGIC) telescopes on La Palma, Spain. Another telescope, the High Energy Stereoscopic System (HESS) in Namibia, found only slightly less-energetic photons from an earlier event, GRB 180720B. Analyses of both events are reported in three papers in the November 21st *Nature*.

While MAGIC and HESS have been online for more than a decade, these two bursts represent their first TeV detections from GRBs. Interestingly, GRB 190114C isn't even exceptionally bright. The MAGIC collaboration attributes the find to its proximity and "suitable observing conditions."

But in an upcoming *Astronomy & Astrophysics*, Antonio de Ugarte Postigo (Institute of Astrophysics of Andalucía, Spain) and colleagues report observations that show GRB 190114C residing in the core of a massive galaxy, which is colliding with another galaxy. This dense central environment is unusual for a long GRB and might have contributed to its exceptionally powerful emission, the team suggests.

■ MONICA YOUNG

SOLAR SYSTEM

Hayabusa 2 Leaves Asteroid Ryugu for Home

THE HAYABUSA 2 SPACECRAFT has completed its mission at 162173 Ryugu — including collecting multiple samples from the asteroid's surface — and is now journeying back to Earth.

The Japan Aerospace Exploration Agency reported that Hayabusa 2 departed the asteroid at 9.2 centimeters per second (0.2 mph) on November 13th. After turning on its ion engine on December 2nd, the spacecraft will take a year to return to Earth.

After arriving in Ryugu's vicinity in June 2018, the spacecraft revealed a rough, diamond-shaped world, similar to (but bigger than) 101955 Bennu, the asteroid that's currently being explored by NASA's Osiris-REX mission.

During its time at Ryugu, Hayabusa 2 successfully released three short-lived asteroid rovers; a fourth rover (Minerva II-2) failed on deployment. However, the climax of the mission came on February 21, 2019, when Hayabusa 2 itself briefly touched down on Ryugu, fired a tantalum pellet at the asteroid's surface, and collected a sample. Next, on April 5th, the spacecraft fired an explosive device to make a crater on the asteroid, then touched down again on July 11th to sample the exposed subsurface.

▶ Hayabusa 2 leaves asteroid Ryugu in this illustration.

Both sample collections went off without a hitch, but we won't know how much was collected until the samples come back. Hayabusa 2 will eject its sample return capsule when it flies by Earth in December 2020, after which the spacecraft will remain in solar orbit. A proposed mission extension to asteroid 2001 WR_1 in June 2023 has not yet been approved.

The first Hayabusa mission struggled to return tiny particles from 25143 Itokawa in 2010. Researchers hope that Hayabusa 2 will return a mother lode of material in comparison.

■ DAVID DICKINSON

IN BRIEF

Store Spectroscopic Data

A new database from the American Association of Variable Star Observers (AAVSO) enables members to store spectroscopic data from any variable object in the sky. The AAVSO Spectroscopic Database, or AVSpec, is complementary to light-curve data collected in the AAVSO International Database. Both databases are available free of charge to everyone. Beginners as well as experienced spectroscopists are encouraged to submit data to AVSpec, as all spectra submitted to the database are hand-verified. "Even the most experienced observers may submit discrepant data due to software glitches or unidentified instrumental defects," explains AAVSO CEO and director Stella Kafka. "By checking every spectrum, we ensure high-quality data for the spectra to be of use in scientific projects." Hand-vetting also provides the opportunity to give constructive feedback to observers, Kafka adds. "In short," says AAVSO Spectroscopy section leader Ryan Maderak, "the database will fully open the door to science that has only been possible on a restricted basis before now."

■ LINDSAY WARD

Find more information and links at https://is.gd/aavsospec.

Good News for Yerkes Observatory

The Yerkes Observatory, built in the 19th century to house the largest refracting telescope in the world, may soon reopen its doors to the public. The castle-like observatory was shut down in October 2018 by the University of Chicago. In response to the closure, members of the surrounding Williams Bay, Wisconsin, community created the Yerkes Future Foundation (YFF). Over the past year, YFF Chair Dianna Colman and others have worked to develop a sustaining model for the observatory's future. On November 5, 2019, the foundation announced "an agreement in principle" with the University of Chicago to transfer ownership of Yerkes Observatory and related property. However, it's not yet known when the observatory will reopen.

■ DEAN REGAS

AKIHIRO IKESHITA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Mars Coughs Up Another Mystery

What's behind the strangely fluctuating levels of oxygen on the Red Planet?

THE CURIOSITY ROVER has now been on Mars for seven years, and in its slow but steady ramble across Gale Crater and up the lower slopes of Mount Sharp, it has taught us much about the Red Planet's ancient geology and chemistry. Most significant has been its confirmation of early Mars's wet environments. But some of its most enigmatic findings have come from sampling and analyzing the current local air.

First there was the methane, which shouldn't be there (*S&T:* July 2019, p. 9). Methane's "lifetime" — how long molecules should survive in the face of known destructive mechanisms — is far too short for accumulations even in the tiny amounts seen. Yet Curiosity has detected bursts of up to 21 parts per billion by volume that seemed to come and go rapidly.

Unexpected methane in a planetary atmosphere has long been held up as a potential "biosignature." That's because here on Earth, organisms produce most of the methane in our air.

Now comes a new report about molecular oxygen (O_2). The report draws from data collected by the Sample Analysis at Mars instrument — the rover's suite of chemistry experiments.

Unlike methane, we expect oxygen on Mars. The atmosphere contains carbon dioxide, water vapor, and other oxygen-carrying molecules, and it is bathed in ultraviolet and cosmic radiation that can rip these molecules apart, leaving free oxygen atoms to combine with each other. So it *should* be there in the trace amounts we observe. But what's strange about the O_2 abundances Curiosity has recorded is the way that they fluctuate over time. Oxygen appears in the spring, its abundance rises rapidly, and then it disappears in the fall and winter. It also seems to vary widely from year to year.

We expect all atmospheric gases to vary seasonally on Mars, following the now-understood variations in atmospheric pressure that arise from the freezing and thawing of carbon dioxide at alternating poles. Yet oxygen's spring rise and winter low are too extreme. Something else is going on.

Any planetary mystery involving oxygen gets our attention because, like methane, it's a potential biosignature. Oxidation, which oxygen and other elements perform, is integral to our notions of life. Even when we try to be open-minded about potential alien life, it's hard to imagine it not needing some kind of "redox" reaction (shorthand for oxidation and reduction). Life at its most basic involves a redox exchange of electrons between "donor" and "receptor" molecules. This is the essential trade upon which all of the chemistry, metabolism, and structure of life rests.

So is this evidence for life on Mars? Almost surely not, although it's fun to speculate. I suspect that the same extreme reactivity of oxygen that makes it so indispensable to life will ultimately explain the conundrum. There's a lot we don't know about the near-surface chemistry of Mars, but we do know about reactive, oxygen-containing molecules such as hydrogen peroxide and perchlorates, which permeate the Martian regolith. My bet is that the springtime wave of both warmth and atmospheric pressure is stimulating some as-yet-unknown chemistry in the soil to burp out this surprising puff of O_2.

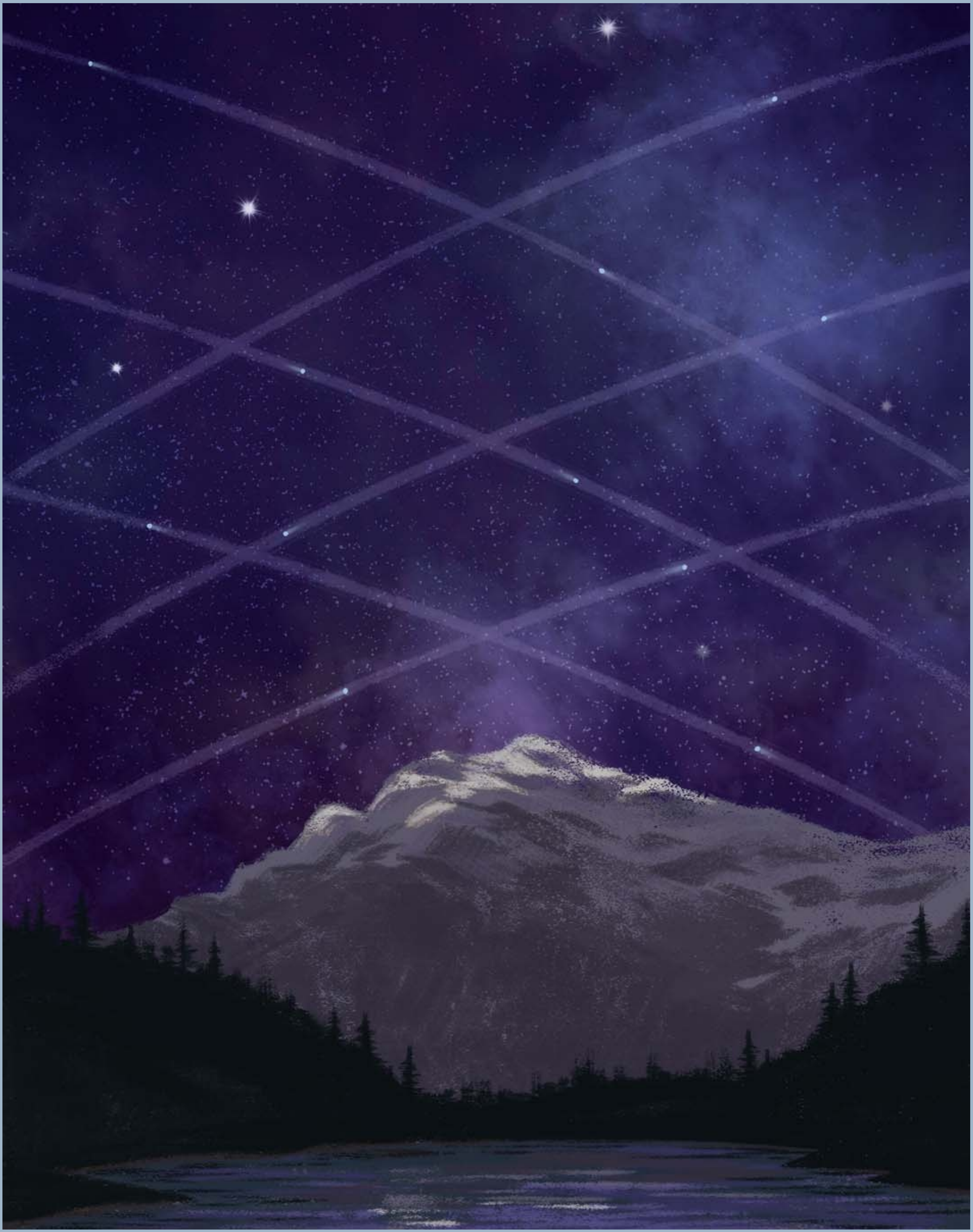
But at the moment all we can do is savor this delightful puzzle and resolve to keep exploring.

■ Contributing Editor **DAVID GRINSPOON** has studied the planets ever since his first undergraduate research job analyzing Mars images from the Viking landers.

Curiosity, seen here in a May 2019 "selfie," throws us another mindboggler.

NASA / JPL-CALTECH / MSSS

 by Monica Young



The *New* Space Race

Multiple companies are launching, or planning to launch, a throng of satellites into low-Earth orbit. The effects on everyone from backyard stargazers to professional astronomers could be profound.

On May 23, 2019, SpaceX launched a packet of sixty 227-kilogram (500-pound) satellites, deploying them to an initial orbit of 440 kilometers (273 miles). These satellites represented the initial phase of SpaceX's Starlink *megaconstellation*, a giant network of satellites buzzing around Earth. Starlink has a lofty goal: to provide worldwide broadband internet access from low-Earth orbit. But it also heralds unintended consequences for astronomy.

During the commissioning phase, while the Starlinks were still flying together, archaeologist and satellite-tracker Marco Langbroek set his sights on spotting them. The satellites' orbital elements weren't available yet, so Langbroek made his own calculation to narrow down which part of the sky to search. And he got 'em. When a flock of some 56 satellites entered his field of view, Langbroek recounted in his blog, "I could not help shouting, 'OAAAAAH!!!!'"

The video in Langbroek's blog soon went viral. The satellites shone at magnitude 2, as bright as Polaris. News outlets and voices on social media warned of a night sky disrupted, and various astronomy agencies, including the International Astronomical Union (IAU) and the American Astronomical Society (AAS), scrambled to issue statements.

Technically, the Starlink launch wasn't a surprise. SpaceX had filed plans years ago, first with the International Telecommunication Union (ITU), which is responsible for assigning frequency space to satellites from countries worldwide, and then with the Federal Communications Commission (FCC), which enforces a modified version of ITU standards in the U.S. Those filings ultimately make space for 11,927 Starlink satellites at various altitudes.

SpaceX is not alone in this venture. When Starlink made the news, an internet company known as OneWeb had already launched its first six broadband satellites with relatively little fanfare. The company plans to launch more — up to 32 at a time — starting in January 2020, in order to fill out an initial network of 648 satellites by the end of 2020. Amazon has likewise filed paperwork for its planned Project Kuiper constellation.

These companies are competing for access to a $1 trillion market, aiming to serve billions of people worldwide who are currently without reliable internet access. Even a small percentage of this global market promises billions in revenue.

Yet, even though plans have been in the works for years, the brightness of the Starlink satellites came as a shock to astronomers. "The ground-based optical and infrared observatories were really taken by surprise with the first launch," says Kelsie Krafton, a public policy fellow at the AAS.

After all, megaconstellations have no precedent. Perhaps the closest thing is Iridium's 66-piece network, which enables the global operation of satellite phones and pagers, but Starlink would outnumber Iridium almost 200:1. As the issues at stake are ones of scale, there's really no comparison.

In response to concerns about the future of the night sky, we have asked experts to provide hard numbers in the face of media hype, quantifying how worried we should be about everything from visual astronomy and astrophotography to astronomical science and space debris. Their answers show the threat to astronomy is real, but also that the future isn't a foregone conclusion: Astronomers are actively connecting with aerospace companies and talking over potential solutions. Nevertheless, the situation is in flux and how everything works out remains to be seen.

▲ **10, 9, 8 . . .** Sixty Starlink satellites launched on May 23, 2019, aboard a Falcon 9 rocket. Another packet of 60 launched on November 11th, shown here. The May launch deployed to an altitude of 440 km and the November launch to 280 km, but both sets of satellites will operate from 550 km.

The Backyard View

Alarming as Langbroek's viral video was, a few reasoned voices in the astronomy community urged caution in the face of the (social) media whirlwind that followed last May's Starlink launch. Within days the satellites' brightness had already begun to fade, as their solar panels turned toward the Sun and their krypton-powered thrusters took them to an operational altitude around 550 km.

Enter SeeSat-L, a somewhat anarchistic group of satellite observers who trade information via a mailing list. Langbroek is a member of this group; so is Cees Bassa, a Dutch radio astronomer at the Netherlands Institute for Radio Astronomy (ASTRON). Bassa and others contributed observations in July and August, compiling at least one magnitude measurement for more than a dozen of the satellites. The observing campaign revealed that the satellites' visual brightness at their operational altitude ranges from magnitudes 4 to 7. Most measured magnitudes cluster around magnitude 6.

That means that for the average citizen living in an urban or suburban area, these satellites will be nearly invisible. But they'll have a noticeable effect on the night sky in rural areas. "From a really dark site, they all are in the range of objects that you can still see with your naked eye," says Langbroek.

Nevertheless, it's still far from obvious what effect mega-constellations might have on backyard astronomy. For one, the view depends on where you look. The initial Starlink network, for example, will consist of 1,584 satellites in 24 orbital planes, with 66 satellites in each ring. (SpaceX is still waiting for approval of a September 2019 filing to the FCC asking to spread the same number of satellites over 72 rings

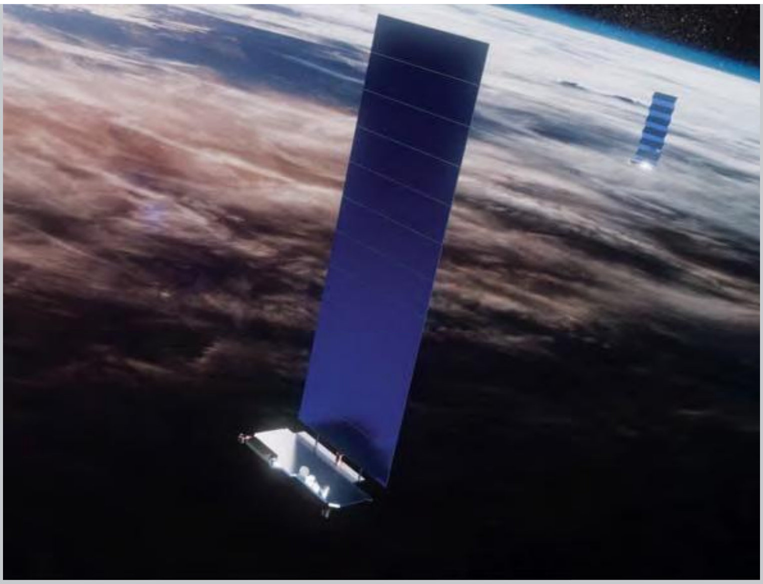
▲ **WAGON TRAIN** On May 24th Marco Langbroek captured a spectacular video of the 2nd-magnitude satellite train. "I was dancing behind the camera," Langbroek says. "After that, of course, the concern came."

instead.) So, Bassa explains, if you happen to look into one of these planes, you'll see one satellite, then two minutes later the next, then two minutes later the next — like the recurring noise of overhead jets if you live near a major airport. Given the large number of orbital planes planned for several competing companies, it won't necessarily be obvious which regions of sky to avoid.

The satellites' visibility also depends on the time of year, observing latitude, and satellite altitude. Satellites are only visible when they reflect sunlight. So, while lower-altitude satellites are brighter (because they are closer to Earth), they are also visible for shorter fractions of the night. According to Bassa's calculations, the initial 1,584 Starlink satellites would be visible from the equator only during twilight. But the

VIRAL VIDEO STILL: MARCO LANGBROEK; STARLINK PACKED AND UNFOLDED SATELLITES: SPACEX (2)

▲ **LOCKED AND LOADED** Sixty Starlink satellites are packed like sardines within the nosecone of a SpaceX Falcon 9 rocket.



▲ **UNFURLING** Starlink satellites, still flying as a flock post-launch, deploy their singular solar arrays in this artist's concept.

situation is markedly different for higher latitudes during the summertime: Starlinks would be visible for most of the night.

Higher-altitude orbits help in some respects. OneWeb's satellites (which are also smaller than Starlinks) fly at 1,200 km and should be at least two to three magnitudes fainter, according to an estimate by Jonathan McDowell (Center for Astrophysics, Harvard & Smithsonian). Moreover, the higher altitude means the company will need fewer satellites overall. However, the satellites will be reflecting sunlight for a larger fraction of the night from all latitudes, and even if they're out of naked-eye range, they'll still be an issue for photographers and professional astronomers.

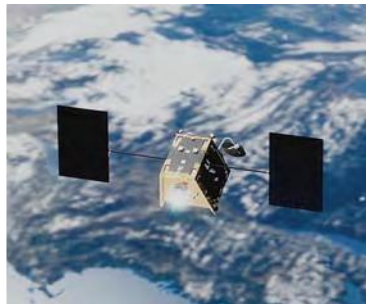
Making (and Removing) Tracks

"For even modest astronomical instruments, these are quite bright objects," Langbroek says. Once the constellations have been assembled, astrophotos are virtually guaranteed to record satellite trails.

In some cases, the problem is easy to deal with. Even now, deep-sky photographers often capture satellite trails, not to mention the trails left by airplanes passing overhead, explains astrophotographer Richard S. Wright, Jr. The techniques for dealing with these kinds of trails are not only well established but also easy to apply.

Astrophotographers don't typically take single exposures of deep-sky objects; they more often take many shorter exposures and stack them together into a single image via image-processing software. Photographers can reject unwanted signals during this process. Although the name and details of the process may vary depending on the software, the basics remain the same: The software looks at the values of a single pixel across multiple frames, then rejects any pixels that are significantly brighter (or fainter) than the others.

However, single-shot and nightscape photographers don't have those same processing options. *S&T* Contributing Photographer Babak Tafreshi notes that a typical 10- to 20-second nightscape exposure would easily pick up the satellites, as would wide-angle images. The only option for removing the trails would be to go through images pixel by pixel.



▲ **ONEWEB** In this artist's concept, a OneWeb satellite fires its thruster. OneWeb had launched six satellites at press time.

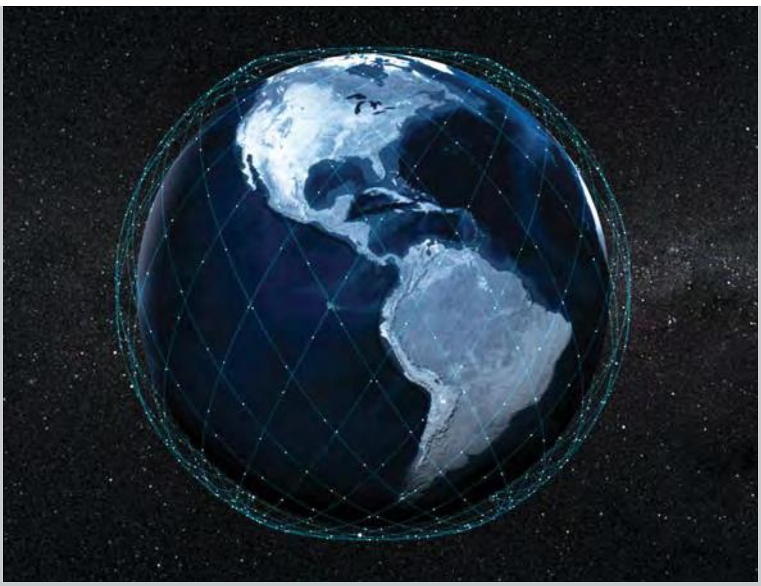
A Limiting Case

The situation may be even more dire for some professional telescopes. Anthony Tyson (University of California, Davis) argues that megaconstellations will most profoundly affect a telescope that hasn't been built yet: the Large Synoptic Survey Telescope (LSST).

The LSST will have an 8.4-meter mirror, an almost 10 square degree field of view, and a 3.2-gigapixel camera. It will record the entire sky visible from Cerro Pachón, Chile, every

NO ACCESS

21.3 million Americans lack broadband internet, according to a 2019 FCC report.



▲ **GLOBAL PRESENCE** This image shows the initial phase of the Starlink constellation: 1,584 satellites in 24 orbital planes at 550 km. (SpaceX has applied to the FCC for a change to this configuration, spreading the same number of satellites across 72 planes.)

▲ **BEAMING BROADBAND** The Starlink network will use specific radio frequencies to provide broadband internet connectivity. SpaceX intends to begin offering coverage to the northern U.S. and parts of Canada in 2020, expanding to near-global coverage by 2021.

STARLINK WEB AND BROADBAND DELIVERY: SPACEX (2); ONEWEB SATELLITE: ONEWEB SATELLITES

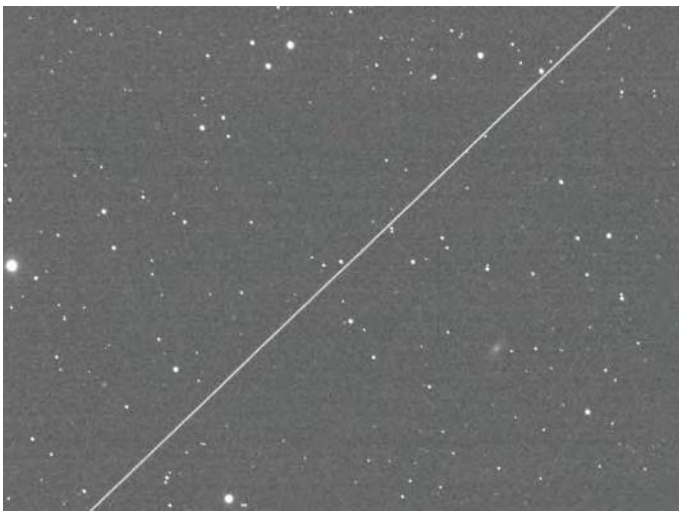
> The more crowded the sky, the less possible avoidance becomes. "At tens of thousands of satellites, it becomes a wild goose chase trying to find an opening."

three nights over the course of a decade (*S&T:* Sept. 2016, p. 14). Other professional telescopes may have comparable sensitivity, but LSST's "wide, fast, deep" approach means that it represents what Tyson calls a "limiting case." The average person might simply call it a worst-case scenario. But in some ways, LSST also represents the future of astronomy, as wide- and deep surveys have become the new normal in the field.

To calculate how bright a satellite would be to LSST, Tyson first looked at a series of images taken by one of the Las Cumbres Observatory's 40-centimeter telescopes at Haleakalā, Hawai'i. If that telescope had been tracking the satellite, it would have recorded visual magnitudes ranging from 5.8 to 7.6. However, a satellite crosses multiple CCD pixels over the course of a typical exposure and, without tracking, the satellite trail appears fainter in any given pixel. Correcting for LSST's different instrumentation, seeing, and other factors, Tyson calculated that the telescope would see the same satellite as having a surface brightness of 12 magnitudes per square arcsecond.

That may sound faint, but LSST's CCDs saturate at 16th magnitude in a 30-second exposure. Of course, many stars have magnitudes greater than 16, which is why LSST reads out images in segments. Every image is recorded by 189 CCDs, each of which is 4,000 pixels on a side. Every CCD is separated into 16 segments. "The whole thing gets read out at the same time, in parallel — 3.2 gigapixels in two seconds," Tyson explains. Bright stars, appearing as saturated points, are effectively segmented out by the readout process.

However, because a satellite appears as a streak rather than a point, crosstalk effects between segments as they're read out create copies of the trail throughout the CCD. So, while a single Starlink trail would only pass through a small number of pixels as it passes across a series of CCDs, copies of the trail would impact the entire CCD, not just the individual pixels. These residual effects are hard to completely remove. Based on FCC filings, Tyson estimates that by the mid-2020s, nearly every exposure within two hours of sunrise or sunset would have a streak from a megaconstellation satellite, significantly impacting the science the telescope can do, including the hunt for near-Earth asteroids.



▲ **LAS CUMBRES CAPTURE** This 120-second exposure using a 40-centimeter telescope on Haleakalā, Hawai'i, shows a Starlink trail 75 minutes after sunset. If the telescope had been tracking the satellite, it would have had a visual magnitude of 6.5. Three additional exposures gave magnitudes ranging from 5.8 to 7.6. Scientists working with the Large Synoptic Survey Telescope used images like this one to help gauge the Starlink constellation's cumulative effects.

TODD BOROSON / LAS CUMBRES OBSERVATORY

If even lower-altitude Starlinks launch — and SpaceX plans to launch more than 7,500 to an altitude of only 340 km — they'll likely be a full magnitude brighter. "What that does is it actually 'blooms' across the entire CCD, from one side to the other," Tyson says. "You basically lose the exposure."

Rather than remove satellite trails, Tyson had originally hoped to avoid them altogether. But the more crowded the sky, the less possible avoidance becomes. "At tens of thousands of low-Earth orbit satellites, it becomes a wild goose chase trying to find an opening," Tyson says.

Another option is to paint the parts that would reflect sunlight at observers black. "The Department of Defense paints many of its birds black," Tyson notes. In fact, many countries have been using these low-tech invisibility cloaks for decades, and he has calculated that black paint could reduce the satellites' brightness by 3.5 magnitudes.

Tyson and other professional astronomers have been passing such recommendations along to SpaceX and OneWeb. SpaceX has responded by announcing plans to make the base of its Starlinks black. The next launch, planned for December as of press time, will have one satellite test such a coating.

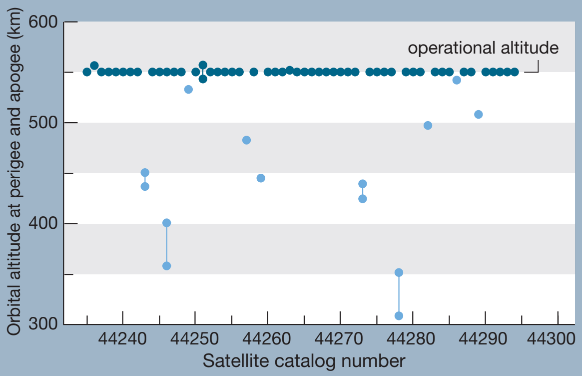
Frequency Protection

Conversations between aerospace companies and astronomers have been most prolific — and perhaps the most optimistic — from the side of radio astronomy, due largely to national and international regulation of radio frequencies.

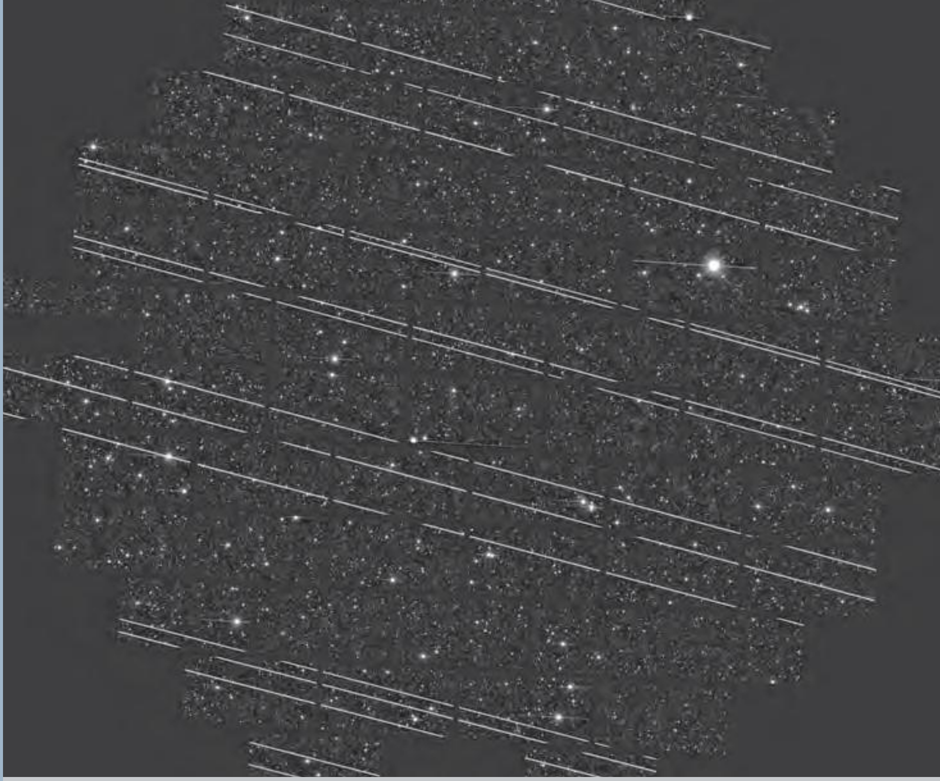
However, the ITU only carves out a few specific frequencies for astronomers. These protected bands, such as the one at 1400 to 1427 MHz used for observing neutral hydrogen in the nearby universe, have regulations in place to prevent interference from other sources. But radio astronomers also observe almost continuously from 1 to 50 GHz, notes Arecibo program director Ashley Zauderer (NSF), even in bands that are not set aside specifically for them. That's because radio astronomy, unlike most uses of radio frequencies, is passive.

"The concern from the radio astronomy perspective is that, up until this decade, above 10 GHz has generally been free of interference," Zauderer says. Most constellation satel-

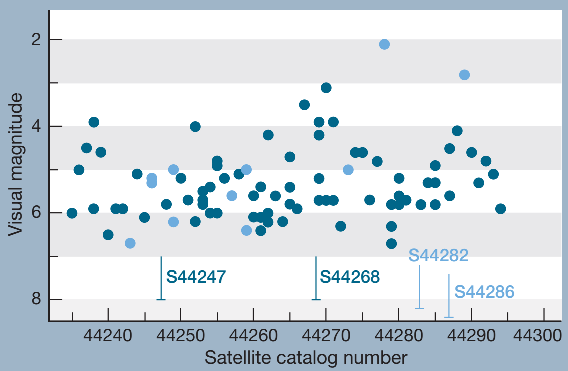
Starlink by the Numbers: Brightness and Visibility



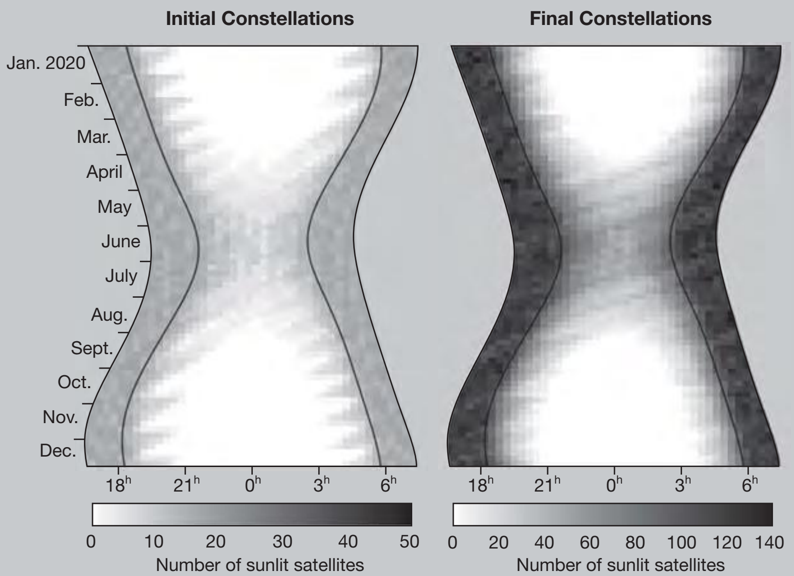
▲ **HOW HIGH?** Observations from the SeeSat-L group contributed to this plot of the altitudes of the Starlink satellites, current as of press time. Fifty Starlink satellites are at an operational altitude of 550 km (dark blue). The ten satellites lower than 550 km are marked light blue. Two of these are intentionally deorbiting, and three more stopped communicating with ground stations and will deorbit naturally.



▲ **STARLINKED** On the morning of November 18th, newly launched Starlink satellites flying at 280 km crossed over the Dark Energy Camera, which is mounted on the 4-meter Blanco Telescope at the Cerro Tololo Inter-American Observatory in Chile. The six-minute exposure of the outskirts of the Large Magellanic Cloud was designed to look for new dwarf galaxies in the Milky Way's vicinity but instead recorded the passage of the Starlink train. These satellites will spread out and fade somewhat in a matter of weeks — but they will still affect professional exposures.



▲ **HOW BRIGHT?** SeeSat-L contributors Jay Respler, Brad Young, Bram Dorreman, and Ron Lee observed Starlink satellites in July and August 2019, when the majority of the first batch of Starlink satellites had reached 550 km. Those at lower altitudes are marked light blue; satellites with no measurements are marked with vertical lines. Most measurements cluster around magnitude 6, the limiting magnitude for a rural site, and well within range of naked-eye viewing at a truly dark-sky site.



▲ **HOW VISIBLE?** The numbers of megaconstellation satellites visible in the night sky are plotted for an observer at latitude 40°N, with darker squares representing more satellites. The charts show satellite density for a given time of day (horizontal axis) and time of year (vertical axis). *Left:* Here's what could be in store by the end of 2020, assuming initial constellations of 1,584 Starlink satellites and 648 OneWeb satellites. *Right:* Future satellite visibility is based on FCC filings, with 11,927 Starlinks, 1,980 OneWeb satellites, and 3,236 Kuiper satellites. The edge of the plot marks sunset and sunrise, while the interior black line marks astronomical twilight.

PLOTS: LEAH TISCIONE / *S&T*; SOURCE: JONATHAN MCDOWELL (2); STARLINK TRAILS: DELVE SURVEY, CTIO / AURA / NSF; SATELLITE VISIBILITY: GREGG DINDERMAN / *S&T*; SOURCE: CEES BASSA lites, though, will use portions of the K_a (26.5–40 GHz) and K_u (12 to 18 GHz) bands for communication, and growing megaconstellations mean this frequency space will increasingly have interference.

To deal with this encroachment, astronomers will have to pursue a combination of technology development and coordination. Right now, for example, most receivers saturate when they come within tens of degrees of a radio-emitting satellite. So National Radio Astronomy Observatory (NRAO) scientists are working to build new receivers that are more resistant to interference.

Coordination with satellite companies will likely play an important role as well. So-called *dynamic sharing*, in which satellites stop transmitting a particular frequency when passing over ground-based radio telescopes, could enable radio astronomers to access parts of the spectrum that might otherwise be unavailable. "I think the technology that we're seeing in these new satellite systems provides a lot of opportunities to not only protect radio astronomy but also expand access to the spectrum," Zauderer muses. "Lots of potential for win-win for everybody here."

It's worth noting, though, that the technology — and therefore the opportunities — vary between satellite constellations. OneWeb, for example, cannot dynamically share radio frequencies because its satellites' beams are both fixed and, due to its satellites' higher orbits, necessarily much larger than Starlink's steerable beams.

◀ **SPACE DEBRIS** This artist's impression of objects in low-Earth orbit is based on actual density data, but the size of the objects has been exaggerated to make them visible at the scale shown.

ESA

The Space Debris Problem

Megaconstellations' potential impact on astronomy is outweighed by their potential to contribute to the growing space debris problem (*S&T:* July 2018, p. 34). Only about 1,950 active satellites were orbiting Earth in early 2019, but SpaceX alone aims to increase that number by 80% by the end of 2020, and by a factor of seven within the decade. These satellites, as well as their accompanying deployment structures, are virtually guaranteed to leave debris behind.

They would challenge a tracking system that's already stretched thin. The U.S. Air Force 18th Space Control Squadron uses radar to track more than 20,000 pieces larger than 10 cm, large enough to shatter satellites and contaminate the space environment. Based on this number, statistical models run by the European Space Agency (ESA) indicate that there are 900,000 pieces between 1 cm and 10 cm. Even one of these smaller but speedy pieces could end a mission. "The energy equivalent of a collision with a 1-cm object is the explosion of a hand grenade," says Holger Krag, head of the ESA's Space Debris Office.

Dead megaconstellation satellites would only add to the current menagerie. With its first launch of 60 satellites, SpaceX reported that three had lost communication with ground stations before they reached operational altitude and were deorbiting naturally. Reentry is expected within a year, in accordance with NASA's guidelines. SpaceX says two additional satellites are being intentionally de-orbited.

However, that doesn't seem to be the full story. "When you look at the reality, the objects' current altitude, there are a number of objects that behave oddly," Langbroek notes. Observations by the SeeSat-L group show that 10 of the satellites had not reached operational altitude by the end of October, and SpaceX has not commented on the five unaccounted-for satellites that have not reached their station.

Even a small percentage of failure is too much, Krag says. "The sheer number, even with good behavior on individual satellites, causes worry."

Another concern is coordination between satellites. Starlink satellites are equipped with autonomous collision avoidance, a feature SpaceX argues puts it on the leading edge of on-orbit debris mitigation. Krag says that ESA's operators perform about one debris avoidance maneuver per year per satellite. Meanwhile, the Starlink satellites had already performed more than a dozen automatic maneuvers within a couple months after launch.

But that works best when facing something inert; encounters between active satellites will require coordination between satellite operators. "Today, there is not even a phone number that I can call," Krag says. "This traffic is not organized at all." That lack of direct communication caused the ESA to redirect its Aeolus wind-monitoring satellite in

September 2019. Calculations had put it on a possible impact trajectory with a de-orbiting Starlink satellite, but the Starlink wasn't moving, so Aeolus had to.

Ultimately, Krag says, data-sharing will be crucial to deciding who should maneuver and how big the maneuver should be. SpaceX is open to working on these solutions with ESA, he adds.

But sometimes, what makes for good space stewardship can have unintended consequences for astronomy. Before the first launch, SpaceX had filed to lower the orbits of its first Starlink satellites from more than 1,150 km to 550 km, so that if one of them did fail, it would de-orbit more quickly. It's these lower orbits that make the objects so bright when seen from the ground.

And professional observatories such as LSST can work to avoid megaconstellation satellites only if the satellites follow their set orbits and don't swerve to avoid a crash. "These guys are moving around! All by themselves!" Tyson exclaims. SpaceX will have to share these autonomous movements promptly if astronomers are to adapt.

Other companies are working to address the space debris issue in different ways. OneWeb, for example, has rolled out a Responsible Space initiative that focuses less on altitude and more on responsible design.

"We're not launching something with a high chance of failure in orbit," Mike Lindsay, then head of OneWeb's advanced mission design, said at a July 2019 conference. "Once it fails in orbit, it becomes everybody else's problem, and we don't view that as acceptable." By aiming for reliable design rather than quick re-entry times, OneWeb is able to place its satellites at 1,200 km, where the company says there is a lower density of objects.

Taming the Wild West

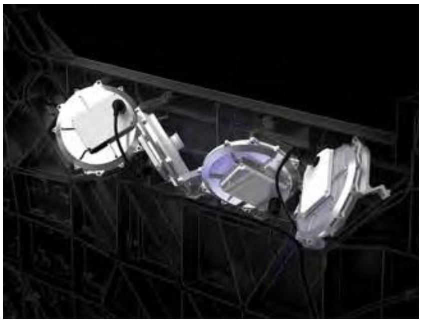
As this issue goes to press, SpaceX has launched another 60 Starlinks on November 11th, with another three launches in the works. Likewise, OneWeb has a single launch of at least 30 satellites set for January and two more marked for early 2020. SpaceX has also filed paperwork with the ITU for an additional 30,000 satellites. Even though the ITU's approval may take years, the request indicates that megaconstellations are a reality that astronomers won't be able to avoid.

A complicating factor is that space remains largely untamed, legally speaking. The Federal Aviation Administration regulates commercial launches, and the ITU and national agencies regulate frequencies (and to some extent satellite orbits). But there isn't anything that protects the night sky from satellites in low-Earth orbit except for a single federal law against "obtrusive space advertising."

Until space law catches up, communication will be key. It helps that the space industry has a certain affinity for the stars. "We've found that pretty much every company we've talked to is very enthusiastic about astronomy," says Jonathan Williams (NSF), but he adds, "They don't always know how to put that into practice." For example, following the hubbub around the May 2019 Starlink launch, SpaceX began working with leading astronomy groups from around the world, including the AAS and the IAU, to lessen their satellites' impact on our view of the universe. The recent decision to paint the base of future Starlink satellites black is just one result of these ongoing conversations.

However, as a sea change occurs in low-Earth orbit over the next few years, we cannot rely on companies' goodwill alone. At least one astronomer involved in these conversations expressed skepticism that companies will come through on their promises. Given the rapid change in rhetoric from the SpaceX CEO's initial Twitter dismissals of astronomers' concerns, skepticism is understandable. Policies protecting sky and space will have to be enacted if we are to ensure our access to the universe.

■ *S&T* News Editor **MONICA YOUNG** usually likes shiny things . . . but sometimes she prefers them to be matte black.



◀ **AUTONOMOUS AVOIDANCE** This figure shows the Starlink satellites' autonomous collision avoidance system. It uses inputs from the Department of Defense's debris-tracking system to maneuver around inert objects.

▶ **NEW EYE ON THE SKY** The Large Synoptic Survey Telescope (LSST) is still under construction atop Cerro Pachón, Chile. It's expected to begin full science operations in 2023 — when the night sky may look significantly different than it does now.

CONSTELLATION CLOSE-UP

Argo Navis

This ancient formation survives only in fragmentary form.

Of the 48 constellations described in Claudius Ptolemy's *Almagest*, 47 survive to the current day. The sole exception is Argo Navis, the ship that carried the mythical Greek hero Jason and his fellow Argonauts to the end of the known world in quest of the Golden Fleece. Its stars ended up distributed among four nautically themed constellations: Carina, the Keel or Hull; Vela, the Sails; Puppis, the Poop Deck; and Pyxis, the Compass. Pyxis is small and dim, but Carina, Vela, and Puppis are all big, bright, and spangled with naked-eye star clusters. If you put them back together, they'd be the biggest constellation in the sky — much bigger than Ptolemy's original Argo, in fact. For shorthand, I will call the original constellation Old Argo Navis, and use Greater Argo Navis to denote modern Carina, Vela, and Puppis.

The standard explanation for Argo Navis's dismemberment is that the French astronomer Nicolas-Louis de Lacaille (1713–1762) chopped it up — and there is some truth to that. It's a fair bet that the constellation would still be alive and well today if Lacaille hadn't sailed to South Africa to observe the southern skies. Lacaille did indeed slice Pyxis off Argo, but he used the terms Carina, Vela, and Puppis only to describe aspects of Greater Argo Navis. He would have been horrified to know that they would end up replacing it. Lacaille doomed Argo to extinction not because he despised it but because he loved it too well.

Another way to view Argo's demise is that it resulted from impersonal forces: the globalization of European culture, the invention of the telescope, and the rising power of science and innovation with respect to tradition and authority.

ION

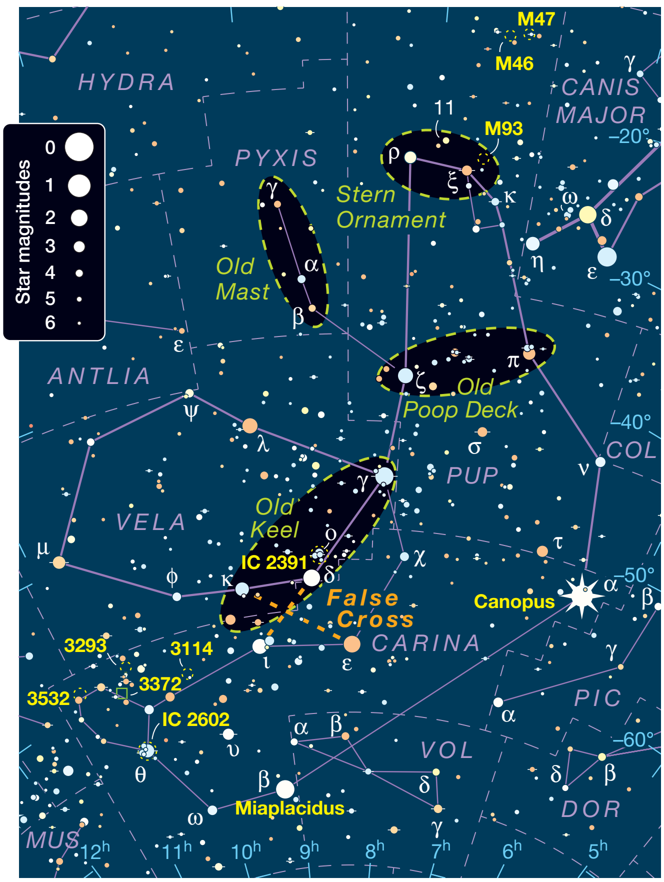
SAILING THE SOUTHERN SKIES Argo Navis once sailed intact, but it has since been splintered into several separate and distinct constellations. Here the Carina Nebula glows high in the Chilean sky above a dish of the ALMA submillimeter array.

ESO / B. TAFRESHI

Argo Navis is a southerly constellation, making it particularly vulnerable to the change in perspective — both physical and cultural — that marked the advent of the modern Western world. The southernmost stars of Old Argo were barely visible from the southernmost edge of the ancient Greco-Roman world. Toward the end of the 1500s, Dutch astronomers ventured south of the equator, where Argo Navis floats high in the sky rather than low upon the waters of the Mediterranean. They found it natural to connect Old Argo Navis to another bright star pattern just out of sight of the ancient world, plus the single most dazzling stretch of the Milky Way. And that, in turn, set the stage for the constellation's dissolution.

Observing Northern Puppis

To understand this better, let's tour Greater Argo Navis as seen from the 48 contiguous United States, which span much the same latitudes as the Mediterranean Sea, the great watery highway that held the Greco-Roman world together. Venice is flush with northern Maine and southern Washington State, Rome is flush with Boston, and Ptolemy's hometown of Alexandria, Egypt, lies a bit north of Jacksonville, Florida. Moreover, while precession (the wobble of Earth's axis) has made some parts of the sky higher and others lower, Argo's western edge happens to lie at one of the two pivot points whose declination has remained almost unchanged during the last two millennia.



Let's imagine that we're sailing from Rome to Alexandria or Boston to Jacksonville on a March evening. Argo's stars lie to our south. What can we see with our unaided eyes?

The most prominent formation is a tight, elegant triangle of medium-faint stars, numbered 1, 2, and 3 in Ptolemy's catalog, and today called 11, Rho (ρ), and Xi (ξ) Puppis, respectively. They form a medium-faint but eye-catching triangle that Ptolemy described as the **Stern Ornament**. For users of binoculars and telescopes, Xi is also the jumping-off star for the rich, compact open star cluster **M93** just 1.5° to its upper right (northwest), one of the little gems of the Messier list. Keen-eyed stargazers with favorable skies, forearmed with certainty of its existence, can now detect M93 even without optical aid. But it's much fainter than any deep-sky object noted by pre-telescopic observers.

Not so with magnificent **M47**, one of the brightest open star clusters in the sky. It lies in a sea of 5th-magnitude stars that Ptolemy neglected and that was appended to northern Puppis in modern times. To my eye, 4th-magnitude M47 is the most prominent feature of that sector, much as M44 (the Praesepe or Beehive Cluster) dominates the constellation Cancer. I can see M47 easily without optical aid from the outer suburbs of Boston, Massachusetts, despite the unfavorable latitude. It's similar in brightness to M41 in Canis Major, which *was* known to the ancients, so Ptolemy could have cataloged M47 but didn't. The same could be said for many other "cloudy" spots in the night sky, most notably the Andromeda Galaxy. Ancient astronomers had no way of knowing that these fluffballs were significant.

That all changed in 1609 when Galileo Galilei turned his telescope to M44 and resolved the cluster into dozens of individual stars. You can experience the same thing by viewing M47 through binoculars or small telescopes, which resolve it into a dozen or so bright, young, blue stars, with a sprinkling of red giants.

Under dark skies, you may also spot **M46** naked-eye as a similar-sized but much fainter cloud of light 1° to M47's left. The contrast between the few bright stars of M47 and the innumerable faint stars of M46 makes this one of the sky's finest fields for binoculars and telescopes of all sizes.

Lower left of the Stern Ornament you can find a faint but striking straight line composed (north to south) of the stars now known as Gamma (γ), Alpha (α), and Beta (β) Pyxidis. Those, together with Delta (δ) Pyxidis just to Gamma's upper left, form Ptolemy's **Old Mast**, which Lacaille sliced off intact to form the modern constellation Pyxis, the Compass. The straight line works well either as a mast or a nautical compass needle.

The Milky Way runs through northern Puppis, so it's full of medium-bright star clusters, a fine area to explore with binoculars and telescopes. But the next feature south of the Stern Ornament that a naked-eye observer is likely to notice is the wide star pair formed by 2.2-magnitude Zeta (ζ) Puppis and 2.7-magnitude Pi (π) Puppis, plus a scraggly line of stars connecting them. According to Ptolemy, these marked

▲ **SPARKLES IN THE STERN** The open star cluster M93 lies in the constellation that Ptolemy called the Stern Ornament and that today we know as Puppis. If you know where to look, you might even be able to spot this compact cluster with the naked eye.

▲ **DOUBLE DELIGHT** The rich open star cluster M46 holds a surprise: the planetary nebula NGC 2348 floats in front of the cluster, but the two objects are not associated. You should be able to spot the cluster without optical aid, but you'll need a telescope for the planetary.

M93: JOSEF PÖPSEL / STEFAN BINNEWIES / DIETMAR BÖCKER / CAPELLA OBSERVATORY; M46: N. A. SHARP / NOAO / AURA / NSF

the poop deck, the ship's highest horizontal surface. I will call it the **Old Poop Deck** to distinguish it from the modern Puppis, which is much bigger. It's barely above the horizon as seen from Calais, Maine, or Venice. But as we sail south toward Florida or Egypt, ever more of Old Argo Navis will rise above the water each evening.

When we reach latitude 37°N (southernmost Virginia or Sicily), Old Argo's brightest star appears above the waves, radically altering the constellation's appearance. This is dazzling **Canopus**, magnitude –0.7, second only to the Sun and Sirius in brightness (see page 45 in the February and March 2019 issues). In modern times, we're likely to assume that anything so bright and low is an oncoming airplane or a beacon on a distant hill. But in Ptolemy's time, before bright artificial lights, Canopus must have been an unmistakable beacon for an Egyptian sailor heading home to pick up yet another shipload of wheat to feed Rome's hungry masses.

Almost half the people in the United States live far enough south to see Canopus. If you're among that lucky group, find a spot with an unobstructed view of the southern horizon such as a hilltop, beach, or treeless plain. Go out when Canopus is highest, around 10 p.m. in mid-February or 8 p.m. in mid-March, and the brilliant star should be instantly obvious unless the sky is extremely hazy. It's an unforgettable sight.

By the time we've sailed down to Egypt or northern Florida, we can see all of Old Argo Navis above the horizon — though just barely. It's best viewed around midnight in mid-February or 10 p.m. in mid-March, when Canopus is sinking and Old Argo's second-brightest star, 1.8-magnitude Gamma Velorum, is near its highest. Gamma forms a prominent zigzag line together with 2nd-magnitude Delta and Kappa (κ) Velorum to its lower left. If you extend that line to Gamma's upper right to include Sigma Puppis, plus a bunch of fainter stars in between, you end up with the stars Ptolemy described as forming Argo's keel. I will call it the **Old Keel** to distinguish it from the modern constellation Carina, which is a very different grouping, barely overlapping with the Old Keel.

Also in view now is **IC 2391**, the Omicron (ο) Velorum Cluster, a prominent hazy patch surrounding 3.6-magnitude Omicron, just 2° upper right of Delta Velorum. Of all Greater Argo's many bright naked-eye star clusters, this is the only one that falls within the region that Ptolemy assigned to Argo Navis. Binoculars show that it's a very coarse cluster dominated by five or six stars ranging from magnitude 4 through 6. One of the stars is a wide double; can you split it in binoculars?

Historical Interlude

We have now visited about half the 45 stars that Ptolemy assigned to Argo Navis. He described the remainder as scattered around the deck and various other parts of the ship. It's a little hard to visualize Old Argo Navis; the depiction in Johannes Bayer's 1603 atlas *Uranometria* (shown on page 26) is as good as any and better than most. Note that the ship is sailing to the left, and the front half is missing, facts that all ancient authors agreed on.

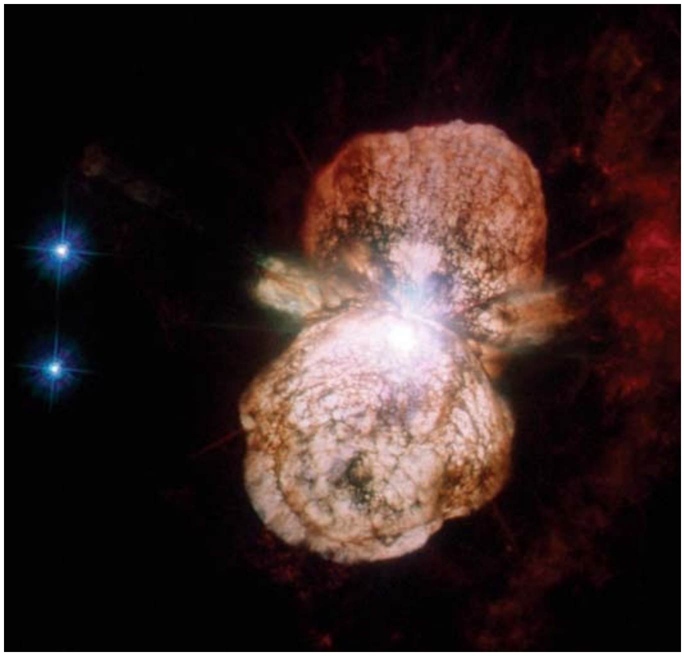
Conspicuously absent is 2.7-magnitude Mu (μ) Velorum. Although it's farther north than many other of Ptolemy's stars, and also fairly bright, he neglected to include it in his catalog.

Granted, measuring the positions of one-thousand-plus stars using ancient technology was a daunting job. Even so, Ptolemy's star catalog is pretty sloppy, especially in its southernmost reaches. He could have done a better job if he had been highly motivated. Just as Ptolemy didn't care much about faint fuzzies, he also didn't care all that much about individual stars except for the ones near the ecliptic, which are essential for measuring the positions of planets. And he cared greatly about planets, both because of the intellectual challenge of analyzing their motions and because he was a passionate astrologer.

My own theory as to why Ptolemy included Delta and Kappa Velorum in Old Argo, but missed Mu, is that Delta and Kappa lie athwart the eye-catching Milky Way. For ancient sailors, Old Argo was where the Milky Way intersected the Mediterranean Sea on spring evenings. It's also where the Milky Way starts to get bright again after a long dull stretch in what's now Monoceros. Sadly for the ancients, the very brightest part lies just a little farther south, out of sight of the Mediterranean and all the major cultural centers of the ancient Western world. It *is* visible from southern Florida and Texas, but to get a good view of Greater Argo Navis as a whole, you need to travel south of the equator, where the entire super-constellation floats high in the evening sky from February through May.

The first modern European ships to reach that far south were those of the Portuguese, probing down Africa's west coast in search of a new route to the Indies, which Vasco da Gama finally achieved in 1498. But eager to maintain their monopoly on the fantastically lucrative spice trade, they published little that might have been of use to others venturing into the Southern Hemisphere.

In 1595 some Dutch merchants, eager to break the Portuguese monopoly, launched an expedition of their own, and its navigators *did* publish a catalog of the far-southern stars. The cartographer Petrus Plancius used that to fill in the blanks left by Ptolemy, publishing the world's first complete celestial globe. In addition to showing many new constellations in the far-southern sky, the globe extended Argo Navis to the east, reaching all the way to Centaurus (see the April 2019 issue of *Sky & Telescope*, page 22).



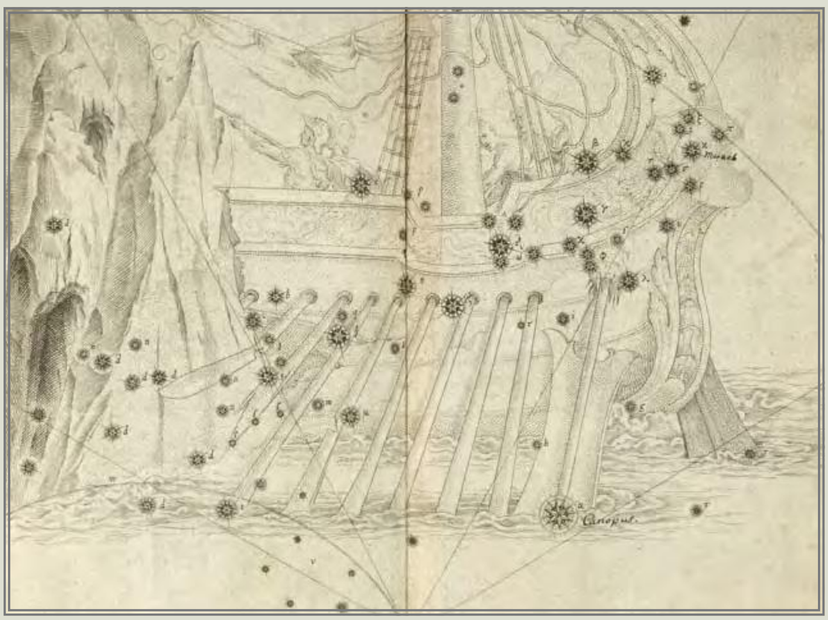
▲ **SUPERNOVA CANDIDATE** Eta (η) Carinae, which powers the eponymous nebula, is one of the most luminous and mysterious stars known. It is shrouded from direct view by a dust cloud called the Homunculus Nebula. It consists of at least two supermassive components, the brighter of which is probably ripe to explode as a supernova — perhaps even tonight.

The final chapter prior to Lacaille took place in 1677, when the British prodigy Edmond Halley interrupted his college

BAYER'S URANOMETRIA

In 1603, Johannes Bayer published *Uranometria*, the first atlas to cover the entire celestial sphere. For most of the sky, Bayer used the recent star catalog of the Danish astronomer Tycho Brahe, which was extremely accurate. For the Ptolemaic stars too southerly to see from Denmark, Bayer used Ptolemy's low-quality data. And for far-southerly stars he used the Dutch star catalogs, which were better than Ptolemy's but nowhere near as good as Tycho's. Bayer labeled the brightest stars in each constellation with lowercase Greek letters, most of which have survived to the current day.

Bayer always tries to be faithful to Ptolemy's descriptions; for instance, he shows Canopus on the end of one of the two steering oars, the ancient equivalent of rudders. He cleverly explains the fact that Argo is only half a ship by showing the Clashing Rocks, though in the traditional Greek myths those smashed only Argo's stern ornament, not its front half.



ETA CARINAE: ESA / HUBBLE / NASA; BAYER CHART: JOHANN BAYER studies to take a telescope to the South Atlantic island of Saint Helena and remeasure the far-southern stars with much greater accuracy. He reclaimed the stars that Plancius had added to Argo and turned them into the constellation Robur Carolinum (Charles's Oak) to flatter Charles II, then king of England. The two different visions — Greater Argo versus Old Argo plus Robur Carolinum — coexisted and competed for the better part of a century.

With that as background, let's visit the Southern Hemisphere and take a look at the stars contested between Plancius and Halley.

◀ **PLANCIUS GLOBE** Petrus Plancius was a Dutch-Flemish astronomer and cartographer. He is renowned for having produced the first complete celestial globe, such as the one shown here.

Greater Argo Navis

The pot of gold at the end of the Carina Milky Way is the incomparable Eta Carinae Nebula, **NGC 3372**, which is a large, prominent bright patch to the unaided eye under any but the brightest skies. It appears much bigger and brighter than the Orion Nebula, despite being six times more distant, in the next Milky Way spiral arm in from our own. The nebula becomes overwhelmingly complex and beautiful with even the slightest optical aid, crisscrossed with dark dust lanes and spangled with bright concentrations. Every increase in aperture and magnification reveals something new; you could spend a lifetime observing this object and see something new each time you look.

By amazing good luck, the Eta Carinae Nebula lies directly behind one of the densest concentrations of naked-eye star clusters in our own arm of the Milky Way, and those clusters are embedded in an extremely rich star field. The overall effect of bright-on-bright-on-bright is unlike anything else in the sky. To my eye, this area outshines the star clouds in Cygnus, Scutum, and Sagittarius by a large margin. It's full of fascinating features, but for now we'll concentrate on the four brightest clusters.

NGC 3532 rivals the Eta Carinae Nebula in brightness, though not in size. It's a stunning, huge, rich collection of bright stars through binoculars and small telescopes. **NGC 3293** is a tiny, almost stellar bright patch to the unaided eye, and optical aid reveals it as an extremely rich and compact group of bright and medium-bright stars, which are responsible for its nickname, the Little Gem. **NGC 3114** is intermediate in size and brightness between NGC 3532 and NGC 3293. Through binoculars it's a sparse group of bright stars that reminds me of a claw.

Well away from the Milky Way, the Southern Pleiades, also called **IC 2602**, consists of 2.8-magnitude Theta (θ) Carinae surrounded by a group of 5th-magnitude stars that I can only partially resolve without optical aid.

Tracing up the Milky Way far to the northwest, the **False Cross** draws the eye irresistibly. It consists of Kappa and Delta Velorum from the Old Keel plus Iota (ι) and Epsilon (ε) Carinae. I have drawn dashed lines onto the standard *Sky & Telescope* stick figure to emphasize the asterism. It's strikingly similar in shape and orientation to the Southern Cross, though a tad bigger and fainter. I see both groupings as kites rather than crosses, since both lack a center star.

Continuing two of the kite's sides to the northwest, the parallelism between Gamma Velorum and much fainter Chi (χ) Carinae reinforces the bond between Old Argo and its southerly extension.

Greater Argo does indeed look like a ship, much more so than Old Argo, since it's now a whole ship rather than just a half. Not only has Old Argo been stretched far to the left, it's also pivoted counterclockwise so that the stars of the Old Keel now mark the bottom of Vela, the Sails.

Enter Lacaille

That's how things stood when Lacaille sailed for South Africa in 1750. His main purpose was to determine the scale of the solar system by measuring Mars's parallax in conjunction with Jérôme Lalande back home in France. That's exactly

▼ **LITTLE GEM** NGC 3293 is a young open star cluster seemingly superposed on wispy clouds of gas and dust lanes in this European Southern Observatory image. The stars likely formed about 10 million years ago, and the cluster lies at a distance of some 7,600 light-years.

PLANCIUS GLOBE: NATIONAL MARITIME MUSEUM, GREENWICH, LONDON, CAIRD COLLECTION; NGC 3293: ESO / G. BECCARI the same reason why British Lieutenant James Cook sailed to Tahiti 19 years later, using Venus rather than Mars as the target object (see page 58).

In retrospect, however, Lacaille's modest contribution to the scale-of-the-solar-system problem is dwarfed by his gargantuan feat of measuring the position and brightness of some 10,000 far-southern stars — all this accomplished in two years using a telescope with a half-inch aperture. He also tallied dozens of deep-sky objects. Lacaille stamped his mark indelibly on the southern sky, and he surely earned the right to do so through his hard work and dedication.

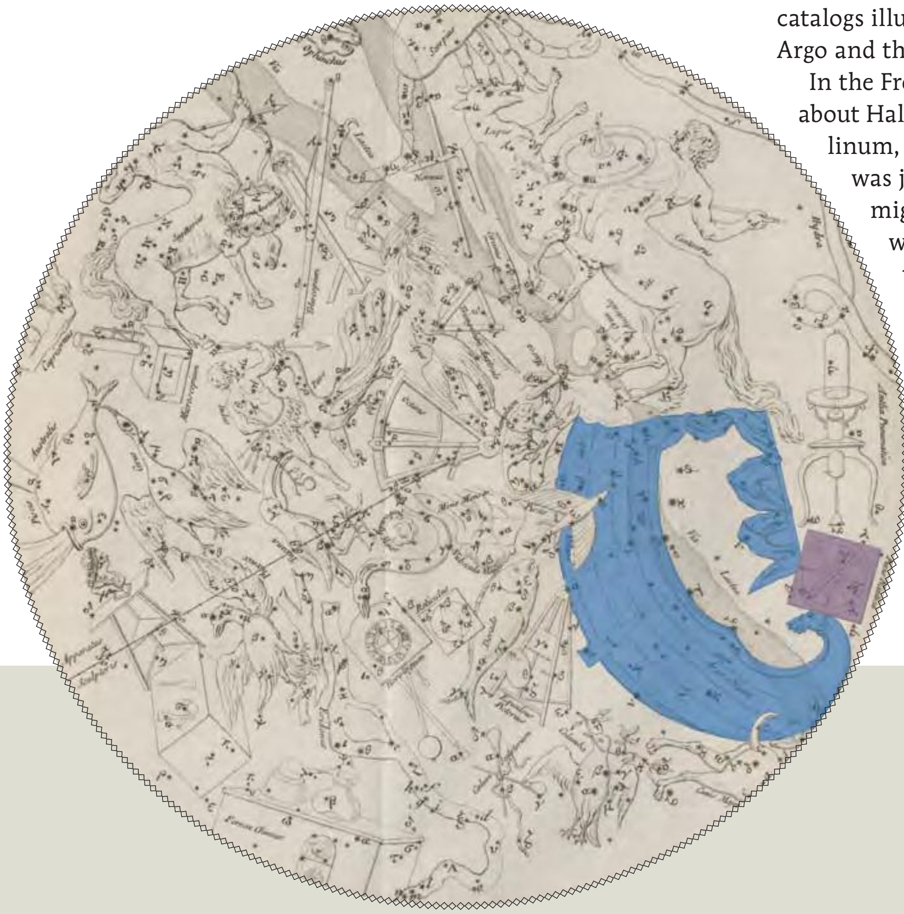
After returning to France, Lacaille published his results in 1756 in a French science journal. He didn't have time to reduce all of his observations to equatorial coordinates (right ascension and declination), but he cataloged almost 2,000 of the brightest stars, together with a map and a lengthy introduction discussing this work.

▶ **A HUMAN COMPUTER** Nicolas Louis de Lacaille (1713–1762) was an outstanding surveyor and astronomical observer with a flair for rapid and accurate computation, an extremely important skill before the advent of mechanical and electronic calculators.

Lacaille then started to polish his results and translate them from French to Latin, a task that was interrupted by his premature death. The results were published posthumously in 1763. Much later, British astronomers completed the task of reducing all his star measurements to equatorial coordinates, publishing a catalog of 9,766 stars in 1847. Comparing the three catalogs illustrates the evolution between the original Greater Argo and the modern Carina, Vela, and Puppis.

In the French introduction, Lacaille complains bitterly about Halley's theft from Greater Argo to form Robur Carolinum, stooping even to sneering at the fact that Halley was just 21 when he invented his constellation. This might be partly national rivalry; France and England were competing for global dominance, resulting in the Seven Years' War (known in America as the French and Indian War) and ultimately Napoleon's defeat at the Battle of Waterloo in 1815. But Lacaille does have a compelling aesthetic argument: He says that Halley desecrated the beauty and symmetry of Greater Argo by stealing its most beautiful stars.

This may explain why Lacaille could be so scathing about Robur Carolinum while he himself stole the stars of the Old Mast to form Pyxis. None of the 14 new constellations



◀ **LACAILLE'S CHARTS** Lacaille's charts and tables covered the entire sky south of the Tropic of Capricorn. They're dominated by two giant traditional constellations: Argo Navis (highlighted here in blue) and Centaurus. Pyxis, composed of stars that Lacaille filched from Argo, appears in purple.

French, 1756			Latin, 1763			English, 1847		
Du Navire *Canopus*	α	1	Argūs *Canopus*	α	1	ARGO	α	1
		6	Equulei Piĉtorii	ν	6	Pictor		6
		6	Canis majoris		6	Canis Major		4½
		6	Montis Mensæ		6	Mensa		6
Pouppe du Navire	*G*	6	Argūs in puppi	*G*	6	Puppis	*G*	5½
		6	Argūs		6	Puppis		6

◀ **LACAILLE'S CATALOGS** The table at left shows excerpts from Lacaille's French and Latin star catalogs, published in 1756 and 1763, respectively, plus the 1847 version published in England. Only the constellation, star letter, and magnitude are included; celestial coordinates and other information have been omitted for clarity. Surprisingly, the 1847 catalog used the nominative form of constellations' names instead of the usual possessive form.

that Lacaille invented contains a star brighter than 3rd magnitude, and precious few even reach 4th magnitude. He reserved all the bright stars to glorify the constellations invented by the Dutch. He even appended 1.7-magnitude **Miaplacidus** (Beta Carinae) to Greater Argo, when he could easily have used it for purposes of his own had he desired to do so.

Bayer had done a rather haphazard job with the far-southern sky, based on unreliable sources, so Lacaille also re-lettered the far-southern constellations. If you see a Greek letter for a star south of declination –30°, it almost certainly comes from Lacaille rather than Bayer. When he came to Greater Argo Navis, Lacaille understandably ran out of letters. Even in this article, which mentions only a few selected bright stars, we have used about half the Greek alphabet. Bayer's practice after running out of Greek letters was to continue with lowercase Roman letters. But Lacaille was greedy; he noted that Greater Argo contains more than 160 stars readily visible to the unaided eye, and contrary to Bayer's practice, he insisted on giving letters to each. So he subdivided his Navire (French for ship) into "la Pouppe, le Corps & la Voilure," meaning the Poop, the Body, and the Sails. Then he ran through the Roman alphabet, both lower case and upper, for each subdivision.

Incidentally, Carina can mean both a ship's keel and its entire structure; Lacaille's use of "Corps" makes it clear that he meant the latter. So it's more accurate to translate Carina as the Hull than the more usual Keel.

I think that Lacaille was showing off. Sure, he saw a lot more stars in Argo than Ptolemy had, but he had the benefit of a telescope. And it's dramatically much easier to see a faint object without optical aid if you have a telescope handy to reassure you that it's not an optical illusion.

You can see the results in the table at the bottom of page 28. Canopus, being one of the 24 truly splendid stars, rates a Greek letter as the Alpha star "du Navire" (of the Ship). Four entries later we have the G star of "Pouppe du Navire," the Poop of the Ship.

Things change a little in the Latin version of 1763. Now each one of the stars has a constellation listed, not just the ones that have letters. That means that unlike both Ptolemy and Bayer, Lacaille had completely tiled the sky with constellations, leaving no gaps between them. But in both the French and Latin versions, Lacaille never uses the terms Poop, Hull, and Sail without also saying "of the Ship." And letterless stars are assigned to Argo, not to its subdivisions.

Nomenclature changes yet again in the 1847 catalog. Now "of the Ship" has been dropped, and Puppis, Carina, and Vela are treated as full-fledged constellations. To drive the point home, letterless stars are assigned to the components, not to Argo itself. But the Greek-letter stars are still "of Argo."

Affairs remained much like that for the next 80 years; both Argo Navis and its constituent parts coexisted uneasily, with different authors using different terminology. And finally, in 1928, the International Astronomical Union decided to extirpate Argo and rename Canopus from Alpha Argus to Alpha Carinae.

Ironically, Lacaille's Roman letters have been forgotten, while the subdivisions that he introduced to make Roman lettering feasible ended up cannibalizing their parent constellations. Things would probably have turned out very differently if he had used numbers rather than letters to denote Argo's naked-eye stars.

WILLY POGÁNY

THE VOYAGE OF THE ARGO

The constellation that Ptolemy called Argo Navis was associated with several different ships in ancient history, but most Greco-Roman authors agreed that it was Jason's Argo. The Argonauts who sailed aboard it included Hercules, Castor, Pollux, Orpheus, and all the other great heroes alive at that time. They sailed to Colchis, in what is now the country Georgia, to retrieve the fleece of the golden ram that ended up in the sky as the constellation Aries. The painting above by Willy Pogány is from Padraic Colum's children's book *The Golden Fleece and the Heroes Who Lived Before Achilles*, still in print almost a century after first publication.

The most memorable character in the Argo legend is the sorceress Medea, daughter of King Aeëtes, owner of the Golden Fleece. She betrays her father for love of Jason, who in turn betrays Medea after they return home to Greece. In one version of the story Jason loses everything that he owns and dies when the prow of the rotting Argo falls on him as he sits under it contemplating his past glory.

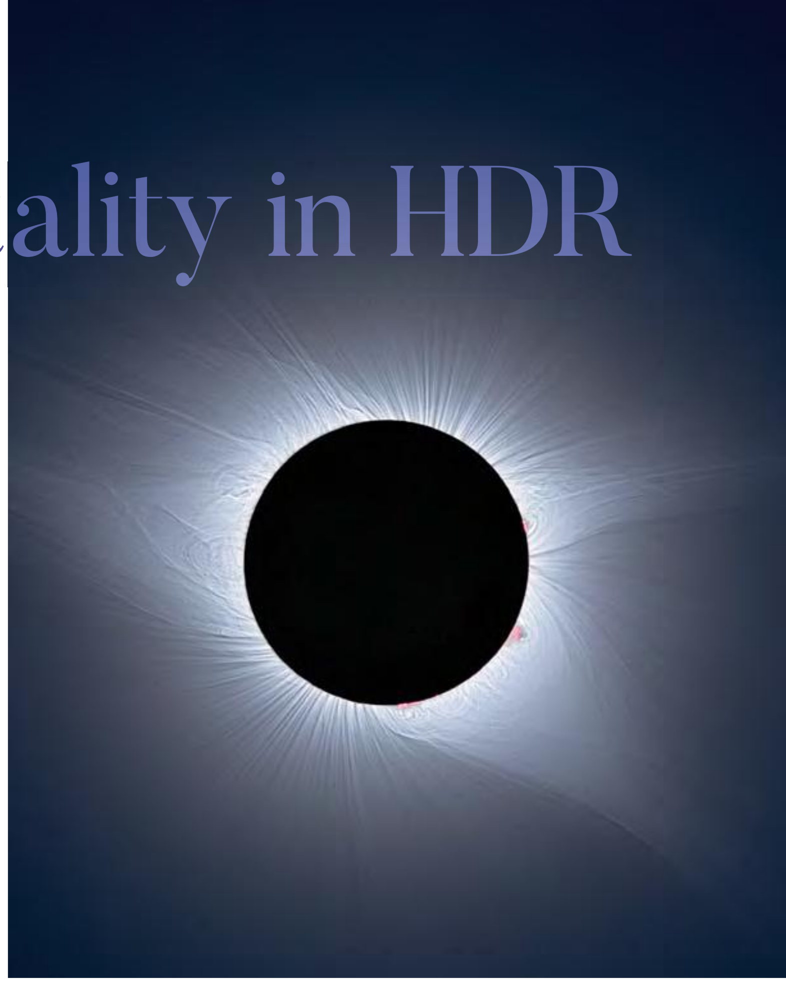
■ Contributing Editor **TONY FLANDERS** had his last complete view of Greater Argo a few hours after watching a total solar eclipse from Argentina on July 2, 2019.

FURTHER READING: My favorite resource for constellation history is Ian Ridpath's superb book and website *Star Tales* (**ianridpath.com/startales/contents.htm**).

Revealing Totality in HDR

This innovative technique can pull out stunning detail in the solar corona.

Photographing solar eclipses is one of the most challenging forms of astroimaging. It requires a great amount of advanced planning, from organizing the equipment you tow along on your voyage towards totality, to recording a series of exposures that capture the huge range of brightness displayed by the Sun's ethereal corona. It's even trickier if you hope to reveal complex magnetic loops that are hidden within the corona. Fortunately, digital photography has made this type of high-dynamic-range (HDR) imaging a bit easier. Here's a technique I use with *Adobe Photoshop* that works on solar eclipse photographs taken through most any lens or telescope.



▲Capturing the entire brightness range of a total solar eclipse in a single exposure is beyond the capability of digital detectors. You can circumvent this challenge by recording progressively longer exposures and then stacking together the results. This image of the eclipse of August 21, 2017 uses 91 exposures shot in 13 bracketed groups of 7 images each at ISO 100. The author used a Canon EOS 70D DSLR and Tele Vue Pronto refractor at f/5.3 riding on a Sky-Watcher Star Adventurer Mini tracking head.

A Good Plan

Part of the trick for revealing the entire dynamic range of the solar corona is to shoot bracketed exposures. Because the corona spans an extremely wide range of brightness, it's impossible to record all the coronal detail in a single exposure. Prominences visible along the eclipsed Sun's limb are best captured in very short exposures of typically 1/500 second or less in an f/5 optical system, whereas photographing the outermost extent of the corona requires keeping the camera's shutter open for up to 1 or 2 seconds, completely overexposing details within the inner corona.

Recording the full range of the corona's brightness requires shooting a rapid-fire sequence of bracketed exposures spanning the two extremes and then combining the shots into a single, HDR image with image-processing software. There are several good ways to shoot the bracketed exposures, but the most efficient is to either employ a camera that has built-in auto-exposure bracketing (AEB), or use a laptop computer with camera-control software such as *Eclipse Orchestrator* (**https://is.gd/EclipseOrchestrator**) to make the exposures. A helpful list of cameras that include auto bracketing is available at **https://is.gd/cameraAEB**.

My best results so far have involved a set of at least seven separate exposures ranging from around 1/500 to 1 second. The more exposures in a bracketed set, the smoother the transition between the individual exposures will appear in the final result. It's also better when you shoot many of these bracketed groups of exposures during totality so that you have lots of images to combine, greatly reducing noise in your final result.

I highly recommend tracking the Sun while you're shooting. Much like when stacking deep-sky astrophotos, alignment of your individual exposures is key to producing the best results. Aligning untracked eclipse images is time

ALL IMAGES PROVIDED BY THE AUTHOR

▶ The individual exposures as captured range from 1/500 to 1 second.

consuming because it can be difficult to find precise reference points such as background stars in all the images, particularly the shortest exposures. No software I've tried can automatically detect stars and align solar-eclipse pictures. Shooting with your camera on a well polar-aligned tracking mount makes it much easier to nudge your individual exposures into alignment.

Stacking Brackets

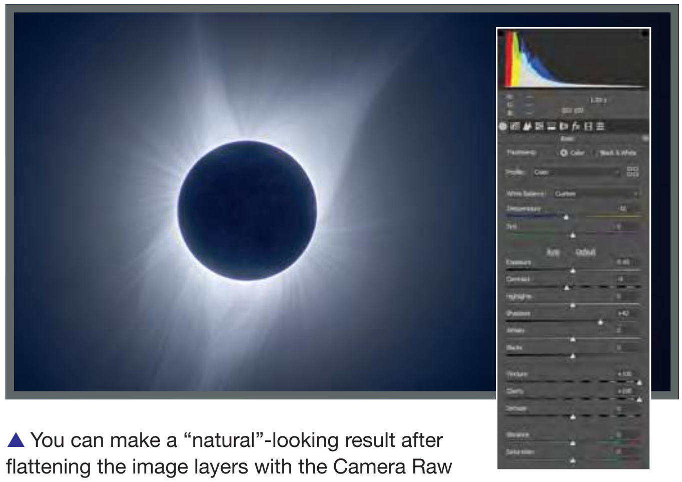
Let's assume your images are all well-tracked and are ready to stack together. There are several specialized HDR image-processing programs for doing the stacking that I've described in the past (*S&T:* Apr. 2012, p. 75). But stacking aligned images is also relatively quick and easy in the current version of *Adobe Photoshop*.

Start by opening the program and selecting File > Scripts > Load Files into Stack from the dropdown menu. The Load Layers window opens, where you'll click the Browse button at right and navigate to your first bracketed set of exposures. Select them all (you can stack almost any format image files, including RAW camera files). When you click OK, in a few moments your images will be layered one atop the other sequentially in the order you shot them, either shortest to longest or vice versa. If you don't see the Layers window, open it using the dropdown menu Window > Layers. Any layer that needs additional alignment can be moved by selecting the Move tool, clicking the layer in question, changing the blending mode to Difference, and nudging it into place using the arrow keys on your keyboard.

To smoothly combine all the layers, you need to change the Opacity setting of each layer so that they collectively contribute to the final visible image sequentially from the bottom layer to the top. For my stack of seven exposures, I changed the opacity setting of layers 2 through 7 at the top-right of the Layers window to 50%, 33%, 25%, 20%, 17%, and 14%, respectively, leaving the bottom layer set to 100%. This should produce a smooth image that shows everything from the Moon's faintly illuminated surface to prominences, extended coronal streamers, and even some of the brightest field stars. Simply choose Layer > Flatten Image and save the result as "group 1.tif".

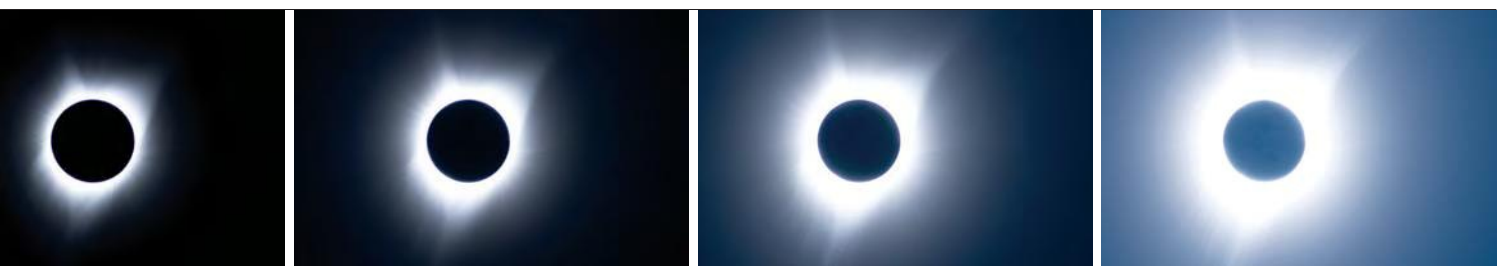
If your goal is a natural-appearing image of totality, a great result can be had by just tweaking this stacked image using *Adobe Camera Raw* (Filter > Camera Raw Filter). This filter lets you adjust the color balance, increase the texture

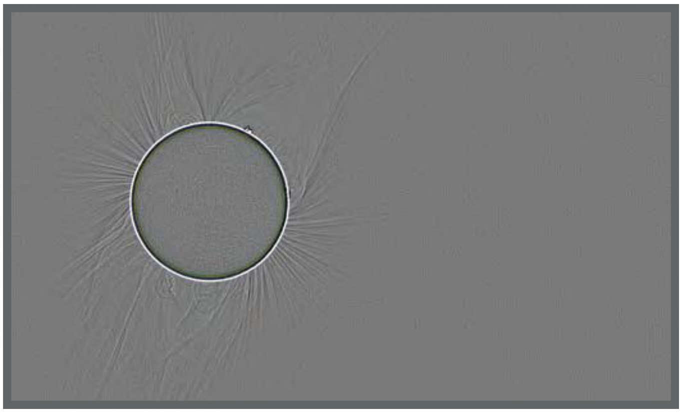
▲ After importing a group of bracketed exposures into *Adobe Photoshop*, you change the opacity of each layer to reflect how much that image will contribute to the final stack based on its position in the stack, thus ensuring a smooth transition between the individual exposures.



▲ You can make a "natural"-looking result after flattening the image layers with the Camera Raw Filter by maximizing the Texture and Clarity sliders, and increasing the Shadows. This produces an excellent image that resembles the naked-eye appearance of an eclipse.

and clarity, and also increase the shadow detail until you start to see some features in the inner corona as well as the Moon's surface. Setting both the Texture and Clarity sliders to 100 and the Shadows to 50 produces an eye-catching result that is very close to what the eclipse looks like to the unaided eye. Adjust the color balance, save the result with a new file name (group 1ACR.tif), and you'll have a great image of the event. But you can do much more with your bracketed set.





▲ Applying the blurred image to its corresponding image stack using the Subtract blending mode produces a detail map that is then stretched to reveal low-contrast details within the solar corona as well as some lunar features.

▲ Applying the subtracted image to the raw stacked image using the Multiply blending mode produces a detailed, though noisy, picture. Reducing the opacity of the target between 50% and 75% can achieve a more pleasing result.

Revealing Coronal Loops

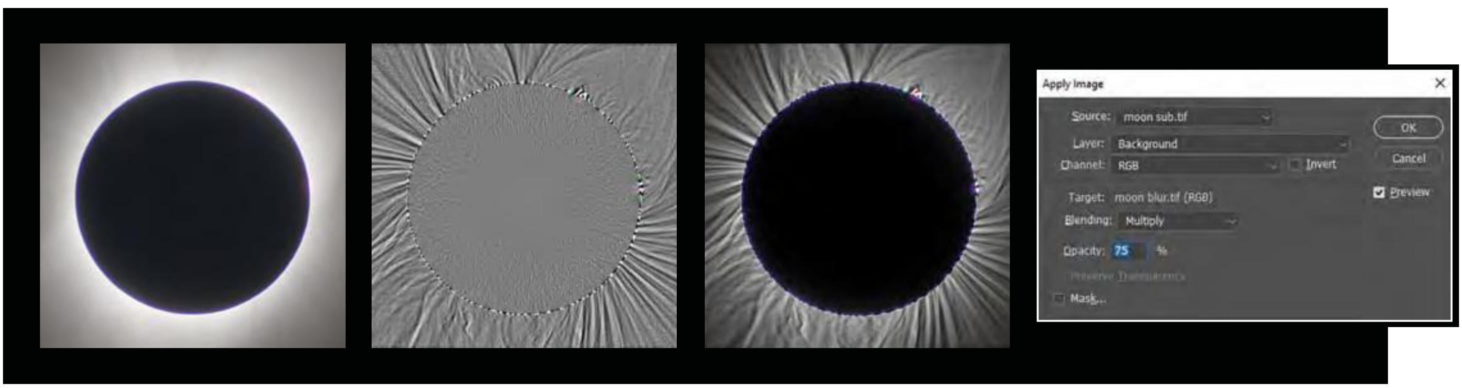
To bring out additional fine detail in the corona, open the first stacked image (group 1.tif) and blur it using the Gaussian Blur filter (Filter > Blur > Gaussian Blur). In the filter window, change the Radius to 3 or 4 pixels (the larger value will add more contrast to your completed photo, though at the cost of suppressing the smallest-scale features), depending on the focal length of the optics you shot with. Save this image with a name that reflects the process used, such as "group 1 blur.tif".

Keep this blurred image file open and reopen the original stacked image (group 1.tif). Next, apply the blurred image to the original by selecting Image > Apply Image from the dropdown menu. In the Apply Image command window, first change the Source from group 1.tif to group 1 blur.tif. In the Target section, change the Blending mode to Subtract, and increase the offset to 128. Click OK, and a very low-contrast map of small-scale differences between your original image and the blurred version remains, though it will appear gray with a dark ring where the limb of the Moon is located. We need to significantly compress the dynamic range of this image by opening the Levels tool (Image > Adjustments > Levels). In this window, change the low value slider at left to 126, and the high value slider at the right to 130, and click OK.

This mapped image should now display the edges of coronal loops and streamers, and some background stars, albeit with a lot of noise. Save this image as "group 1 subtract.tif".

Next, you need to apply this detail map to the original stack. Open group 1.tif and again select Image > Apply Image from the dropdown menu. Here you have several options depending on how aggressive you want the processing to appear. Change the Source to group 1 subtract.tif and the blending mode to Multiply. Immediately, you'll see lots of high-contrast loops within the corona, though it will be extremely noisy and rather "overcooked." When applying this process, I prefer to lower the Opacity to about 75% before clicking OK.

This result displays a lot of coronal detail but is very noisy. You can reduce the noise by opening the Camera Raw Filter again and dropping the Texture slider to -50.



▲ *Left:* To correct the sharpening artifact around the lunar limb, return to the original stacked image and crop it with the Moon centered. *Middle:* Create a blurred image using the Radial Blur filter set to Spin at 3 pixels, then apply it to the cropped Moon picture and stretch the result using the Levels tool. *Right:* Applying the radial-blurred subtraction map to the cropped Moon image with the same settings used for the full eclipse stack results in an image showing coronal detail right to the limb of the Moon.

If I only have one set of bracketed exposures, the only things left to do are to adjust the color balance and fix the Moon as well as the over exposed ring around its limb, which is an artifact of this extreme sharpening method. I find that stacking several sets of bracketed exposures reveals crisper details in the corona without needing to employ aggressive noise-reduction methods on the final result. The results of stacking multiple bracketed sets are superior, though the Moon becomes slightly smeared as it moves across the solar disk on each progressive set of images.

Combining several stacked and aligned sets of processed exposures is done the same way as stacking the initial sub-exposures using File > Scripts > Load Files into Stack. As before, change the opacity of each layer so that together they progressively contribute to the final view. When you're pleased with the result, flatten the layers by selecting the dropdown menu item Layer > Flatten Image.

The last step is to layer the Moon back in and address the bright artifact around its edge. I find this requires two versions of the same image processed slightly differently. First, open your stacked but unprocessed image and crop it as a square around the Moon. Be sure to leave about 50 pixels or more beyond the lunar limb, and save the result at "moon.tif."

Let's blur this image but in a slightly different way using Filter > Blur > Radial Blur. In this new window, select Spin as the Blur Method, Quality Best, and change the Amount to 3 and click OK. Save this as a new file titled "moon blur.tif".

At this point, you process the Moon image just as you did the full stacked eclipse image by first applying the radial-blurred image to create the subtracted difference map. Then compress the levels, save the result, and apply it to the Moon picture again using the Overlay blending mode (and reduce this to 75% opacity). The resulting Moon image will have the coronal details visible almost to its limb, but the Moon itself will appear odd due to the radial blurring.

Now copy this sharpened lunar image (Select > All, Edit > Copy), open up your single stacked and processed eclipse image, and paste this new processed Moon image as a new layer. To align it to the base image, change the layer Blending Mode in the Layers window from Normal to Difference. Using the Move tool, move the top layer until the majority of the two images cancel each other out and turn black, except for the ring around the limb of the Moon. When you're satisfied, make a circular selection with the Elliptical Marquee tool that includes the Moon and the ring artifact. When you've circled it all, choose Select > Inverse from the dropdown menu and hit the backspace key on your keyboard. When you change the layer blending mode back to Normal, the bright ring should be reduced to a thin line.

At this point, I open the stack I saved that was processed using the Camera Raw filter (group 1ACR.tif), select the

▲ After pasting the processed Moon limb image into the full eclipse picture, change the layer blending mode to Difference and nudge the layer into place. When aligned, the majority of the Moon layer will become black, with only the ring artifact and some coronal details being visible.

Moon, and then paste this into the stack. After aligning the final Moon layer, flatten the image and perform any final adjustments such as noise reduction and color balance.

The end product is an image showing the entire range of brightness and detail captured in your images. If you're planning on photographing an upcoming eclipse, it wouldn't take much to add bracketing into your routine. Images like these allow us to see extremely small tonal variations, as well as stars much fainter than were noted during the event. Good luck!

■ Associate Editor **SEAN WALKER** processed photographs from solar eclipses for decades before witnessing one in person.

▶ Select the Moon from the Camera Raw-filtered image and paste it onto the final stack. Once aligned, flatten the layers and perform any final color correction or noise reduction.

Data from the Gaia spacecraft are unveiling the Milky Way's tumultuous past, shedding light on dark matter and our galaxy's violent future.

Amina Helmi couldn't believe her eyes. It was a little after noon on a sunny spring day in the Netherlands, and she was staring at a plot that she had been waiting to create for 20 years. To a bystander, it wouldn't look like much: a large blob of dots in the shape of a triangle. But Helmi knew that it had a big story to tell.

Those dots were stars. And within half an hour, she and her colleagues recognized the pattern of stars as a scar from a truly colossal collision — one that disfigured our galaxy roughly 10 billion years ago. That's when the Milky Way swallowed a smaller companion in a crash that massively altered the galactic disk and scattered stars far and wide.

The encounter was the latest in a number of monumental mergers that slowly bulked up our galaxy over time. But then the Milky Way grew eerily quiet. For the past 10 billion years, only small events have rocked it, allowing it to live a relatively peaceful existence. But that is now changing. Today, some small dwarf galaxy is likely wreaking havoc on our home, sending ripples and waves throughout the galactic disk. Soon, two other galaxies will come hurtling in.

That is the picture that has emerged over the last three years thanks to Gaia, a European mission that is charting the heavens in unprecedented detail. Although astronomers have long suspected that the Milky Way devoured a number of unlucky small neighbors, uncovering evidence has not been easy. But with Gaia's data, astronomers can now hunt down alien interlopers — stars born within smaller galaxies that were later cannibalized by our monstrous galaxy — and thus piece together the Milky Way's violent biography.

Torrents of the

ANCIENT COLLISION Some 10 billion years ago, the Milky Way subsumed a smaller galaxy, whose stars now move through the Milky Way on elongated, retrograde trajectories (yellow arrows from simulated event, in galaxy smeared to evoke ours).

"I knew there would be nothing that could do what Gaia could do," says Helmi (Kapteyn Astronomical Institute, The Netherlands). "I knew that this was our chance."

Galactic Ghosts

Gaia's mission is simple, but not easy. That's because the location of every star that spangles the night sky is but a 2D projection: We see its angular position on the celestial sphere, but not its distance. To chart the stars in 3D, scientists need to see the stars from different angles — an effect that causes them to shift back and forth with respect to the background stars. That shift is tiny, but astronomers can use it to calculate the stars' distances and thus perfectly pinpoint them within the heavens.

So astronomers built Gaia, which hovers at the Sun-Earth system's second Lagrangian point and thus loops around the Sun with us, allowing it to capture those different vantage points. And while the shift is minuscule, Gaia has a resolution so high it could spot an object half the size of a dime sitting on the Moon as seen from Earth.

Such sharp vision enables the space telescope to not only capture the stars' precise coordinates, but also their 3D velocity — another property that is equally tricky. Although astronomers can detect a star's velocity as it moves toward or away from Earth (via shifts in the starlight's wavelengths), it is challenging to precisely determine a star's velocity on the plane of the sky. Sure, these stars travel at hundreds of kilometers per second compared to the Sun, but given their vast distances, that translates to incremental changes in the apparent position.

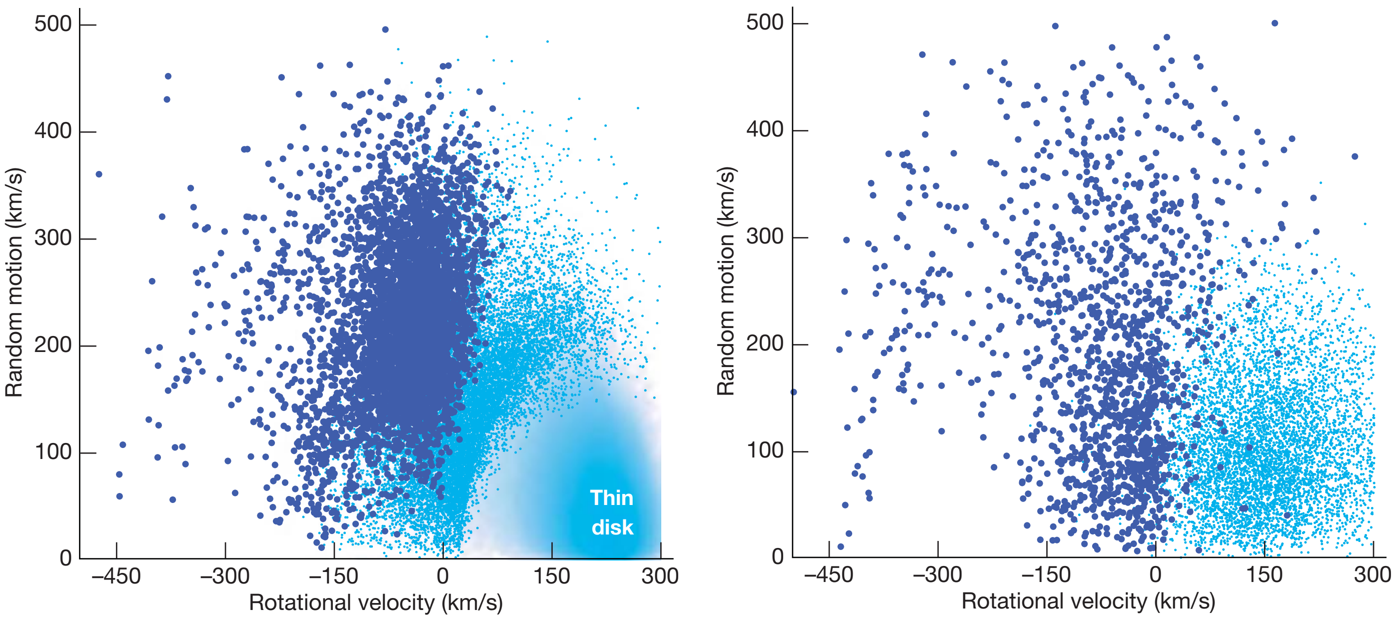
Gaia has a resolution so high it could spot an object half the size of a dime sitting on the Moon as seen from Earth.

Gaia's incredible precision allows astronomers to finally see those minuscule changes. And once they have calculated both position and velocity, they can easily chart the Milky Way's stars in unprecedented detail. Using this crucial information, researchers can piece together our galaxy's history for the first time by searching for the scars from our tumultuous past.

Some of the small galactic neighbors that the Milky Way has devoured are still being "digested" today, torn up and stretched into vast streams of stars that weave through our galaxy (*S&T:* Apr. 2017, p. 22). But it has been hard to uncover those streams at all, let alone in any detail. Previous to Gaia, astronomers had spotted only two dozen.

Milky Way

▼ **EVIDENCE OF A MERGER** When Helmi's team plotted the rotational velocity of thousands of Gaia stars (*x*-axis) versus their motions toward or away from the galactic center and up and down in the disk (*y*-axis), they found a large group (dark blue, left graph) that moved the same way as predicted by a simulation (right graph) of what would happen if the Milky Way had merged with a satellite galaxy (dark blue stars).

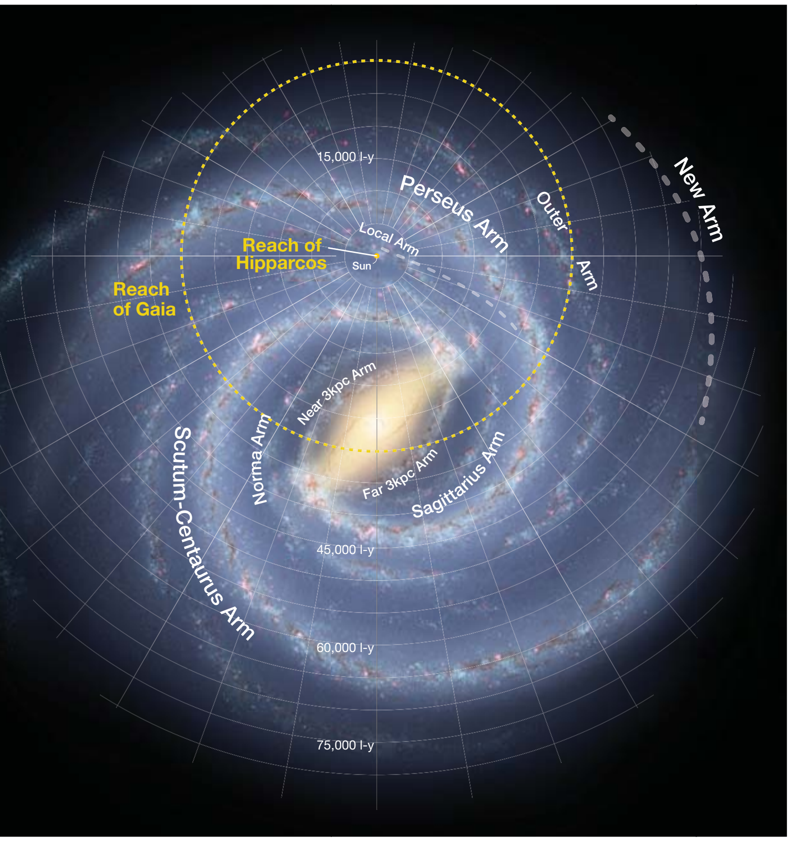


The first issue is that the streams begin to blend into the Milky Way over time, blurred out like muddy rills mixed into a much larger river. But even then, a few telltale scars remain. Stars that were captured in a collision, for example, often move against the status quo — traveling together along erratic orbits compared with the majority of stars in our galaxy. Now that astronomers can untangle the orbits for a billion stars (thanks to those positions and velocities), uncovering which stars are newcomers has become much easier.

"That is the miracle that Gaia has given to us," says Wyn Evans (University of Cambridge, UK).

The second issue is that prior work had charted the galaxy out to roughly 300 light-years, a small corner of the Milky Way. Gaia, on the other hand, is able to map all the stars within 30,000 light-years — well past the distance to the galactic center. "Before we could explore only the solar neighborhood — and it was really a small neighborhood," says Teresa Antoja (University of Barcelona, Spain). "Now we can study beyond our city."

And that has made all the difference. When Gaia's preliminary data release became available in September 2016, Vasily Belokurov (University of Cambridge, UK) used it along with positions in the Sloan Digital Sky Survey to find some 10,000 stars that travel together in elongated orbits. The stars eventually move from the center of the galaxy to the outskirts



▲ **GAIA'S REACH** The previous mapping satellite, Hipparcos, charted stars' positions out to 300 light-years from the Sun — less than a dot at this diagram's scale. Gaia surpasses that by a factor of 100.

R. HURT / NASA / JPL-CALTECH

The dwarf galaxy hurtled toward the Milky Way and punched through the disk of our galaxy, only to pop back out the other side.

and back again — a signature of a single major crash.

"I think it is really hard to think of another explanation, to be honest," team member Evans says. Because the plotted velocities formed a sausage shape, the team dubbed the ancient dwarf galaxy the Gaia Sausage.

Shakes and Tremors

More than a year later, when Gaia's second data release arrived on April 25, 2018, astronomers across the world were poised at their laptops, ready to download the data immediately and begin the search — even those on the West Coast of the U.S., where it was 3 a.m. local time. In the Netherlands, where it was a sunny spring day, Helmi and her colleagues analyzed 20,000 Gaia stars within the Milky Way's halo. They quickly discovered that half of them appear to be moving on eccentric orbits that travel in the opposite direction as the Sun does around the galaxy — suggesting that they did not form in the Milky Way at all.

To pin down whether that was the case, the team analyzed the chemical compositions of some 600 of those stars. In every galaxy, the abundance of heavy elements increases over time as more and more supernovae erupt and unleash new material into the cosmos. The exact increase works much like a fingerprint, creating a pattern that is specific to each galaxy and allowing astronomers to determine whether a group of stars belongs to the Milky Way — and if it doesn't, the type of galaxy it originated within.

Helmi's group of stars, for example, contain a different pattern of heavy elements compared with what's made in the Milky Way, supporting the notion that they didn't grow up here. Instead, the stars likely formed within a single large dwarf galaxy that was pulled into a dangerous dance with the Milky Way roughly 10 billion years ago. That's when the dwarf galaxy hurtled toward the Milky Way and punched into the disk of our galaxy, only to pop back out the other side. For a brief moment it looked as though it might continue racing away from the Milky Way, but it could not escape such a massive galaxy's gravitational pull. It slowed down, reversed course and plunged back into the Milky Way's disk. It danced back and forth like a pendulum for a little more than a billion years, but was eventually swallowed.

The team named this long-gone dwarf galaxy Gaia-Enceladus in honor of Gaia, both the Greek personification of Earth and the space observatory, and Enceladus, one of the children of Gaia and Uranus, the sky. It is particularly apt given that the merger likely rocked the Milky Way in a similar manner to the ancients' Enceladus, who was once believed responsible for earthquakes below Mount Etna in Italy.

Although Helmi didn't realize it at the time, many of the stars in her sample overlap with the stars in Belokurov's sample: The Gaia Sausage and Gaia-Enceladus appear to be one and the same. But the teams don't agree on the precise details of the collision. Belokurov and his colleagues, for example, now argue that *two* mergers occurred at this time, not just one.

That's because the group of stars can actually be divided into two subgroups: *radial stars*, which move directly toward and away from the galactic center on elongated orbits, and *retrograde stars*, which move in more circular orbits but in the opposite direction as the bulk of the Milky Way stars do. Not only are the groups kinematically different, but Belokurov's team also argues that they're chemically unique.

As such, his team thinks that the radial stars were deposited when the Sausage Galaxy — a dwarf galaxy as large as the Large Magellanic Cloud — fell into the Milky Way. The retrograde stars were later deposited by the Sequoia Galaxy, a dwarf the size of the Small Magellanic Cloud. The two galaxies were a loosely bound pair, but the Sausage likely fell in first and began to disrupt the Milky Way, Evans says, then the Sequoia joined the mayhem. "A one-two punch," he says.

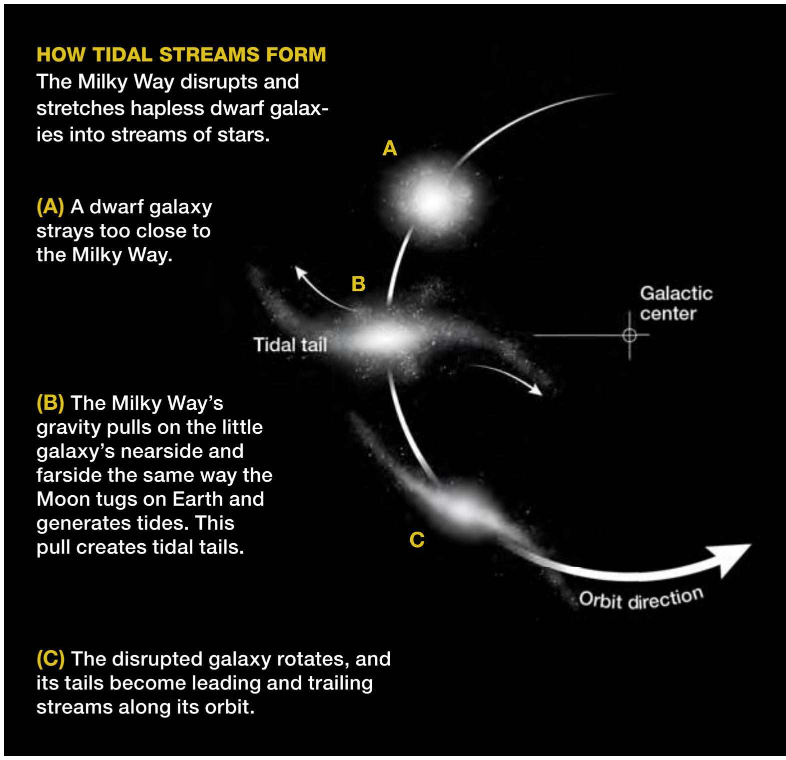
Helmi agrees that it's a possibility, but simulations of a single merger can also produce two distinct groups of stars. Plus, she adds, the chemical data come from such a small subgroup that it's hard to be conclusive just yet.

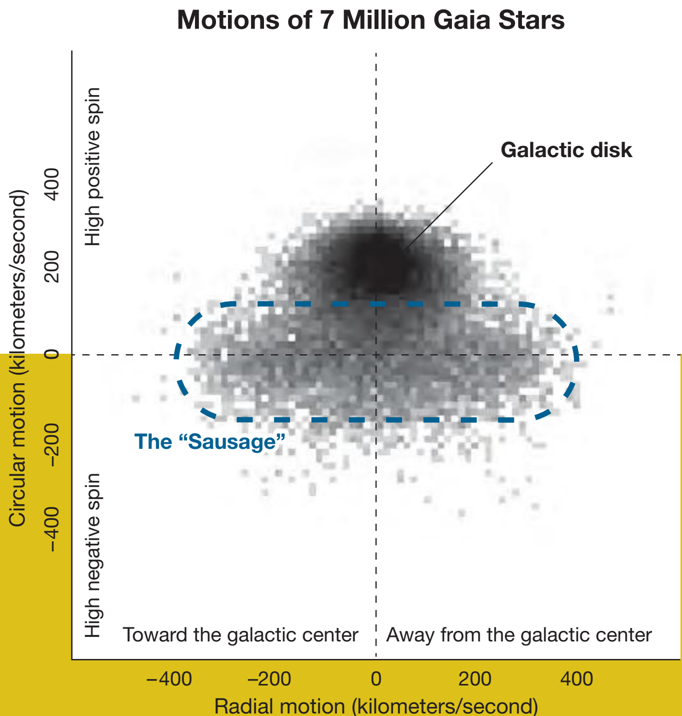
Either way, yet another clue has recently endorsed the fact that there was a collision. In early 2019, Roger Mor (University of Barcelona, Spain) and colleagues fed 2.9 million Gaia stars into a simulation that recreated the galaxy's star-formation history, only to find that roughly 9 to 10 billion years ago our young galaxy started to become relatively sterile. It's well known that a merger — say with the Gaia-Enceladus or the Sausage and the Sequoia — will stimulate a rush of star formation and then a drop-off. The fact that the team sees this drop is compatible with a major merger, Mor says.

Intriguingly, the results also suggest that about 5 billion years ago, another event ignited a stellar baby boom, followed by a second drop in star formation. The authors speculate that the Milky Way must have collided again.

The Milky Way's Dark Side

The stars referred to as the Gaia Sausage or the Gaia-Enceladus debris make up only the largest tributary of a torrent. Astronomers have discovered a rich network of star-studded debris streams — albeit deposited from a vast number of smaller collisions.





◀ **THE SAUSAGE** The now-destroyed Sausage Galaxy takes its name from the shape the stars make in a plot of their velocities. The horizontal axis is a star's motion toward and away from the galactic center, while the vertical axis represents a star's circular motion around the galactic center. Stars in the disk rotate around the center with a speed of approximately 220 km/s. The stars that make up the "sausage," on the other hand, have negligible circular velocity, but they zoom in and out of the center with a speed that can be almost twice as high.

THE SAUSAGE: V. BELOKUROV / UNIV. OF CAMBRIDGE, UK, AND GAIA / ESA; TIDAL STREAMS: GREGG DINDERMAN / *S&T*; SOURCE: C. BICKEL / *SCIENCE* 2018

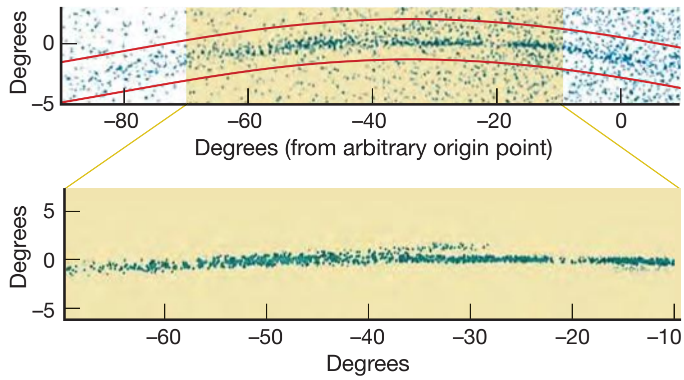
"Gaia has been a box full of chocolates for us," says Khyati Malhan (Stockholm University, Sweden). Since Gaia's second dataset was released, hundreds of papers have been published using the satellite's observations.

"Most of us are very lucky to be in this place and in this time," says Antoja. "This topic in general, galactic dynamics, this will be the golden age."

For Malhan, it didn't take long to uncover evidence of past collisions. Within five days, his team had harvested five streams. Now, they've spotted more than a dozen. "It has been a huge surprise," he says. "We weren't shocked to see this many streams — but that Gaia's proper motions are so bloody accurate and so bloody precise that it was so easy to pick out even these very low-contrast features."

Although new streams are now commonplace (astronomers know of roughly 50 within the Milky Way's halo), each find is still a thrill. Every time a stream is announced at a conference, it's met with a round of applause. That's in part because these streams will enable astronomers to unveil our galaxy's full formation history — down to the smallest mergers — but they also just might answer what is arguably the largest mystery within astrophysics: dark matter.

Every time a dwarf galaxy falls into the Milky Way, it deposits both stars and dark matter. Take the S1 stream as an example. It's likely the remnant of a dwarf galaxy that fell into the Milky Way roughly 9 billion years ago. Then, 1 billion years ago, it began passing the Sun like head-on traffic and depositing roughly 10% more dark matter than we would otherwise experience in this section of the galaxy.

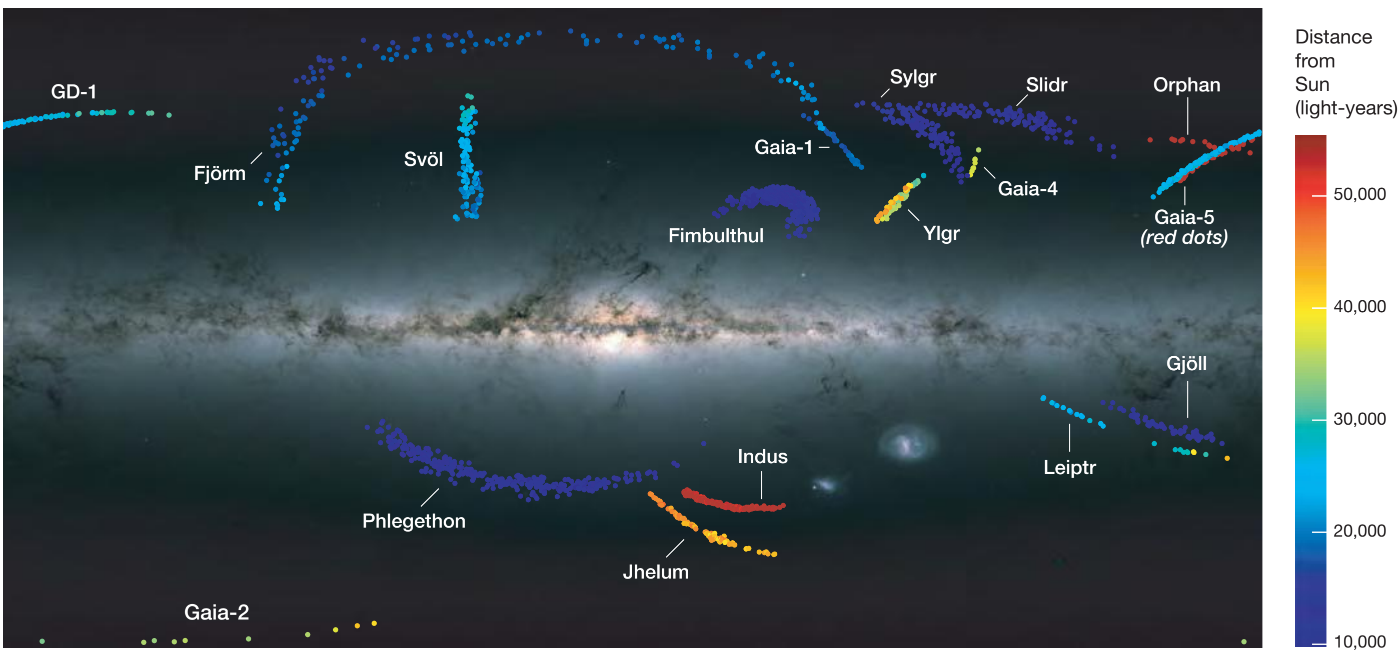


▲ **MIND THE GAP** Gaia data of the stellar stream GD-1 reveal clumping and gaps (top), which are more obvious in the cleaned, zoomed-in version (bottom). Ana Bonaca and others suggest that the gap at the –40° mark and the spur extending from it might be the result of a dark matter clump punching through. (The gap at –20° is thought to mark where GD-1's parent cluster disrupted.)

"A dark matter hurricane — we called it — is blowing through the solar system," Evans says. "It's blowing through the Earth."

And if dark matter is blowing through our planet, then it's blowing through our laboratories. That could mean we might actually spot a dark matter particle. Because our ability to detect such particles increases with their speed, the fact that they're zipping through our laboratories suggests that they might be easier to see than previously thought. That said, it's a hard problem to solve, and experiments are still ongoing.

▼ **STELLAR STREAMS** Shown are the streams Khyati Malhan and his colleagues have found in Gaia data so far using their algorithm. Some had been previously detected, such as Jhelum and Indus; others were brand new and now have names incorporating "Gaia" or taken from ancient rivers in Norse mythology.



GD-1 GAP: INITIAL DATA: A. M. PRICE-WHELAN & A. BONACA / *ASTROPHYSICAL JOURNAL LETTERS* 863:L20 (2018); CLEAN DATA: A. BONACA ET AL. / *ASTROPHYSICAL JOURNAL* 880:38 (2019); STELLAR STREAMS: GALAXY: ESA / GAIA / DPAC, STREAMS DATA: K. MALHAN ET AL. / *MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY* 2018 AND R. IBATA ET AL. / *ASTROPHYSICAL JOURNAL* 2019

▲ **STOLEN CLUSTERS?** Belokurov's team suspects that 21 of the Milky Way's globular clusters might have come from the Sausage Galaxy, and six from Sequoia. Of those, the Sausage's NGC 4147 *(left)* is well placed for Northern Hemisphere observers this month, and its NGC 2298 *(middle)* is near the horizon. The Milky Way's most massive globular, Omega Centauri *(right)*, might once have belonged to Sequoia.

A second promising avenue is the fact that those stellar streams could interact with clumps of dark matter hanging around the Milky Way. In 2018, Adrian Price-Whelan (now Flatiron Institute) and Ana Bonaca (Harvard) saw hints that GD-1, a stream of stars falling through the halo from high above the galactic disk, might have been hit by one such clump. In 2019, they and their colleagues eliminated a number of other possibilities, thus bolstering the argument. If true, the implications are pretty wild.

The stream is not the result of a collision with a dwarf galaxy. Rather, it was once a tightly packed sphere of stars known as a globular cluster. Roughly 3 billion years ago, it ventured too close to the Milky Way's center and was stretched into a ribbon of stars. That stream should resemble a pearl necklace, but Gaia revealed a gaping hole within it. And both Price-Whalen and Bonaca argue that a massive object — likely a dark matter clump — punched through GD-1 roughly 500 million years ago.

"Since dark matter is dark, there are not that many ways we can learn about its nature," Bonaca says. "So that's why it's really important and exciting to follow-up on this lead."

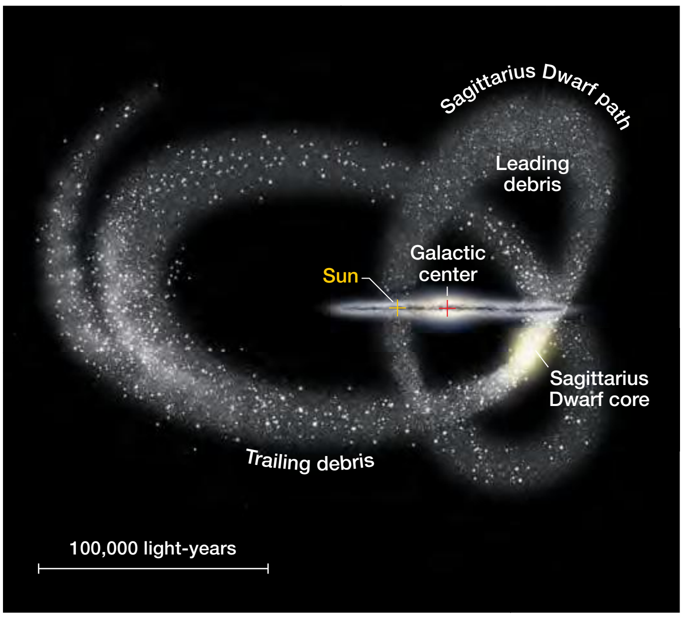
If astronomers can determine the size of this dark matter clump, for example, they will have an important clue in their quest to understand the mysterious substance. Dark matter particles can be crudely separated into two groups: warm and cold. Warm dark matter particles, which by definition move faster, cannot coalesce easily, which means that they cannot form small clumps of dark matter. But cold dark matter particles, which move more slowly, clump quite easily. The sheer existence of small clumps of dark matter would eliminate many models of warm dark matter.

Such a discovery would be transformative — in part because it wouldn't be confined to the Milky Way. Instead it would feed into cosmological models that are used to explore how galaxies across the universe merge and grow. "Because we are living in the Milky Way, the best bet we have to understand the other galaxies in the cosmos as well is to understand our own backyard," Malhan says.

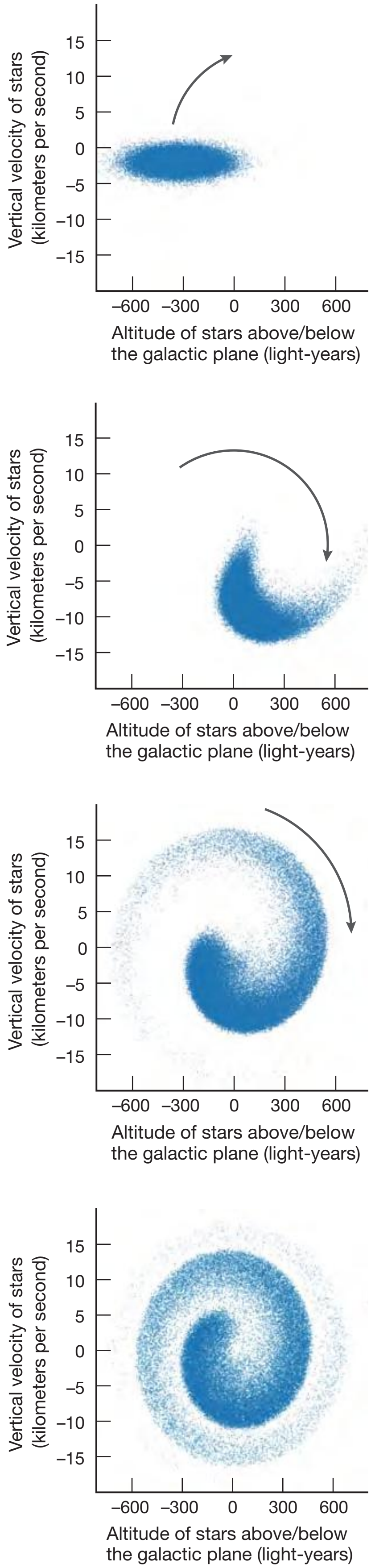
Spirals on a Shifting Canvas

Although the bulk of colossal collisions occurred more than 10 billion years ago — allowing the Milky Way to live a rather quiescent life since then — the events are not as prehistoric

▼ **SAGITTARIUS DWARF** The disrupted core of the Sagittarius Dwarf Galaxy is currently en route to pass through the Milky Way's disk from below, on the opposite side of our galaxy from the Sun. The dwarf's multiple passes have left a complex trail of stars.



NGC 4147: NASA / STSCI / WIKISKY; NGC 2298: NASA / ESA HUBBLE SPACE TELESCOPE / HUBBLE LEGACY ARCHIVE, PROCESSED BY FABIAN RRRR / WIKIMEDIA COMMONS CC BY-SA 3.0; OMEGA CEN: ESO; SGR DWARF AND STREAM: GREGG DINDERMAN / *S&T*



◀ **SPIRAL STRUCTURE** This series of graphs from a simulation shows the distance of a group of stars above or below the Milky Way's disk plotted against their velocity in the same direction. The stars begin below the plane, then move up through it. As time progresses, the stars trace out a spiral shape just like one seen in the movements of some Gaia stars. Astronomers suspect the Sagittarius Dwarf Galaxy created the pattern.

T. ANTOJA ET AL. 2018

as they might seem. Some surprises within the Gaia data actually point toward collisions happening *today*.

Antoja was yet another astronomer who pored over the second dataset the minute it was released — only to find that the motions of 6 million stars near the Sun are all aligned in a peculiar spiral pattern akin to a snail shell. Today, many astronomers suspect that the culprit is the Sagittarius Dwarf Galaxy, a system that's less than 1⁄100,000 of the Milky Way's mass.

Roughly 2 billion years ago, the scenario goes, Sagittarius passed through our galaxy's outer disk, beyond the Sun. It survived the fly-through, then fell back in roughly 800 million years ago — and escaped again. It's now in the middle of another crash and lies hidden just below the plane of the Milky Way. Every time it swoops in close, it gravitationally disturbs stars within the galactic disk, generating waves. "It's similar to the surface of a pond," Belokurov says. "If you throw a stone, it starts to ripple."

And yet, no one expected that the puny galaxy (which has already lost 95% of its mass) would have such an effect on our colossal one. "This is like the revenge of the small galaxy on us," Helmi says.

And it isn't the only dwarf to seek retribution. In 2009, Sukanya Chakrabarti (now at the Rochester Institute of Technology) and Leo Blitz (University of California, Berkeley) suggested that ripples within the Milky Way's gas disk were caused by a collision with a different dwarf galaxy. The pair predicted how massive and distant the galaxy would have to be, but couldn't find it.

Then, last year, astronomers using Gaia's second data release discovered a new dwarf galaxy called Antlia 2 (*S&T:* Mar. 2019, p. 11). It's the size of the Large Magellanic Cloud, but much fainter. And it's sitting squarely where Chakrabarti and Blitz predicted that the offending galaxy should be today. As such, the team argues that the new galaxy is responsible for the shake-up within the gaseous disk (*S&T:* Oct. 2019, p. 10). But Belokurov isn't convinced that Antlia 2, and not the Sagittarius dwarf, is responsible.

While astronomers might not agree on the specifics of the collision, it is nevertheless causing them to rewrite this section of the Milky Way's biography. They long speculated that the Milky Way bulked up via galactic cannibalism, but many had presumed such events only rocked the Milky Way's outer halo, leaving the main bulk of the galaxy relatively intact. "Gaia has blown up that idea," says Kathryn Johnston (Columbia University), a theorist who has not been involved in a number of these observations.

The findings demonstrate that the stellar groups within our galaxy are in a constant state of flux — sculpted by collisions that occurred billions of years ago and ones that are ongoing today. They even point toward the fact that our sky will continue to be a shifting canvas for eons to come.

"Everything is going to be a mess in a few hundred million years," Price-Whelan says. That's when the Large and Small Magellanic Clouds will come hurtling toward the Milky Way, eventually rocking our galaxy much like the Gaia-Enceladus shake-up. But because they're much larger than Sagittarius, the Magellanic Clouds will also funnel so much new gas into the Milky Way that a number of new stars will be born.

"There will be fireworks to come," Evans says.

■ **SHANNON HALL** is an award-winning freelance science journalist based in the Rocky Mountains. Her favorite galactic collision is the ongoing interaction between the Whirlpool Galaxy and NGC 5195.

OBSERVING
March 2020

1 DAWN: The month opens with Mars, Jupiter, and Saturn in a tidy line, 19° long and lying left of the Sagittarius Teapot. The planets will linger there throughout March. Watch as Mars approaches and then overtakes Jupiter in the second half of the month.

2 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:45 p.m. EST (see page 50).

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

11 EVENING: If you can find a dark viewing site with a clear line of sight toward the western horizon, look for the soft glow of the zodiacal light in deepening twilight. You should see a hazy pyramid of light stretching up through Taurus into Gemini and beyond, tilted slightly to the left, during the next two weeks (see page 48).

18 DAWN: The waning crescent Moon, Mars, and Jupiter form a tight triangle, with Saturn roughly 7° left of the trio.

19 SPRING BEGINS in the Northern Hemisphere at the equinox, 11:50 p.m. EDT (8:50 p.m. PDT).

19–20 NIGHT: Algol shines at minimum brightness for roughly two hours centered at 10:40 p.m. PDT (1:40 a.m. EDT).

20 DAWN: Mars catches up to Jupiter and is positioned less than 1° below the much brighter planet.

21 DAWN: Look very low on the horizon toward the east-southeast to spot the thin sliver of the waning crescent Moon and Mercury, less than 6° separating the two. Use binoculars to catch the pair before the Sun rises.

22 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:30 p.m. EDT.

24 EVENING: Venus is at greatest eastern elongation and stands high in the west as twilight fades.

28 DUSK: The waxing crescent Moon, Venus, and Aldebaran form a shallow triangle after sunset above the western horizon.

29, 30 DUSK: Find the growing Moon between the horns of Taurus, a little more than 3° from Aldebaran; the next evening, it will be less than 1° from Zeta (ζ) Tauri.

31 DAWN: Mars closes in on Saturn and now the two planets are less than 1° apart. Jupiter guards over the pair, 5° to their upper right.
— DIANA HANNIKAINEN

▲ Sirius shines like a beacon above the forests of Minnesota. BOB KING

MARCH 2020 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

FIRST QUARTER

March 2
19:57 UT

FULL MOON

March 9
17:48 UT

LAST QUARTER

March 16
09:34 UT

NEW MOON

March 24
09:28 UT

DISTANCES

Perigee	March 10, 06^h UT
357,122 km	Diameter 33′ 28″
Apogee	March 24, 15^h UT
406,692 km	Diameter 29′ 23″

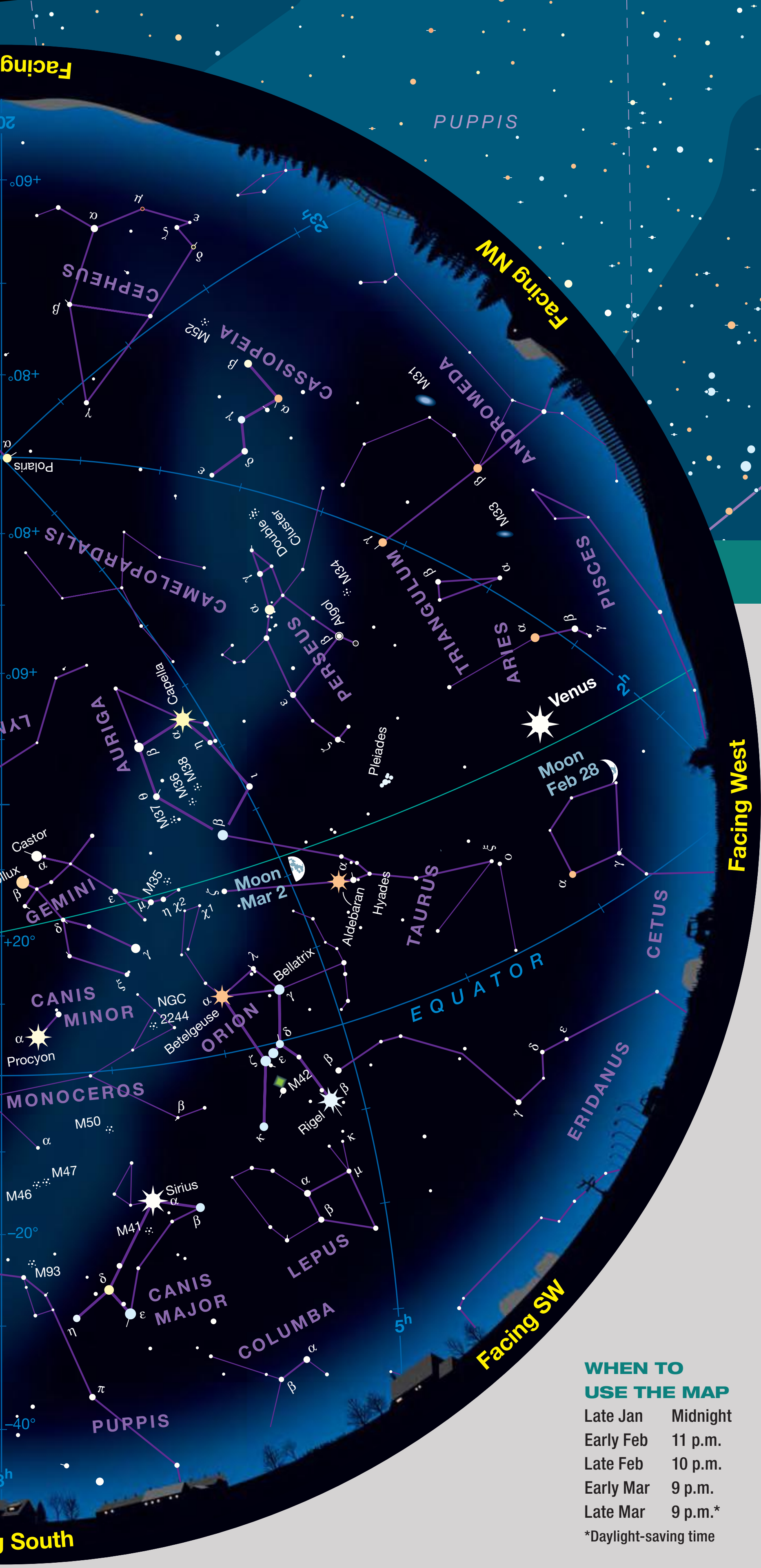
FAVORABLE LIBRATIONS

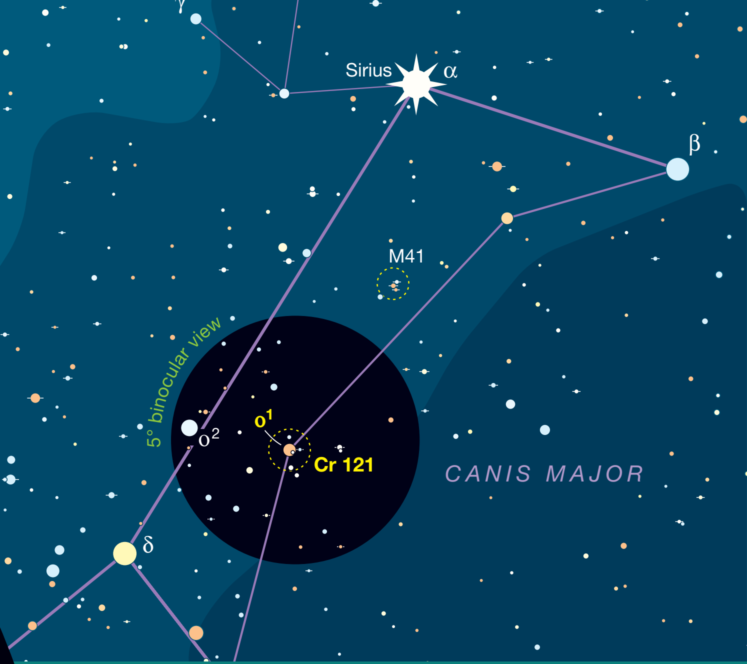
• Inghirami Crater	March 8
• Pingré Crater	March 9
• Casatus Crater	March 10
• Boguslawsky Crater	March 11

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.





WHEN TO USE THE MAP

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

*Daylight-saving time

Binocular Highlight by Mathew Wedel

One Cluster or Two?

One of my favorite objects in the winter night sky is **Collinder 121** in the constellation Canis Major, the Big Dog. It's a complex view, because what we see isn't all one object.

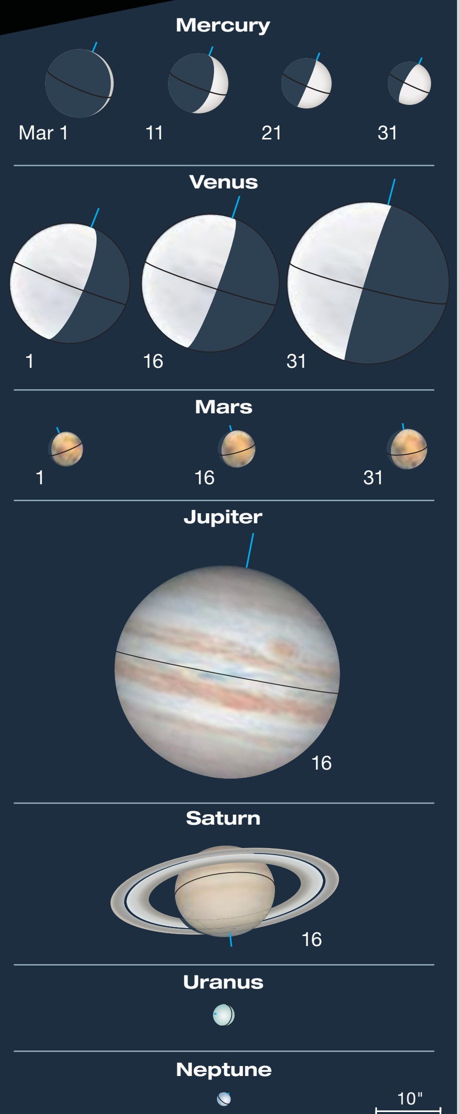
Let's start with the visual anchor of the field, the bright star **Omicron¹ (o¹) Canis Majoris**. It's a monster, a *K*2 red supergiant, between 8 and 13 times the mass of our own Sun, and at least 220 times as large in diameter. It's a young star in absolute terms, only 18 million years old — stars that big simply don't last long before blowing themselves apart as supernovae.

Omicron¹ is only one of a gaggle of bright young stars in the field. Most of the rest are of type *O* and *B*, and they make up the Canis Major OB 2 association. CMa OB2 is centered a little more than 1,900 light-years away, not vastly different in distance from the nearby cluster Messier 41, which lies at 2,300 light-years. Like most of the nearby *OB* associations, CMa OB2 is pretty, especially in binoculars — but it's not Cr 121.

The real Cr 121 is a young, compact cluster that lies beyond CMa OB2 at a distance of about 3,200 light-years, but sorting it out from the foreground association took a lot of careful parsing of parallax data by many different teams of professional astronomers. Interestingly, our emerging conception of Cr 121 as a separate object from CMa OB2 is a pretty good match for the original description of the cluster by Per Collinder in 1931. He was apparently farsighted in more ways than one.

All these objects — CMa OB2, Cr 121, even M41 — are our neighbors in the Orion Spur of the Milky Way. Be neighborly and look in on them, will you?

■ **MATT WEDEL** will probably never separate CMa OB 2 and Cr 121 visually, but he sees no harm in repeated attempts.



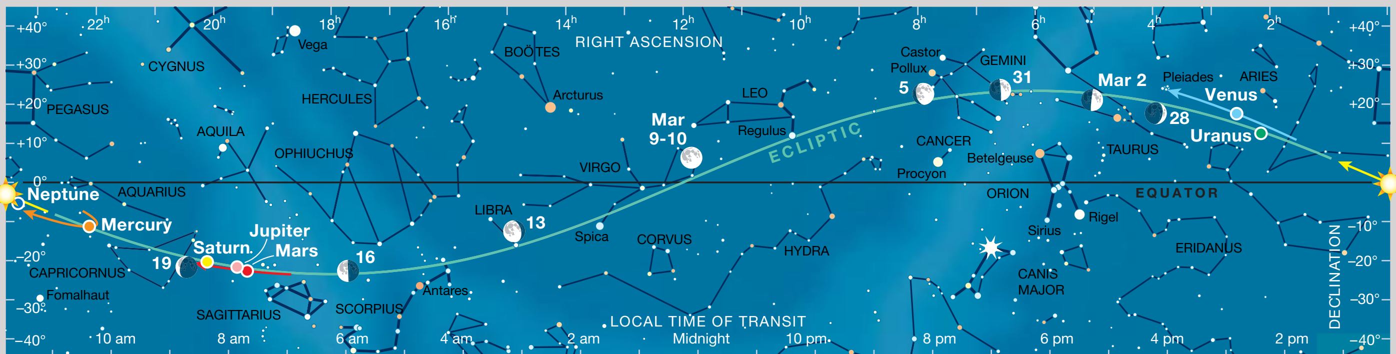
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury:** very low at dawn from the 13th to the 25th • **Venus:** high at dusk, sets in late evening • **Mars, Jupiter, and Saturn:** reasonably high by dawn, close to each other in early March, very close by month's end

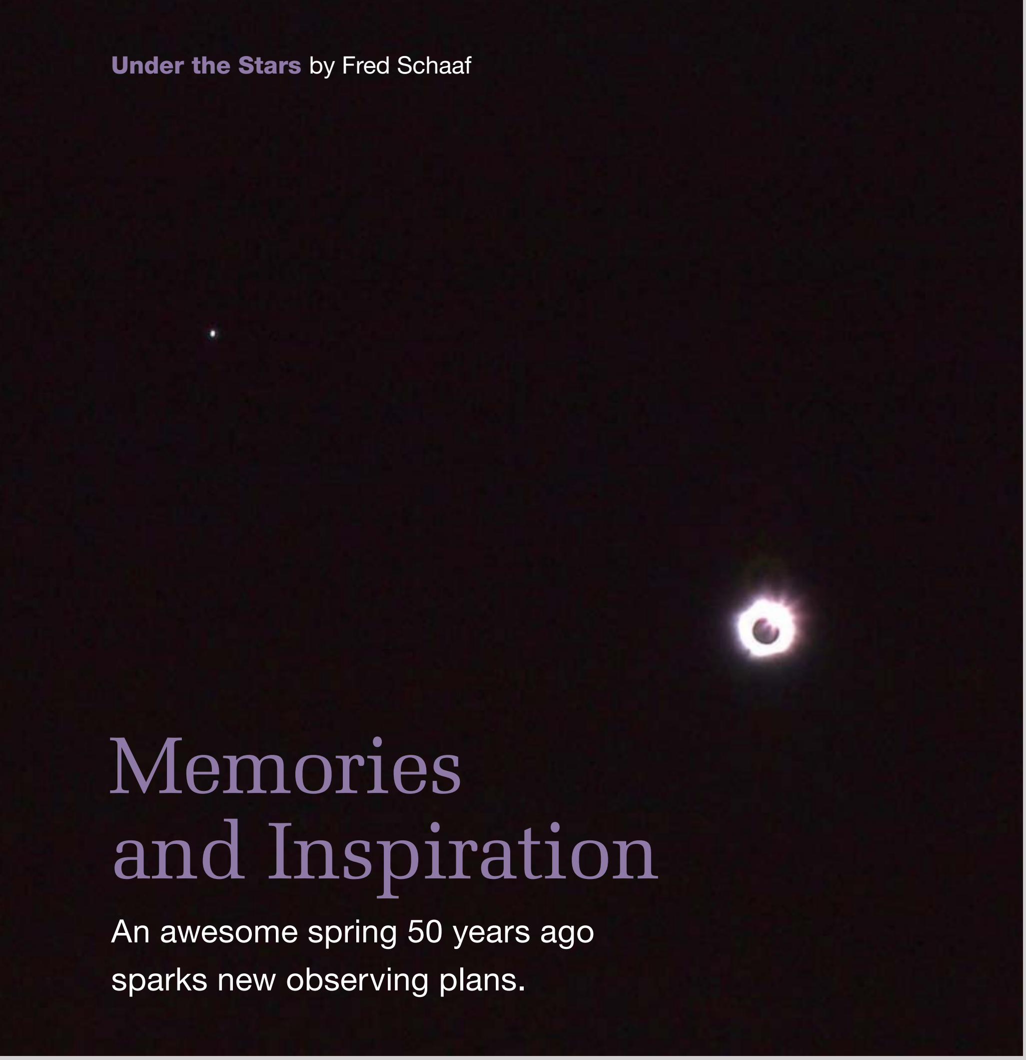
March Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$22^h\ 48.4^m$	–7° 36′	—	–26.8	32′ 17″	—	0.991
	31	$0^h\ 38.5^m$	+4° 09′	—	–26.8	32′ 01″	—	0.999
Mercury	1	$22^h\ 13.0^m$	–7° 23′	9° Mo	+3.7	10.6″	4%	0.631
	11	$21^h\ 58.8^m$	–10° 58′	23° Mo	+0.9	9.4″	27%	0.718
	21	$22^h\ 21.0^m$	–11° 07′	28° Mo	+0.2	7.8″	48%	0.861
	31	$23^h\ 03.2^m$	–8° 18′	27° Mo	0.0	6.7″	62%	1.005
Venus	1	$1^h\ 31.6^m$	+10° 46′	45° Ev	–4.3	18.8″	63%	0.889
	11	$2^h\ 12.5^m$	+15° 22′	46° Ev	–4.4	20.5″	58%	0.815
	21	$2^h\ 52.9^m$	+19° 24′	46° Ev	–4.4	22.6″	53%	0.739
	31	$3^h\ 32.4^m$	+22° 45′	46° Ev	–4.5	25.2″	48%	0.662
Mars	1	$18^h\ 39.5^m$	–23° 32′	62° Mo	+1.1	5.5″	91%	1.712
	16	$19^h\ 24.5^m$	–22° 41′	66° Mo	+1.0	5.9″	90%	1.590
	31	$20^h\ 08.9^m$	–21° 07′	71° Mo	+0.8	6.4″	88%	1.469
Jupiter	1	$19^h\ 23.4^m$	–22° 04′	51° Mo	–2.0	34.2″	99%	5.767
	31	$19^h\ 43.6^m$	–21° 22′	76° Mo	–2.1	36.9″	99%	5.337
Saturn	1	$19^h\ 59.9^m$	–20° 36′	43° Mo	+0.7	15.5″	100%	10.734
	31	$20^h\ 10.2^m$	–20° 08′	70° Mo	+0.7	16.1″	100%	10.320
Uranus	16	$2^h\ 07.9^m$	+12° 27′	38° Ev	+5.9	3.4″	100%	20.578
Neptune	16	$23^h\ 19.0^m$	–5° 31′	7° Mo	+8.0	2.2″	100%	30.918

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



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



Memories and Inspiration

An awesome spring 50 years ago sparks new observing plans.

◀ One of the author's most memorable moments — among many such moments — was the total solar eclipse in March 1970.

JOHN MECKLEY

The spring of 2020 is a time of great astronomical anniversaries for me.

First of all, March marks 44 years of my astronomy newspaper column in *The Press of Atlantic City.* It's a column I'm still writing (I started at the age of 21) and only twice have I not written it — the first time being the week my mother died.

My newspaper column debuted with the great Comet West in March 1976. But greater anniversaries — for me as an observer — are the 50th anniversaries in this spring of 2020. There were three inspiring sights for me in the spring of 1970, each one being at its best in a different month — March, April, and May. So in this current column and my next two I'll be recounting those observations in the exact anniversary month of each (along with a few other more currently visible topics).

Why am I discussing my memories of those past wonders here? It's in the hope that you readers who haven't been amateur astronomers for very long will set your goals and expectations high. I want you to know that you'll see truly staggering sights if you keep watching the sky long enough and often enough.

Three astronomy wonders that shaped me 50 years ago. The spring of 1970 was the most inspiring and thrilling season I've ever had as a skywatcher. That's saying a lot, considering that at other times in my life I've witnessed many different incredible sights. I've observed a sky-filling, multi-armed, rotating-as-one-vast-structure aurora. I've viewed a thousand-per-hour outburst of meteors with up to six meteors at once. I've beheld a green, slow, likely-meteorite-producing fireball as bright as a half Moon dropping red sparks as bright as Venus and Jupiter. And the only time in 143 years that Jupiter and Mars came to opposition anywhere near each other — in fact, very near each other — I saw the pair overwhelm even the impact of the nearby full Moon.

That last event is also a big anniversary for me now, a 40th anniversary on Leap Day 2020 — it occurred on February 29, 1980, which was also my coldest night as an observer, when the temperature dropped to –23°F (–31°C).

So what in one season could top even those marvels? The three astronomy wonders of that long-gone spring were my first total eclipse of the Sun (March 1970), my first great — and still my most beautiful — comet (April 1970), and my first transit of Mercury across the face of the Sun (May 1970).

First totality. My brother drove us in a red Volkswagen "bug" across the Delaware Memorial Bridge right at sunrise and back across it right at sunset. In between, we arrived at the little coastal community of Wachapreague, Virginia, on the Delmarva Peninsula to witness the March 7, 1970, total eclipse of the Sun. It was a dark one, with a strong red "360° sunset" band, and very clear air to see a white, white solar-maximum corona at its most intense. Roughly 20 miles north of us a launch from the Wallops Island Navy Base surprised us as the rocket shot up, shining into the darkness, to make measurements during the eclipse. But I could only glance briefly at the rocket behind me, for nothing could tear my gaze away from the "eye of God" in the midnight-blue and Venus-adorned sky. I came home changed — changed for life. Now I count the days down to the 2024 total solar eclipse, which after three saros cycles will bring the path of totality back to just a few hundred miles west and north of where it was in 1970. I plan to be there.

Next month. My first sight of Comet Bennett was a stunning one in bright twilight in late March 1970. But my most beautiful views of it came in April — so I'll be discussing it in this column in next month's issue.

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

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

Brilliant Venus, Plus a Fine Triad

Venus reaches its 8-year highest at dusk, while Mars, Jupiter, and Saturn bunch at dawn.

This is a heady, truly amazing month for planet-watchers.

For viewers at mid-northern latitudes, Venus reaches greatest elongation and its highest angular altitude in what is arguably the best evening apparition of its 8-year cycle of recurring appearances. The bright planet also ends the month just a few degrees short of an extremely close encounter with the Pleiades that will occur early in the month of April.

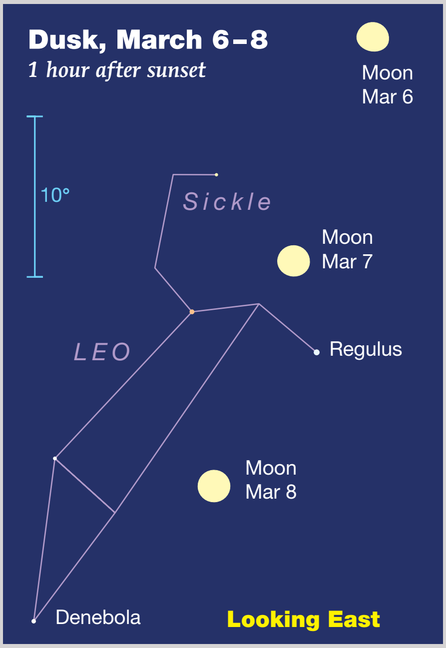
Meanwhile, in the final hours of night, the three classic superior planets gather into a tight, changing grouping all month. The crescent Moon joins Jupiter and Mars for a compact bunching on March 18th. Mars passes very close to Jupiter on March 20th and then, just 11 days later (at month's end), very close to Saturn.

DUSK AND EVENING

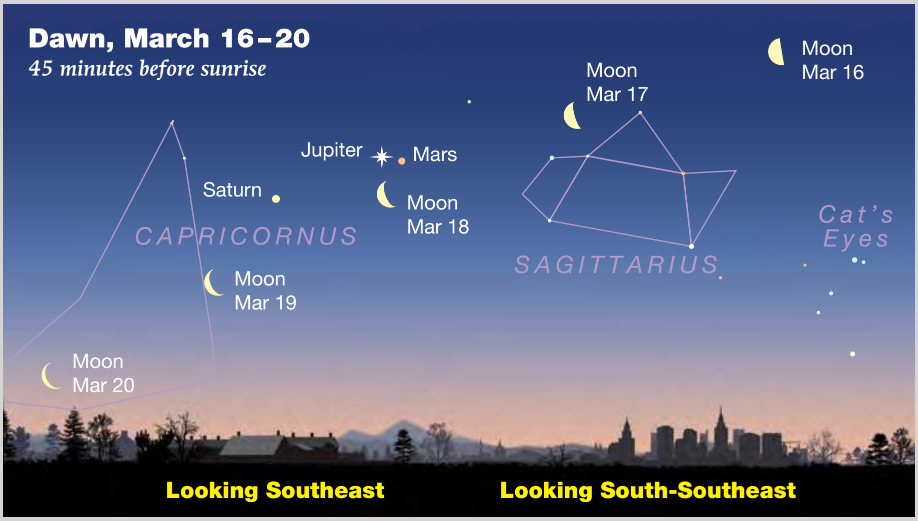
Venus makes 13.004 orbits around the Sun for every eight Earth orbits. So on any given night, Venus is almost exactly where it was relative to the Sun, Earth, and stars 8 years, 16 years, and so on ago — and *will* be 8 years, 16 years, and so on into the future. The synchronization of orbits isn't quite precise, but it's close enough to maintain the similarities of the 8-years-apart apparitions of Venus for much longer than a human lifetime. And of the five kinds of evening apparitions of Venus, our current one has the highest peak and the most captivating close conjunction with a stellar object — the Pleiades. The peak occurs near the time of Venus's greatest eastern elongation from the Sun — this year on March 24th — and the Pleiades conjunction about a week and a half later.

Venus stands almost 44° above the horizon at sunset for viewers at latitude 40° north later this month. The interval between sunset and Venus-set grows to more than 4 hours in March. Venus attains a greatest elongation of 46.1° from the Sun on the American evening of March 24th, although you might see Venus appear more precisely half-lit in your telescope quite a few days earlier due to the cloudiness of its "terminator" (watch for and note which night you see the terminator at its straightest). Venus is at perihelion (closest to the Sun in space) on the American evening of March 19th.

The disk of Venus grows from 19″ to 25″ wide this month, while the phase of the disk shrinks from about 63% to 48% lit. The brilliance of Venus increases from magnitude –4.3 to –4.5

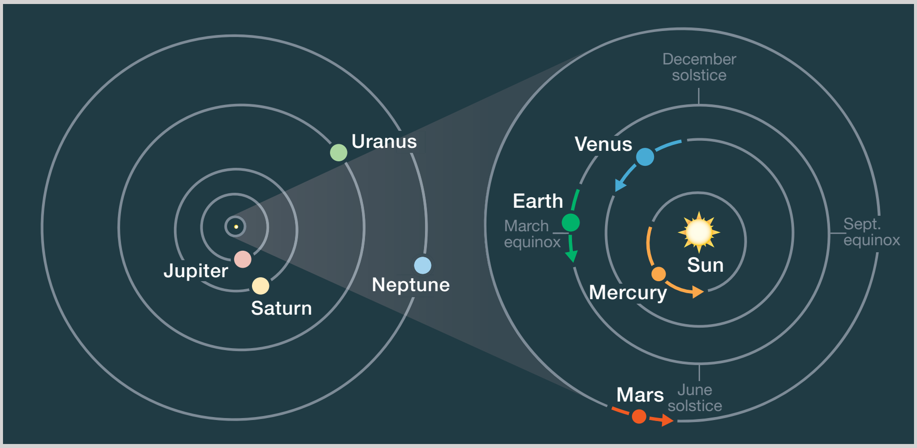


◀▼▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your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



in March. Venus starts the month in eastern Pisces, crosses Aries, and ends the month in western Taurus just a few degrees below the Pleiades.

Uranus is roughly 2¼° south-southeast of Venus on the American evening of March 8th, just a few hours after **Neptune** is at conjunction with the Sun.



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

PRE-DAWN AND DAWN

Mars, **Jupiter**, and **Saturn**, west to east in that order, begin the month spanning a little more than an hour in risetimes, all 2 to 3 hours before sunrise. At month's end, however, the order is Jupiter, Saturn, and Mars, with risetimes all occurring within a period of less than a half hour.

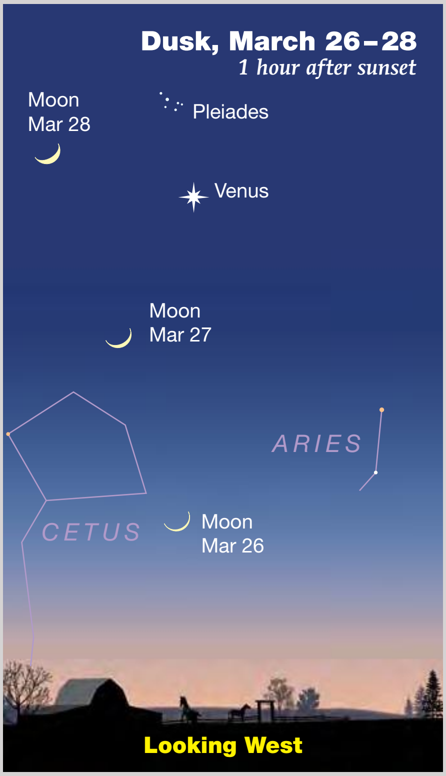
The three planets are east of the Teapot of Sagittarius, with Saturn and Mars slipping into Capricornus during the month. Mars is the most active performer in this drama. It glides east, overtaking Jupiter just after mid-month and Saturn on the very last day of March. Jupiter brightens only from magnitude –2.0 to –2.1 in March and Saturn stays at +0.7. But Mars kindles from +1.1 to +0.8, making it almost the equal of Saturn in brightness when they're in conjunction with each other on March 31st (a fine chance to compare their colors).

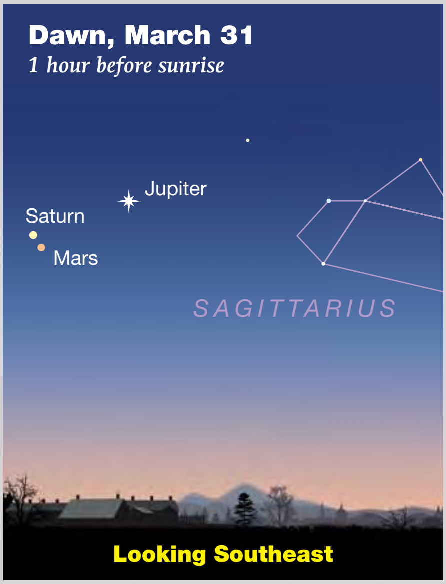
Mars passes only ¾° south-southeast of much more brilliant Jupiter on the North American morning of March 20th. The Red Planet measures just 6″ across that day (with a decidedly shadowed edge), Jupiter almost exactly six times wider.

As Mars crosses the gap between Jupiter and Saturn, we are treated to the spectacle of three bright planets in a line less than 7° long.

Mars lies less than 1° south of Saturn during the American dawn of March 31st, with Saturn's globe 16″ across. The rings then span 36″, and like Jupiter's globe, appear six times wider than the angular diameter of Mars.

Very challenging to observe is a much closer conjunction that Mars has this month. I'm talking about the Red Planet passing less than 0.02° south of 14th-magnitude **Pluto** around 5:15 UT on March 23rd! It's an event I've waited for since first noticing it in the printouts from Steve Albers's breakthrough conjunction computer program more than 25 years before Pluto was demoted from planethood. Sadly, the gap will have widened to about 10′ by the time the pair rises in North America, but that's still extraordinarily close.





SUN AND MOON

The Sun comes to the March equinox at 11:50 p.m. EDT on March 19th, starting spring in the Northern Hemisphere and autumn in the Southern Hemisphere.

The Moon is a waning crescent forming a dramatic compact triangle with close-paired Jupiter and Mars 1° to 2° above it on the American morning of March 18th (Saturn is farther off to their left). The waxing lunar crescent is far lower left, almost 10°, of Venus at nightfall on March 27th, and almost as far left of Venus the next night.

FRED SCHAAF is the author of *The Starry Room*, published 32 years ago by John Wiley & Sons and republished 18 years ago by Dover Publications.

GLOWING SKIES The grand cone of the zodiacal light tilts upward from the western horizon about 90 minutes after sunset on March 25, 2019 as seen from northern Minnesota. Composed of sunlit interplanetary dust, it's a prominent sight from a dark-sky site this month.

BOB KING

Starts with Z

Find a dark spot away from city lights and look toward the western horizon after sunset to see a pillar of ethereal light.

We're made of stardust. Except for hydrogen, helium, and traces of lithium and beryllium, which were created in the Big Bang, most of the rest of the elements grew in the bellies of stars and were subsequently released through stellar winds and supernova explosions. Elements combined to make more complex compounds, which ultimately became the familiar world of animals, plants, rocks, and people.

Our granular nature remains well-camouflaged throughout our lives, but there are scenes we might gaze upon to appreciate the underlying elemental and dusty nature of the cosmos. One of the most awe-inspiring is the *zodiacal light*, a tilted wedge of glowing comet and asteroid debris centered on the ecliptic that towers in the western sky from late winter to spring and again in the eastern sky before dawn during the fall months.

Many first-time zodiacal light hunters pass the light by because they're looking for something small, but under a dark sky with no Moon the luminous thumb of interplanetary dust extends across 30° of azimuth and some 60° in altitude. Think big, look wide. Stick out an arm and march six fists up from the horizon. That's how tall it is! You'll need a wide-angle lens to squeeze it all into a camera's view.

On exceptional nights under pristine skies, the cone never ends but tapers into a tenuous braid of haze roughly 8° wide called the *zodiacal band* that reaches all the way to the eastern horizon. One of my favorite sights is tracing the light upward to where it meets the Milky Way between Orion and Auriga. Here, right before your eyes, you can see how the plane of the solar system is inclined steeply to that of our galaxy, 60.2° to be exact.

And if there's any doubt that the luminous detritus lies in the plane of the solar system, Venus will set you straight this season. Reaching greatest elongation east of the Sun on March 24th, it gleams at magnitude –4.4 smack in the middle of the zodiacal tower.

Dust left by comets passing near the Sun as well as debris from colliding asteroids accumulates within the ecliptic plane and supplies the necessary material, much of it in tiny grains between 10 and 300 micrometers across. For comparison, a strand of hair measures between 17 and 180 micrometers thick. The debris extends from the Sun to beyond the orbit of Mars.

If you've ever seen sunbeams piercing dusty air, you'll instantly understand the origin of the zodiacal light. Dust concentrated in the solar system plane backscatters sunlight to create a luminous haze, brightest and widest nearest the Sun, that fades with increasing solar elongation before brightening ever so slightly at a spot in the midnight sky 180° opposite the Sun. This spot is called the *gegenschein*, where each dust particle is fully illuminated by direct sunlight like a host of tiny full Moons.

Observers in the Northern Hemisphere get their best views of the zodiacal light when the ecliptic tilts up at a steep angle to the horizon at dusk or dawn, propping up the light cone into good viewing position.

Viewing will be optimal from March 11–25 when the bright Moon vacates the sky. Find a dark location with a good western view and minimal horizon glow from nearby cities and start looking about 75 minutes after sunset. Peak brightness and altitude occur between 90 minutes and 2 hours after sundown.

If you've not seen it, the zodiacal light is brighter than you might think. The bottom of the cone compares well to the brightest parts of the Milky Way, while the top resembles the fainter stretches of our galaxy in Taurus and Auriga.

Rosetta's COSIMA instrument studied the composition of dust released by Comet 67P/Churyumov-Gerasimenko starting in 2014 and found that it comprised equal parts carbon-rich compounds and silicates. That breaks down to carbon, oxygen, silicon, iron, and magnesium, among others. Much of the carbon in the universe was forged in the cores of sunlike stars and later released into space in stellar winds. The others joined the fray primarily through massive explosions of supergiant stars and white dwarfs. What a joy to see this stellar handiwork aglow again at twilight's end.

Sirius-ly

◀ **NIPPING AT EACH OTHER** This photo, taken in 2017, gives a good impression of Sirius and its tiny companion, the white dwarf Sirius B (fondly known as the Pup), as seen through an amateur telescope at high magnification.

ONE OF THE MOST FAMOUS UFOs stands straight up on the meridian near the end of evening twilight this month. We know it as Sirius, but it's often mistaken for something more sinister by those not familiar with its regular appearances. Not only does Sirius get our attention because it's the brightest star in the sky, but its relatively low altitude (as viewed from North America) means it often twinkles vigorously, its light refracted by the shifting atmosphere.

This creates the illusion of motion, especially if you stare at it for an extended period of time. Add in the Earth's rotation, which slowly moves the star westward, and you can understand why planetarium directors regularly get calls from people wondering about that "big, bright, moving light."

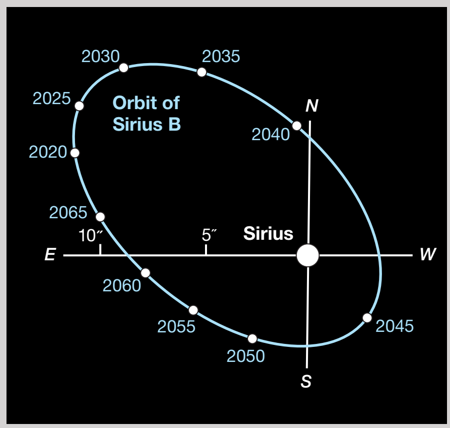
For amateurs, Sirius offers the tantalizing possibility of seeing its white dwarf companion, Sirius B, nicknamed the Pup. The dwarf shines at magnitude 8.4 (on the bright side), but its proximity to Sirius, shining 10,000 times brighter, makes finding it a lifelong challenge for some of us. I finally spied the little guy in March 2017 in a friend's 18-inch telescope at 300× on a night of exceptional seeing. I'd tried to see it many times before but was thwarted by poor seeing conditions common at Sirius's low altitude from my observing location.

The Pup's apparent distance from Sirius varies from 3″ to 11.3″ during its 50.1-year orbital period. This translates to a true distance of between 8.2 a.u. and 31.5 a.u. *Apastron*, when the two stars were farthest apart, occurred in 2019, but greatest *apparent* separation happens in 2023.

Around minimum separation few telescopes can pry them apart. But this year the two dogs nip at each other from a distance of 11.2″, just a fraction of an arcsecond shy of the maximum. You know what that means: Time to go for it!

Sirius B lies northeast of the primary at a position angle of 70°. To maximize your chance of seeing it, you'll need a 6-inch or larger telescope, a high magnification of 250× or more and, most importantly, excellent seeing, when the stars and planets appear crisp and stationary. If you use a reflecting telescope, be aware that a diffraction spike from the diagonal holder can temporarily block the Pup from view. If you see a spike pointing at the same position angle as the companion, wait a little while and try again. To improve your odds, keep Sirius just out of the field of view or use an occulting bar at your eyepiece's focal plane to completely mask it from view.

I experienced a great thrill in finally seeing this personal Holy Grail and hope you do too. As you fix your eye on the tiny point of light struggling through the glare, you're seeing a star 12,000 kilometers across — nearly the diameter of the Earth — with a mass almost identical to that of the Sun.



▶ **SIRIUS ORBIT** During its 50.1-year orbital period the Pup's distance from Sirius varies from 8.2 to 31.5 times Earth's distance from the Sun, or from a little closer than Saturn to just beyond Neptune. The two are currently near their maximum apparent separation of 11.3″ after closest approach in 1994.

SIRIUS: GABRIELA AND FABIO CARVALHO; SIRIUS ORBIT: GREGG DINDERMAN / *S&T*, SOURCE: DAVID DICKINSON

Like an Extra Big Pizza Pie

IF YOU'RE INTO THE MOON, you'll see the biggest one of the year on the night of March 9–10. That's because it will be a full Moon that occurs close to the time of *lunar perigee*, or when the Moon is nearest the Earth. Full Moon occurs at 17:48 UT on March 9th followed by perigee at 6^h UT on March 10th. The Moon achieves a maximum apparent diameter of 33′ 28″ in the wee hours of the 10th.

Will it look larger than normal? Possibly, if you're a careful observer.

▲ **PIE IN THE SKY** March sees the largest full Moon of the year. Remember to compare March's full Moon with October's, when you'll see the smallest full Moon of the year.

But there's one way to know for sure. Take a picture. Then take another picture on either October 1st or October 31st, when the Moon will be full again but close to *apogee* — farthest from the Earth — and only about 29′ 30″ across. The 4-arcminute difference will be startlingly obvious in side-by-side photos.

Groovin' with Euterpe

IF YOU LOVE MUSIC you're sure to be inspired by the asteroid 27 Euterpe, which comes to opposition on March 14th at magnitude 9.4. Named for the Greek muse of music, Euterpe (yoo-TUR-pee) is a stony asteroid about 100 kilometers across residing in the main asteroid belt. It's also the parent body of the Euterpe family, a clan of more than 450 bodies that likely originated in an asteroid collision and now share similar orbital characteristics. As it inches westward, Euterpe will be an easy catch as it remains within 5° of 4th magnitude Nu (ν) Virginis all month.

Minima of Algol

Feb.	UT	Mar.	UT
3	8:31	3	0:45
6	5:21	5	21:34
9	2:10	8	18:23
11	22:59	11	15:13
14	19:49	14	12:02
17	16:38	17	8:51
20	13:27	20	5:40
23	10:17	23	2:30
26	7:06	25	23:19
29	3:55	28	20:08
		31	16:57

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

Action at Jupiter

JUPITER RISES in the small hours of the morning in February and March, and it's high enough to observe in detail an hour before sunrise.

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

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

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

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

March 1: 1:04, 11:00, 20:56; **2:** 6:51, 16:47; **3:** 2:43, 12:39, 22:34; **4:** 8:30, 18:26; **5:** 4:22, 14:17; **6:** 0:13, 10:09, 20:05; **7:** 6:00, 15:56; **8:** 1:52, 11:48, 21:43; **9:** 7:39, 17:35; **10:** 3:31, 13:26, 23:22; **11:** 9:18, 19:14; **12:** 5:09, 15:05; **13:** 1:01, 10:56, 20:52; **14:** 6:48, 16:44; **15:** 2:39, 12:35, 22:31; **16:** 8:27, 18:22; **17:** 4:18, 14:14; **18:** 0:10, 10:05, 20:01; **19:** 5:57, 15:53; **20:** 1:48, 11:44, 21:40; **21:** 7:35, 17:31; **22:** 3:27, 13:23, 23:18; **23:** 9:14, 19:10; **24:** 5:06, 15:01; **25:**

BOB KING

0:57, 10:53, 20:48; **26:** 6:44, 16:40; **27:** 2:36, 12:31, 22:27; **28:** 8:23, 18:18; **29:** 4:14, 14:10; **30:** 0:06, 10:01, 19:57; **31:** 5:53, 15:48

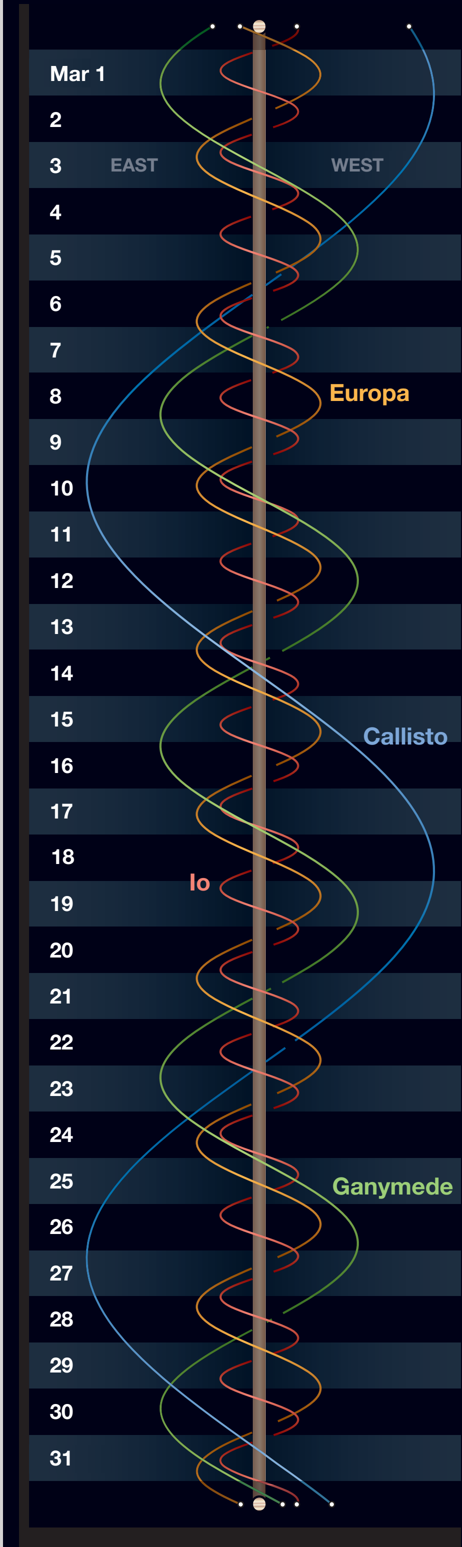
These times assume that the spot will be centered at System II longitude 326°. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 326° and 1²/₃ minutes later for each degree more than 326°.

Phenomena of Jupiter's Moons, March 2020

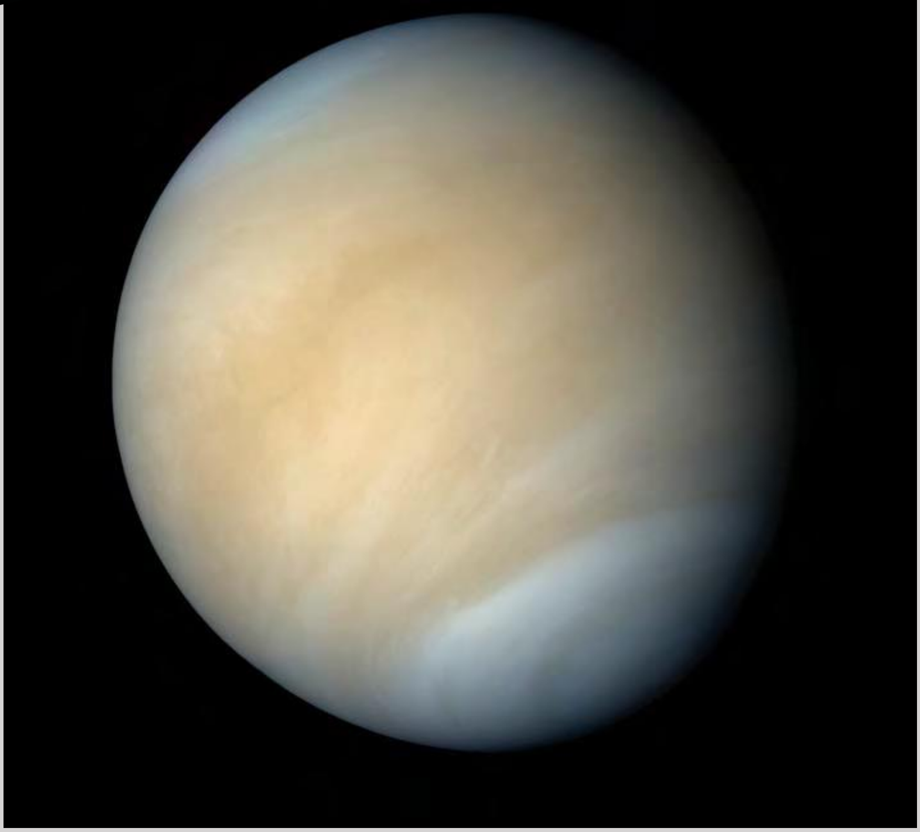
Date	Time	Event
Mar. 1	1:35	I.Oc.R
	19:27	I.Sh.I
	20:27	I.Tr.I
	21:42	I.Sh.E
	22:42	I.Tr.E
Mar. 2	6:55	II.Ec.D
	11:43	II.Oc.R
	16:47	I.Ec.D
	20:04	I.Oc.R
Mar. 3	6:54	III.Sh.I
	9:56	III.Sh.E
	11:02	III.Tr.I
	13:56	I.Sh.I
	14:11	III.Tr.E
	14:57	I.Tr.I
	16:10	I.Sh.E
	17:12	I.Tr.E
Mar. 4	2:04	II.Sh.I
	4:06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

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

Jupiter's Moons



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



Perpetually shrouded by a thick atmosphere, Venus was thought to be habitable as recently as the mid-20th century.

NASA / JPL

Lampland's Hot Glimpse of Venus

Early infrared measurements hinted at the planet's hellish surface conditions.

Brilliant in the evening sky, Venus reaches greatest elongation east of the Sun on March 22, then begins its descent toward inferior conjunction at the start of June. As the planet heads sunward, it grows larger and displays a crescent phase like the Moon does. This is one of the most fetching views in the sky with small telescopes. In the runup to inferior conjunction, the nightside of Venus is a challenging target for amateur astronomers equipped to image in near-infrared wavelengths, and its discovery has an intriguing, though little-known, history.

That history begins with Percival Lowell, who, in addition to devoting a great deal of attention to Mars, was a keen — if equally controversial — student of Venus. As a test object for Lowell Observatory's newly unveiled 24-inch Clark refractor in 1896-97, Lowell and various assistants studied the planet in Flagstaff and the observatory's temporary station at Tacubaya, Mexico (now part of Mexico City). After a few weeks of observing the planet, Lowell set the astronomical world on its ear, publishing in rapid succession a series of papers claiming the discovery of a peculiar hub-and-spoke system of markings that he believed to be the actual surface visible through a thin, semi-transparent atmospheric veil. The markings, he wrote, were ". . . not only permanent, but permanently visible whenever our own atmospheric conditions are not so poor as to obliterate all detail on the disc." Lowell went on to state, "The markings, which are of a straw-coloured grey, bear the look of being ground or rock, and it is presumable from this that we see simply barren rock or sand weathered by æons of exposure to the Sun. The markings are perfectly distinct and unmistakable, and conclusive as to the planet's period of rotation." By following these markings, he claimed the planet was tidally locked, with one face permanently facing the Sun throughout its 224.7-day orbit.

Lowell's claims were met with withering criticism by experienced observers E. E. Barnard and E. M. Antoniadi, who had never seen anything remotely like the hub-and-spoke system he recorded. The criticism arguably contributed in a major way to the nervous breakdown Lowell suffered in April 1897, which left him incapacitated and unable to pursue his astronomical work for four years.

When he finally returned to Flagstaff in 1901, he continued to obsess about ways of vindicating his work on Venus and gaining the upper hand over his critics. Indeed, it was the effort to prove that Venus has a long rotation period implied by these observations that led him to acquire the Brashear spectrograph and to place it in the hands of his assistant, Vesto Slipher. (This was later used to demonstrate the large velocities of the spiral nebulae.) Lowell was not one to admit a mistake and remained steadfast in his views about Venus until his death in 1916. In particular, he never wavered from his belief in a synchronous rotation, where one side of Venus was oppressively hot and the other in a perpetual deep freeze.

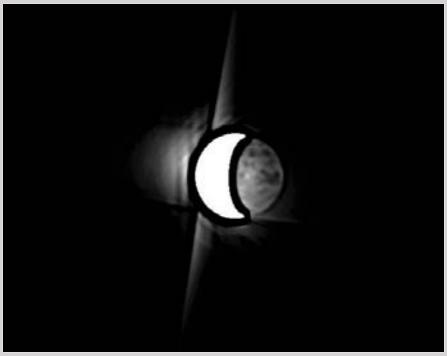
A Glimpse of Hell

After Lowell's death, his staff astronomers Vesto Slipher, Earl Slipher, and Carl Otto Lampland did their best to shore up the observatory's reputation by publishing high-quality data and avoiding, in Vesto's words, "startling telegrams."

As part of this rehabilitation, Lampland — prim, proper, and painfully shy about publishing his work — began a fruitful collaboration of measuring the temperatures of planets with W. W. Coblentz of the Radiometry branch at the National Bureau of Standards. In 1924, using the observatory's 42-inch reflector, they focused the light of a targeted planet onto a tiny thermocouple junction in a vacuum tube, producing a small electric current that was then amplified and measured in an iron-clad galvanometer located at the base of the dome. By interposing various filter screens or a 1-cm water cell that cut off radiation transmission beyond certain wavelengths, the pair could then parse the resulting spectrum into its visible and infrared components. In this way they could measure the temperature of a swath of the planet's surface.

Mars, of course, was the chief object of study, but Venus also received its fair share of attention. Coblentz later recalled, "The first morning when Lampland set the thermocouple on the dark, unilluminated cusps of Venus, not thinking of the implications involved, I called to him that 'a lot of heat' was radiated from the dark portions of the planet, and that it was of different intensities from the tips of the two cusps. Jumping down from the observing platform he came into the galvanometer room, saying that he thought I must be mistaken. Telling him to make the measurements himself, I climbed the ladder to the great reflecting telescope and made the thermocouple settings on the image of the planet, while he read the galvanometer scale,—and verified my measurements. He then told me how it might affect the 'P.L. theories.'"

Remember that Lowell viewed Venus as a planet with a thin atmosphere and synchronous rotation. This one observation indeed affected the "P.L. theories" — in fact, it utterly demolished them. Lampland's observations, which showed the temperature of the nightside to be indistinguishable from the dayside, contradicted the synchronous rotation and provided a first blistering insight into conditions on this hellscape world. As we now know, Venus is surrounded with a dense atmosphere of mostly carbon dioxide, which prevents heat from escaping into space, producing surface conditions that are those of a virtual blast furnace fueled by the planet's runaway greenhouse effect.



▲Imaging through a 1-micron infrared filter on May 1, 2017, Australian amateur Phil Miles revealed surface details normally obscured at visual wavelengths by the planet's opaque atmosphere.

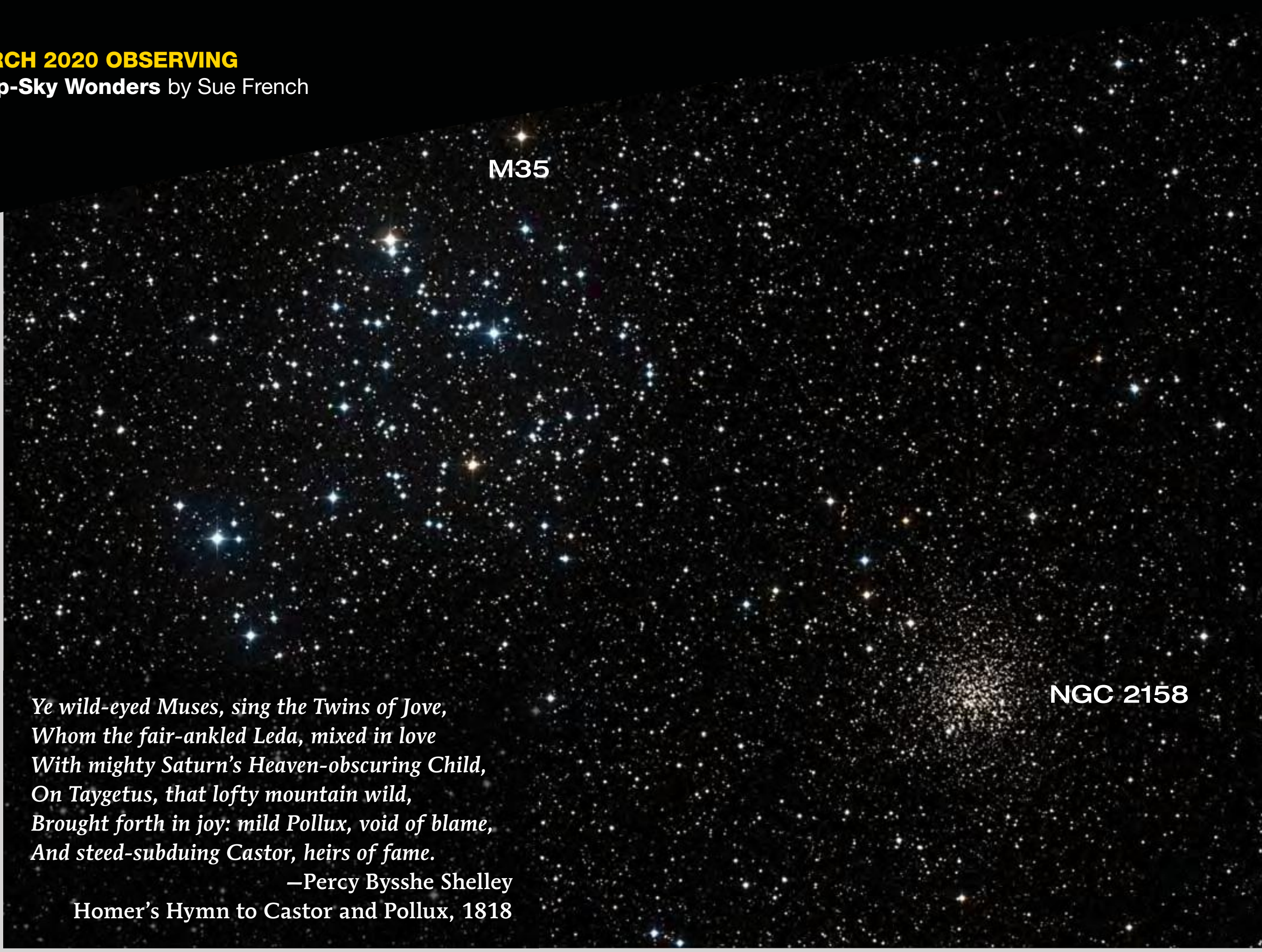
In fact, the infrared radiation emitted by the surface of Venus, first detected by Lampland, has a wavelength of about 1 micron, and though this part of the spectrum lies outside the visual range, amateurs equipped only with a telescope, a monochrome camera, and a 1-micron infrared filter can image Venus's nightside glowing right through the planet's clouds. French amateur Christophe Pellier was among the first to record this in 2004.

As Venus's crescent becomes thinner with more and more of the nightside on display, amateurs may wish to record for themselves the heat-glow of the nightside during the brief period after sunset. In doing so, they may recall the discovery of a shy, reluctant astronomer who embraced the truth revealed by his observations even though it meant giving up some of his former employer's ideas.

▼*Left*: Percival Lowell observes Venus through the 24-inch Clark refractor at Lowell Observatory in Flagstaff, Arizona. *Right*: Carl Otto Lampland holding one of the radiometers used to detect infrared radiation from planet surfaces, including that of Venus's nightside.

LOWELL AND LAMPLAND: LOWELL OBSERVATORY

■ Contributing Editor **BILL SHEEHAN** is a long-time student of the planets based in Flagstaff, Arizona.



POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

The Twins of Jove

Westernmost Gemini harbors a great variety of nebulae and clusters.

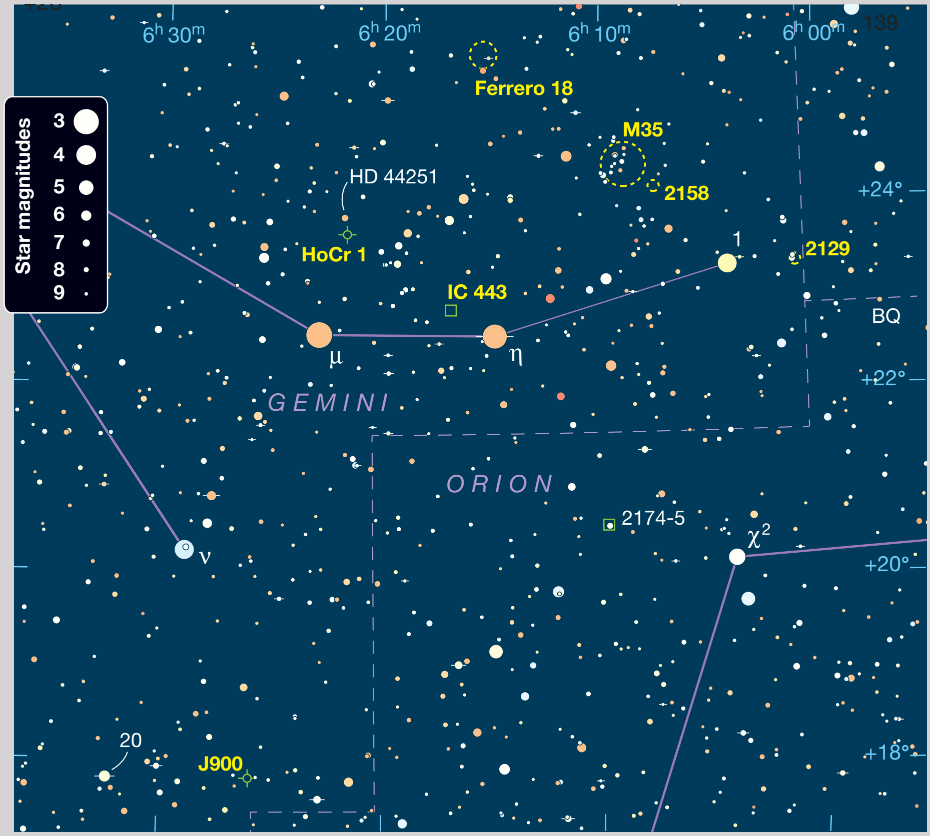
According to some tales, Leda had two mortal children with her husband King Tyndareus and two immortal children with the Greek god Zeus (Jove), who came to her in the form of a swan. Although the original is lost, copies of Leonardo da Vinci's painting *Leda and the Swan* show brothers being hatched from one swan's egg and sisters from another. The girls are Clytemnestra and the beautiful immortal later known as Helen of Troy, "the face that launched a thousand ships." The boys are Castor and immortal Pollux, who grace the sky as the bright winter constellation Gemini, the Twins.

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

The splashiest deep-sky wonder in Gemini is the breathtaking open cluster **Messier 35**. Even through 15×45 image-stabilized binoculars, M35 is big, bright, and beautiful, with many fairly bright to very faint stars. A zigzag line of field stars makes it look like a pointy-capped mushroom growing up out of Castor's foot. The little, fuzzy ball of nearby NGC 2158 marks the southwestern edge of the cap.

In my 130-mm refractor at 37×, M35 shows about 65 mixed bright and faint stars in the core group, which has ragged edges and spans roughly 25′. I can imagine yet another mushroom, with its cap pointing west, formed from the brightest stars of the core. Outliers stretch the cluster to 40′ and extend as far as NGC 2158. M35's brightest gem is the topaz primary of the double star ΟΣ 134, while the companion star to the south is a pale sapphire. Although M35 is mainly adorned with blue-white stars, a few shine golden yellow, as does the lovely beacon off the cluster's eastern side. With a wide-field eyepiece giving a true field of 58′ and magnification of 102×, M35 is a stunning jewel box.

NGC 2158 shares the field of view with its flashy cousin, but it's much farther from us — and certainly looks it! In the 37× view described above, NGC 2158 is merely an 8′-wide glow with three superimposed stars: a pair north-



east and a brighter star south-southeast of the cluster's center. The cluster is very pretty at 102×, showing perhaps a dozen members stippling the haze. The faintness of the stars is testament to their distance of 16,500 light-years, six times farther away than the suns of M35.

Philippe Loys de Chéseaux is generally credited with the discovery of M35. He included it in a list of 20 nebulae and star clusters that he compiled in the years 1745 and 1746. Among the objects that de Chéseaux deemed ordinary star clusters, it was simply listed as the one above the northern feet of Gemini. Despite its proximity to such a well-known object, NGC 2158 wasn't found until 1784. Discoverer William Herschel called the cluster a miniature of M35 in his *Catalogue of One Thousand New Nebulae and Clusters of Stars*.

Other enticing objects surround M35, among them **NGC 2129**. This cluster is an easy find 42′ east of the yellow, 4th-magnitude star 1 Geminorum in Castor's northwestern foot. Through my 105-mm refractor at 127×, it packs two bright and about 20 faint to very faint stars into a parcel of sky 7′ across. The cluster is very pretty in my 10-inch reflector, which shows half again as many stars. William Herschel discovered NGC 2129 just before NGC 2158 on the same night.

A nice asterism known as **Ferrero 18** sits 1.9° northeast of M35. In my 130-mm scope at 63×, the group includes the northeastern corner of a prominent square outlined by several field stars. The square's southeastern corner is occupied by a yellow-orange, 7th-magnitude star at the asterism's southern edge. I count 24 stars loosely scattered within 18′. In the view through his 8-inch reflector at 71×, Finnish observer Jaakko Saloranta thinks the group looks a bit like the constellation Scorpius. Ferrero 18 was found by French amateur Laurent Ferrero during his search for uncataloged star clusters.

Our next target is the elusive supernova remnant **IC 443**. Its position is easy to pinpoint, because the bright star Eta (η) Geminorum marks its western edge. With my 130-mm refractor, I've only seen the nebula's brightest arc, which lies 45′ east-northeast of the star. Its gauzy profile is faintly visible at 37× with an O III filter or at 63× without

Star Groups and Nebulae in the Celestial Twins

Object	Type	Mag(v)	Size	RA	Dec.
M35	Open cluster	5.1	28′	6^h 09.0^m	+24° 21′
NGC 2158	Open cluster	8.6	8′	6^h 07.4^m	+24° 06′
NGC 2129	Open cluster	6.7	7′	6^h 01.1^m	+23° 19′
Ferrero 18	Asterism	—	17′	6^h 15.4^m	+25° 30′
IC 443	Supernova remnant	9	50′ × 40′	6^h 16.8^m	+22° 47′
HoCr 1	Probable planetary nebula	—	73″ × 59″	6^h 21.7^m	+23° 35′
J900	Planetary nebula	11.7	9″	6^h 26.0^m	+17° 47′

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

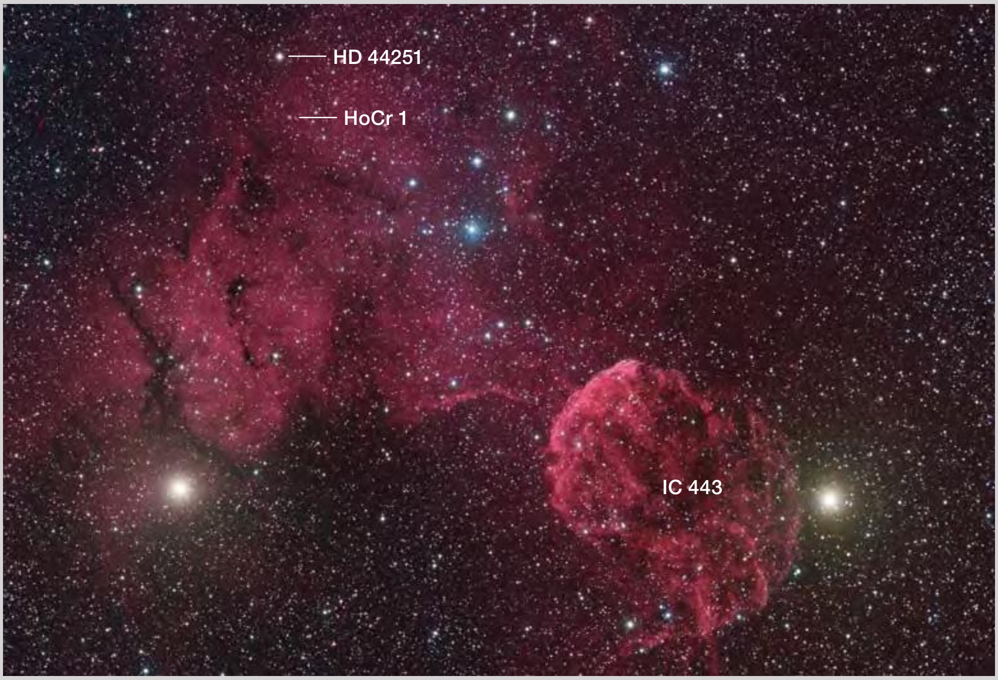
the filter. It gently curves through a shallow pan outlined by six stars. A seventh star off the pan's southeastern end adds a very short handle. This part of IC 443 is called the Jellyfish Nebula, because in images it looks like a jellyfish bell and has tentacles of nebulosity trailing southwest.

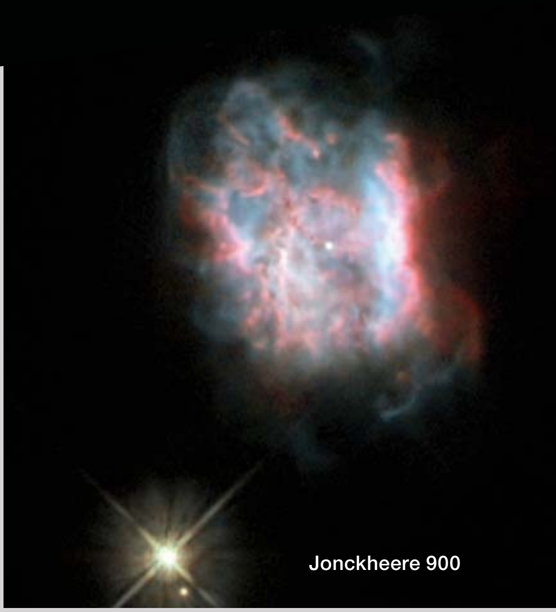
IC 443 displays two sections when viewed in my 10-inch scope at 44×, with either a narrowband or an O III filter. The northeastern arc appears brightest. It's shaped like a fat parenthesis mark nearly ½° long, one-third as wide, and concave toward the southwest. The section near Eta is much more difficult — I can only detect it as an amorphous patch of light southeast of the star and perhaps 12′ across.

German astronomer and astrophotography pioneer Max Wolf discovered IC 443 and dimmer IC 444 to its east-northeast with a 2¼-inch, portrait-lens astrograph in 1892.

Not far from IC 443, the probable planetary nebula **Howell-Crisp 1** dwells 1.1° north-northwest of Mu (μ) Geminorum and only 11′ south of the 7.3-magnitude star HD 44251. I couldn't spot it with my 14.5-inch reflector at 276× — until I added a narrowband filter. Then, a little touch of mist made its debut, resting on the northeastern wing of a 10′ asterism that resembles a butterfly. HoCr 1 seems slightly elongated and about 35″ long, with a very faint star nuzzling the northeastern end. Knowing what to expect, I could then detect the nebula using averted vision with the filter removed. In many images, the nebula looks rather blocky.

Michael Howell discovered HoCr 1 on an image he made in early 2006. Later that year, he began a collaboration with fellow narrowband-imager Richard Crisp to identify it. Astronomer George Jacoby provided high-resolution images and is listed as the primary investigator in a 2010 paper in *Publications of the Astronomical Society of Australia* that includes this object. Spectral data support its classification as a planetary nebula.





Finally, we'll visit the planetary nebula **Jonckheere 900**. You'll find it 1.5° due west of the pretty double 20 Geminorum, whose components shine yellow and yellow-white. J900 is easy to see through my 105-mm refractor at 47×, appearing stellar. At 122× it becomes a tiny nebula with a star on its south-southwestern edge. I tried some intermediate magnifications, but star and nebula blended together as one little blob.

Robert Jonckheere was one of the leading double-star discoverers of the 20th century. Among his finds were some nebulae and galaxies masquerading as double stars. In 1912 Jonckheere announced that J900 is a 3″ planetary nebula showing two stellar points within. In 1917 Edward Emerson Barnard wrote that with the 40-inch Yerkes Observatory refractor, the nebula spanned 7.9″ and was possibly a little brighter in the east, but he saw no central condensation or stars. Jonckheere replied that he'd seen three condensations in 1915, and he attributes the difference in the nebula's apparent size to the aperture of the telescopes. His original estimate of 3″ was made with a 12.8-inch refractor, and his 1915 estimate with a 28-inch refractor was 6.1″. The presence of knots in J900's structure was later confirmed photographically. What do you see through the eyepiece of your telescope?

■ Contributing Editor **SUE FRENCH** wrote this column for the March 2014 issue of *Sky & Telescope*.

IC 443: SEAN WALKER / S&T
J900: ESA / HUBBLE & NASA / JOSH BARRINGTON

▶ NIGHT VISION EP

Tele Vue is now an authorized dealer for the Tactical Night Vision Company's TNV/PVS-14 L3 Gen3 Un-Filmed White Phosphor night vision monocular. The TNV-14 White Phos Gen 3 Night Vision Monocular with Accessories ($4,263) is a filmless white phosphor night vision device with manual gain control for astronomical use bundled with adapters that couple it with Tele Vue eyepieces. White Phosphor night vision produces a colorless intensified view, providing greater detail and light amplification than standard thin-filmed green tubes. The unit includes the night vision device with an eyepiece adapter to attach select Tele Vue eyepieces, a 48-mm filter holder, FoneMate adapter, and Tele Vue PhoneMate (not shown) to attach your smartphone. Due to International Traffic in Arms Regulations (ITAR), these devices can only be sold to U.S. citizens residing within the country.

Tele Vue Optics
32 Elkay Dr., Chester, NY 10918
845-469-4551; televue.com

◀ DIRECT-DRIVE PARAMOUNT

Software Bisque announces The Paramount Apollo 500 robotic telescope mount ($32,500). This direct-drive alt-azimuth fork mount can accommodate up to 400 lbs with 24 inches of clearance between tines. Each axis incorporates high-resolution, on-axis absolute encoders and high-torque, direct-drive motors for quick and precise slewing and tracking of targets at speeds of up to 60° per second. An included high-performance instrument rotator eliminates field-rotation in long exposures when tracking anywhere in the sky. The Paramount Apollo comes with the *Paramount Software Suite*, which includes charting and planning programs, device control, and custom scripting that runs on Windows, macOS, and Linux.

Software Bisque
862 Brickyard Circle, Golden, CO 80403
303-278-4478; bisque.com

▶ PORTABLE MOUNT

iOptron introduces the latest addition to its series of portable equatorial Go To mounts, the GEM45 ($2,098). The mount head weighs just 15.8 lbs yet can support up to a 45-lb load. The mount advertises permanent periodic error correction (PPEC) to produce smooth tracking during long-exposure astrophotography. Alignment is simple with the GEM45's integrated iPolar electronic polar finder, and users can quickly swap telescopes on the mount with its Universal Self-Centering Saddle plate, which accepts both Vixen and Losmandy-style dovetail bars. The GEM45 is controlled via the Go2Nova 8407+ hand controller, which includes a database of more than 212,000 objects. The mount comes with a heavy-duty LiteRoc tripod, counterweight shaft, an 11-lb counterweight, and AC adapter.

iOptron
6F Gill St., Woburn, MA 01801
866-399-4587; ioptron.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.

Captain Cook's As

The celebrated explorer was also a remarkably proficient and prolific astronomer.

Two hundred and fifty years ago, in March 1770, Lieutenant James Cook of the British Royal Navy was busy mapping the coastline of New Zealand during the first of his three great voyages. Thanks to these voyages, which crisscrossed the Pacific Ocean east to west and north to south, Captain Cook (as he later became) is widely recognized as one of the greatest explorers of all time. Fewer people know that astronomy also played a major role in his life and expeditions.

Cook observed transits of Venus and Mercury across the face of the Sun, a number of solar and lunar eclipses, lunar occultations (including one of Saturn), and comets. Most important, he became extraordinarily skilled at the astronomical observations necessary for determining his local time, latitude, and longitude.

The roots of Cook's astronomical career can be traced back to 1758, when he served in the British Royal Navy in

TAHITI One of the main purposes of James Cook's first voyage was to observe the 1769 transit of Venus from Tahiti. This painting by expedition artist William Hodges shows the same location when Cook revisited it on his second voyage.

tronomy

Canada. A chance meeting with a surveyor piqued his interest, and on his own initiative, Cook started learning the skills necessary for surveying. Due to the high quality of his charts and the influence of some friends in high places, Cook was assigned to survey the island of Newfoundland in 1763.

Cook's primary surveying instruments were a *theodolite* and a *telescopic quadrant*. Theodolites measure the horizontal and vertical angles between two points; they're still essential tools for any surveyor. The telescopic quadrant measures the angle between a target object and the zenith (its *zenith distance*), an essential step in determining the observer's latitude. Both theodolite and quadrant must be leveled with great accuracy, which prevents their use aboard a ship.

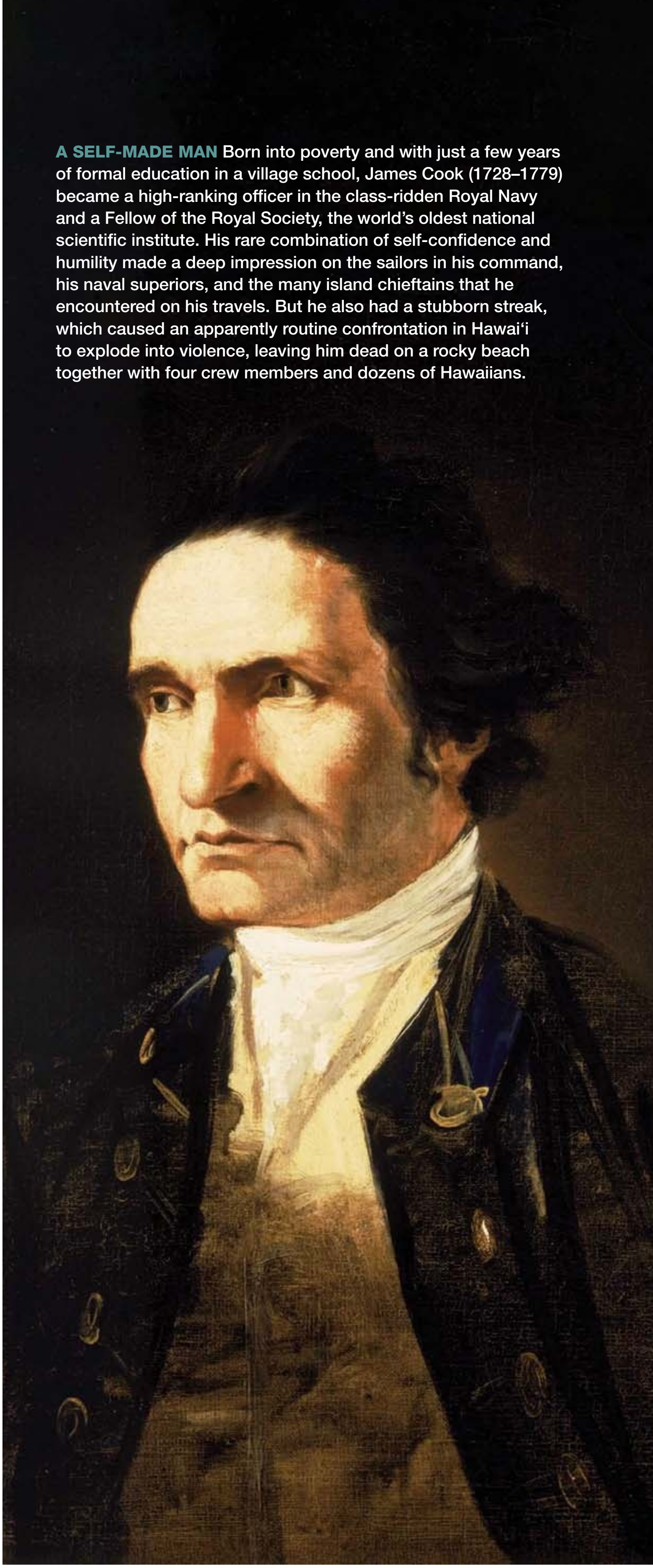
Although he had good latitudes for Newfoundland, Cook also needed a reference point with known longitude, which in turn required at least one accurate measurement of Greenwich Time. (See the sidebar on page 61.) He found an opportunity in the form of an annular solar eclipse, whose centerline passed just south of Newfoundland on August 5, 1766. Cook's observations, made with the telescopic quadrant, were of the zenith distances of the Sun at first and last contact.

Cook didn't have the data or mathematical skills necessary to determine the longitude from his observations, so he took his results back to England, where a professional astronomer did the calculations. These involved determining the local time of Cook's zenith-distance measurements and correcting for refraction, the Moon's parallax, and the Sun's semidiameter. The astronomer also applied the same corrections to observations of the same eclipse made from Oxford, England. Knowing the difference between the local times of the first and last contacts for the two locations as well as the known longitude for the Oxford observations, the astronomer calculated the longitude of Cook's location with an error of only 4.7 miles.

Cook's superiors were impressed by the care, accuracy, and dedication Cook applied to his work, and Cook learned the value of astronomical observations. Cook's Newfoundland charts set a new standard for thoroughness and accuracy; they remained in use for more than a century.

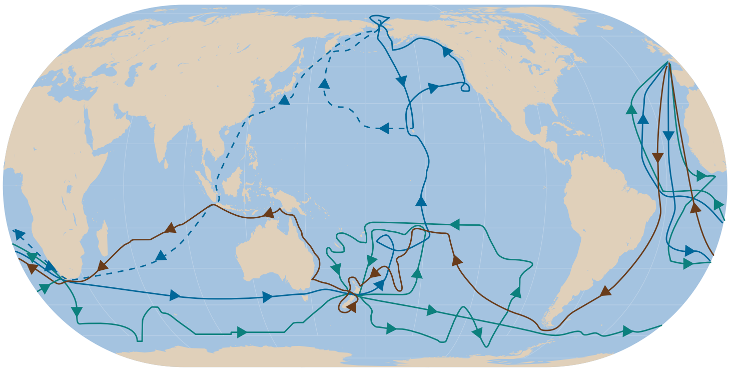
The Longitude Problem

The oldest method for determining longitude at sea is *dead reckoning*: estimating the distance traveled from a known longitude based on the ship's direction and speed. Wind and ocean currents make it very hard to do this accurately. During the circumnavigation of the globe by Ferdinand



A SELF-MADE MAN Born into poverty and with just a few years of formal education in a village school, James Cook (1728–1779) became a high-ranking officer in the class-ridden Royal Navy and a Fellow of the Royal Society, the world's oldest national scientific institute. His rare combination of self-confidence and humility made a deep impression on the sailors in his command, his naval superiors, and the many island chieftains that he encountered on his travels. But he also had a stubborn streak, which caused an apparently routine confrontation in Hawai'i to explode into violence, leaving him dead on a rocky beach together with four crew members and dozens of Hawaiians.

TAHITI: NATIONAL MARITIME MUSEUM / WIKIMEDIA COMMONS; BACKGROUND PAPER TEXTURE: PABLOHART / GETTY IMAGES; COOK PORTRAIT: NATIONAL MARITIME MUSEUM / WIKIMEDIA COMMONS



▲ **VOYAGES OF EXPLORATION** Cook's first, second, and third voyages are shown in brown, green, and blue, respectively. The dotted blue line shows his ship's voyage home after Cook was killed in Hawaii.

Magellan's fleet between 1519 and 1522, his estimate of the longitude of the Philippines was off by 53 degrees, or approximately 3,500 miles.

In 1612, two years after he discovered Jupiter's four bright satellites, Galileo realized that their regular motions could serve as a "universal clock" for determining longitude. In 1668 the great Italian-French astronomer Giovanni Domenico Cassini published accurate tables of the positions of Jupiter's satellites, which were used to improve maps of Europe. The timing of other predictable astronomical events such as solar eclipses, lunar eclipses, and occultations of bright stars by the Moon could also be used, but they aren't frequent enough to be practical.

Observing Jupiter's satellites is problematic because it requires a stably mounted telescope. That's fine when observing from land but problematic aboard a ship. What was needed was a predictable astronomical event that happened frequently and could be observed accurately at sea. In 1514 the German mathematician Johannes Werner suggested using the distance between the Moon and the Sun or other reference star for determining longitude. The Moon's orbital motion causes it to move through the background stars at 13.2° per day, or 33′ per hour. So if the distance between the Moon and a known star can be measured accurate to, say, 3.3′, that determines the time — and hence the longitude — within six minutes, which is six nautical miles at the equator.

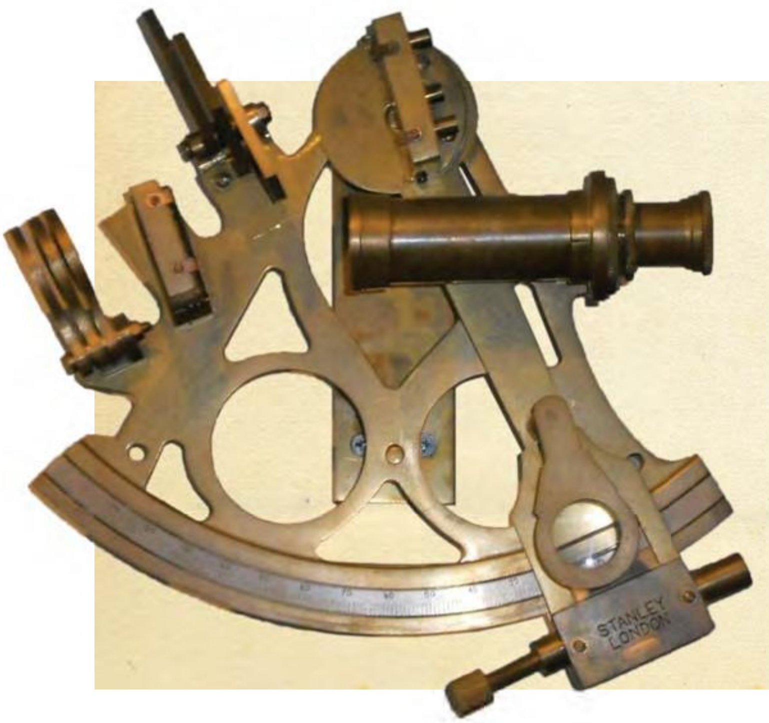
Unfortunately, unlike Jupiter's satellites, which are far from the Sun and strongly bound to their massive planet, the Moon is attracted roughly equally by Earth and the Sun, making its motion very complex. Only in 1755 did the German astronomer Tobias Mayer come up with a way to compute the Moon's orbit sufficiently accurately to be useful for the lunar distance method.

The other alternative was to use a mechanical clock set to Greenwich Time. By the mid-1700s the best pendulum clocks had achieved an accuracy of a few minutes per year, but only if mounted on a stable platform. At the time of Cook's first voyage (1768 to 1771), the only clock that could keep accurate time at sea was John Harrison's H4 chronometer, which was unavailable because it was being evaluated for the Longitude Prize set up by the British Parliament in 1714.

But Harrison's H4 clock was only expected to provide accurate time during the two-month trip from Britain to the West Indies; its cumulative error would have made it almost useless for Cook's multiyear voyages.

For his first voyage Cook used lunar distances as his primary method for determining Greenwich Time. He measured the angular distance between the Moon and the Sun or reference star with a sextant, and recorded the local time. He consulted the *British Nautical Almanac* to determine at what time the angular distance would be the same if observed from Greenwich.

Although the lunar distance method is simple in concept, other factors make it more complex in practice. Atmospheric refraction causes the Moon and the star to appear higher than they actually are. The Moon is also close enough to Earth that its apparent position must be adjusted for parallax. So in addition to obtaining the angular distance between the Moon and the star, it's necessary to measure the altitudes of the two objects above the horizon, as shown on page 62. Applying the corrections for refraction and parallax (called *clearing*) requires the use of spherical trigonometry. To simplify the computations, mathematicians developed a clever method using logarithms. This operation didn't require the



◀ **THE ONCE AND FUTURE SEXTANT** Sextants use mirrors to superpose the images of two distinct objects, much as rangefinders in old-fashioned cameras do. The angle between the objects can then be read off a finely calibrated scale. In 2016 the U.S. Navy reemphasized training with sextants, because they are immune to antisatellite weapons, electromagnetic pulses, and hacking.

What was needed was a predictable astronomical event that happened frequently and could be observed accurately at sea.

users to understand the underlying mathematics but only to follow a number of well-defined steps, looking up the necessary astronomical data from the *Nautical Almanac* and logarithm values from another book.

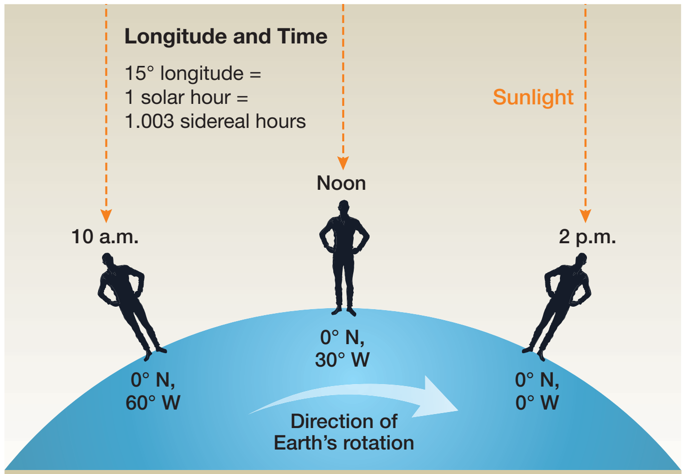
By the time of Cook's second voyage (1772 to 1775), he brought along a few chronometers that were copies of Harrison's H4 clock. Only one proved reliable, the one made by Larcum Kendall and referred to as K1, though Cook always called it "the watch." The chronometers were set to Greenwich Time and were meant to eliminate the need for universal clocks based on astronomical phenomena. But astronomical observations were still necessary for determining local time. At first, Cook was reluctant to trust the timekeeping capabilities of chronometers and continued to use lunar distances to determine longitude.

To overcome the uncertainties that crept into the K1 watch's accuracy over long timespans, Cook revisited two locations whose longitudes he'd determined during his first voyage. These were Venus Point in Tahiti (where he observed the June 3, 1769, transit of Venus) and Ship Cove, on the northern tip of the South Island of New Zealand, where he spent an extended period repairing his ship.

Over the course of his three voyages, Cook visited Venus Point five times and Ship Cove six times. Knowing the longitudes of both locations, he could reset the time of the Kendall watch. He discovered that it worked very well indeed. Cook departed Ship Cove in November 1773 and returned 11 months later after sailing a counterclockwise route around the southern Pacific from latitude 71°S near Antarctica to 9°S in the tropics. The time kept by the Kendall watch (after applying its known correction rate) was found to be off by just 19 minutes and 31 seconds. Although not as accurate as the lunar distance method, it was much faster and easier to use, and it eliminated the possibility of observational and computational error. Cook was so impressed that he took the K1 on his third voyage as well.

The astronomical equipment that Cook carried included sextants, a telescopic quadrant, telescopes (both refractor and reflector), and an astronomical pendulum clock. Although he and his assistants could use the sextants both at sea and on land, the other instruments were useful only on land. Each time Cook dropped anchor for fresh water and food, firewood, ship repairs, or to rest his crew, he took the opportunity to set up a tent observatory. Weather permitting, he'd make observations in order to determine a more accurate latitude and longitude than he could obtain at sea. Professional astronomers accompanied Cook on all his voyages to oversee the observations and computations, though his own observations often proved at least as accurate as theirs.

Charles Green (1734–1771) was Cook's astronomer for his first voyage on the ship *Endeavour*. The British Navy supplied two ships for Cook's second voyage: the *Resolution* (with Cook as captain) and the *Adventure* (with Tobias Furneaux as captain). William Wales (1734–1798) was the astronomer on the *Resolution* and William Bayly (1737–1810) on the *Adventure*. Two ships also went on the third voyage: the *Resolution* (with Cook as captain) and the *Discovery* (with Charles Clerke as captain). Bayly served as the astronomer on the *Discovery*, while Cook himself took on the duties of astronomer aboard the *Resolution*.



Longitude and Time

Your orientation in space is determined by your latitude and the local time, so those values are relatively easy to measure astronomically. For instance, it's local noon by definition when the Sun is at its highest. And the Sun's zenith distance at that moment is equal to your latitude minus the Sun's declination, which can be found for any given day in an astronomical almanac.

Longitude is much harder because all people at any given latitude go through the same cycle of space orientations, regardless of their longitude. Two hours from now, a person 30° directly west of you will see the Sun at the same spot in the sky that you do right now. But if you have a clock (either mechanical or astronomical) that tells you the time in Greenwich, at longitude 0°, you can compute your longitude by subtracting Greenwich Time from local time and dividing by 15. Conversely, if you are at a spot with known longitude, you can compute Greenwich Time from local time.

LEAH TISCIONE / S&T

◀ **CAPTAIN COOK'S WATCH** The Kendall K1 chronometer, shown here, was Cook's favorite timepiece. He always called it "the watch" even though it was five inches in diameter and weighed a little more than three pounds.

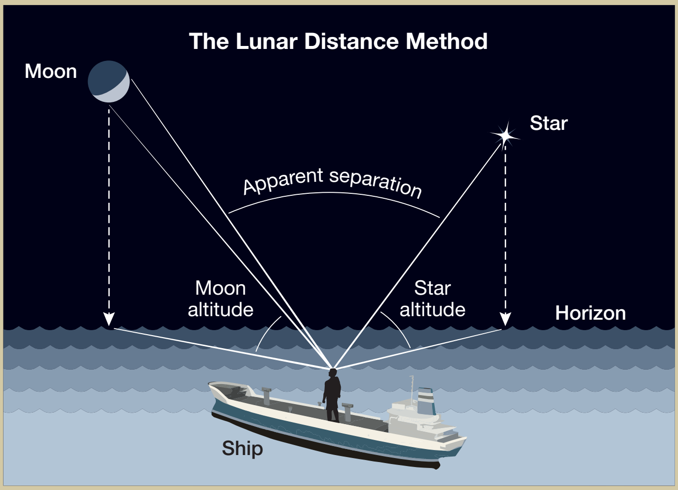
Nevil Maskelyne, Astronomer Royal from 1765 to 1811, didn't sail with Cook on any of his voyages, but he did play a key role in Cook's astronomical career. Maskelyne oversaw the British efforts for the 1769 transit of Venus, when several countries sent observers to widely scattered locations in hopes of measuring the distance to Venus by parallax. He sent Green to Tahiti, Wales to Canada, and Bayly to Norway. Maskelyne also evaluated the contenders for the Longitude Prize, and his bias for using lunar distances delayed the acceptance of John Harrison's H4 chronometer as the best method for determining longitude at sea.

Here are a few examples of longitudes determined during Cook's voyages. In June 1770, during his first voyage, Cook landed in Queensland, Australia, near the location of modern-day Cooktown (named for him) after his ship nearly sank when it ran into the Great Barrier Reef. While there, Green timed two eclipses of Io, yielding longitudes that deviated from the modern value by only 2.7 and 9.8 miles. During the second voyage, Wales's longitudes for New Zealand's North and South Islands differed from the ones that Green measured during the first voyage, with Green's being 36 miles too far east for the South Island and 27 miles too far east for the North Island. Cook was upset by the error and blamed himself, but the discrepancy between these two highly skilled observers shows how difficult determining longitude could be.

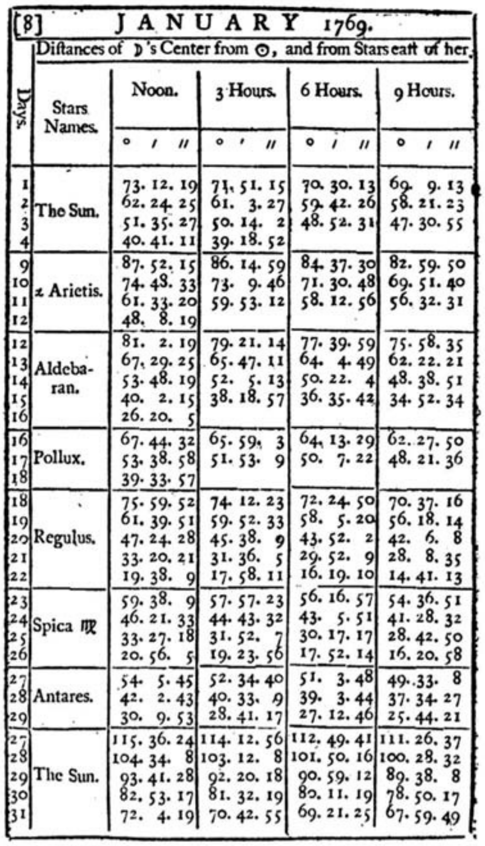
Though Cook's best-known legacy is his exploration of the Pacific Ocean, his contributions to navigation through astronomical observations and the use of "the watch" were equally important.

■ **TED RAFFERTY** is a retired astronomer who worked for the U.S. Naval Observatory for 32 years.

FURTHER READING: The late journalist Tony Horwitz traveled to many of the exotic locations that Cook visited on his voyages. He tells Cook's story in parallel with his own in the fascinating book *Blue Latitudes: Boldly Going Where Captain Cook Has Gone Before* (Picador, 2003). The title plays with the fact that the original *Star Trek* TV program was modeled largely on Cook's voyages, and Captain James T. Kirk of the starship Enterprise was named after Captain James Cook. The *Captain Cook Society* website is an excellent starting point for online information.



▲ **LUNAR DISTANCE METHOD** Because the Moon moves through the stars so rapidly, it's possible to calculate Greenwich Time by measuring the Moon's angular separation from the Sun or other reference star. To compensate for atmospheric refraction, you also need to measure the angular altitudes of the Moon and star above the horizon.



[8] JANUARY 1769.

Diftances of ☽'s Center from ☉, and from Stars eaft of her.

Days.	Stars Names.	Noon. ° ′ ″	3 Hours. ° ′ ″	6 Hours. ° ′ ″	9 Hours. ° ′ ″
1	The Sun.	73. 12. 19	71. 51. 15	70. 30. 13	69. 9. 13
2		62. 24. 25	61. 3. 27	59. 42. 26	58. 21. 23
3		51. 35. 27	50. 14. 2	48. 52. 31	47. 30. 55
4		40. 41. 11	39. 18. 52		
9	α Arietis.	87. 52. 15	86. 14. 59	84. 37. 30	82. 59. 50
10		74. 48. 33	73. 9. 46	71. 30. 48	69. 51. 40
11		61. 33. 20	59. 53. 12	58. 12. 56	56. 32. 31
12		48. 8. 19			
12	Aldebaran.	81. 2. 19	79. 21. 14	77. 39. 59	75. 58. 35
13		67. 29. 25	65. 47. 11	64. 4. 49	62. 22. 21
14		53. 48. 19	52. 5. 13	50. 22. 4	48. 38. 51
15		40. 2. 15	38. 18. 57	36. 35. 42	34. 52. 34
16		26. 20. 5			
16	Pollux.	67. 44. 32	65. 59. 3	64. 13. 29	62. 27. 50
17		53. 38. 58	51. 53. 9	50. 7. 22	48. 21. 36
18		39. 33. 57			
18	Regulus.	75. 59. 52	74. 12. 23	72. 24. 50	70. 37. 16
19		61. 39. 51	59. 52. 33	58. 5. 20	56. 18. 14
20		47. 24. 28	45. 38. 9	43. 52. 2	42. 6. 8
21		33. 20. 21	31. 36. 5	29. 52. 9	28. 8. 35
22		19. 38. 9	17. 58. 11	16. 19. 10	14. 41. 13
23	Spica ♍	59. 38. 9	57. 57. 23	56. 16. 57	54. 36. 51
24		46. 21. 33	44. 43. 32	43. 5. 51	41. 28. 32
25		33. 27. 18	31. 52. 7	30. 17. 17	28. 42. 50
26		20. 56. 5	19. 23. 56	17. 52. 14	16. 20. 58
27	Antares.	54. 5. 45	52. 34. 40	51. 3. 48	49. 33. 8
28		42. 2. 43	40. 33. 9	39. 3. 44	37. 34. 27
29		30. 9. 53	28. 41. 17	27. 12. 46	25. 44. 21
27	The Sun.	115. 36. 24	114. 12. 56	112. 49. 41	111. 26. 37
28		104. 34. 8	103. 12. 8	101. 50. 16	100. 28. 32
29		93. 41. 28	92. 20. 18	90. 59. 12	89. 38. 8
30		82. 53. 17	81. 32. 19	80. 11. 19	78. 50. 17
31		72. 4. 19	70. 42. 55	69. 21. 25	67. 59. 49

▶ **LUNAR DISTANCE TABLE** This page from the *Nautical Almanac* shows lunar distances for January 1769 as they would appear to an observer in Greenwich, England.

KENDALL CHRONOMETER: NATIONAL MARITIME MUSEUM; LONGITUDE AND TIME: LEAH TISCIONE / S&T; NAUTICAL ALMANAC: ROYAL OBSERVATORY, GREENWICH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Getting Gear From Here

UNDER THE MILKY WAY TONIGHT One reward for those willing to travel is the opportunity to escape big-city light pollution and enjoy the splendors of a pristine night sky. Photographer Cory Schmitz captured this evocative view of the Milky Way from Namibia.

How to plan a successful observing or astrophotography trip to a far-flung corner of the world.

Stargazing and astrophotography often involve travel, whether you're chasing an eclipse or simply journeying to southern latitudes to get your first look at unfamiliar constellations. But how do you get your astro-gear from here to there? As I've found, there's much more to it than simply having sturdy luggage.

A Telescope in Tangier

A funny thing happened on a recent trip to Morocco. My wife, Myscha, and I crossed the Strait of Gibraltar on a ferry from Tarifa, Spain. However, when we arrived in Morocco, customs officers in Tangier took great interest in my 5-inch Maksutov telescope — so much so that they held on to it and required me to seek permission to bring it into the country. What followed was several hours spent hunting for officials and trying to convey our situation with the small amount of French and Arabic I know (English isn't widely spoken in Morocco). Luckily, we encountered a very helpful taxi driver who went above and beyond the call of duty to advocate for us. He saved the day. We were eventually allowed to reclaim the scope, but with the rather odd stipulation that we notify local police whenever we decided to use it.

Morocco is an amazing country to visit and features some wonderfully dark skies beyond the Atlas Mountains, far from the bright lights of the coastal cities. And our friends in Moroccan customs will likely see plenty of telescopes and other strange astronomical gear when visitors arrive for the August 2027 total solar eclipse!

ALL PHOTOS BY THE AUTHOR UNLESS OTHERWISE NOTED

to There

Reach Out and Tweet Someone

Engaging in a discussion on Twitter, I realized that our Moroccan adventure wasn't unusual — many other astronomers had similar tales to tell. So, what's the best way to navigate international borders when traveling with telescopes?

First of all, it's important to put your worries in perspective. I've observed from six different continents, and our delay in Tangiers is the only notable run-in I've had with local authorities. However, things *can* go badly wrong. Recently a pair of Australian travel bloggers visiting Iran were jailed in the notorious Evin Prison for three months because they flew a camera drone without a license. Thankfully, to the best of our knowledge, no astronomers have been detained for practicing their hobby.

The U.S. Department of State offers a country-by-country rundown (**https://is.gd/dos_travel**) listing what's allowed and what's not, for import and export. Other nations provide similar listings online. Unfortunately, details pertaining specifically to astronomical equipment are scarce. Photographic gear is the most similar category usually included on government websites. Bear in mind, however, even information from official sources *can* be out of date or incorrect. As fellow astrophotographer Cory Schmitz advises, "Don't just trust a country's government website — search the internet for information about traveling with photographic equipment."

Another useful approach is to gather "human intel" by talking to other traveling astronomers. This is often the best way to get up-to-date news about the situation in a specific country. Astronomy forums, message boards, Reddit, and Twitter regularly contain such discussions, especially in the lead-up to a high-profile event, such as a total eclipse. Twitter, in particular, is a great place to meet like-minded amateur astronomers from around the world.

Regardless of what your research turns up, it's not unusual to find yourself at the whims of the individual customs official who happens to be on duty when you arrive. In such a situation, do your best to be patient and polite as you explain your intentions clearly and honestly.

Strength in Numbers

A lot of the logistical headaches that are a part of international travel can be avoided by signing up for an organized tour. The benefits are numerous and usually include taking care of customs paperwork and visas. In addition, your accommodations and ground travel are normally part of the package. (Several firms that offer astronomical tours regularly advertise in this magazine.)

But group travel isn't for everyone. Surrendering the ability to come and go when you want and where you want is the price you pay in exchange for the convenience and peace of mind of a group tour. In my experience, breaking away from the herd makes it easier to meet and make friends with local people — many of whom may have never looked through a telescope. A brief view of the Moon does wonders to circumnavigate language barriers and bridge cultural divides.

If you can find a local astronomy club, it might be possible share some observing time with its members — something especially appealing if you're traveling without a telescope of your own. We managed to track down friendly clubs in Australia and New

▲ **IMPOUNDED!** This 5-inch Maksutov telescope awaits its fate in a Moroccan customs office. Although the scope may seem innocent enough, to the overly cautious eyes of local officials, it had a suspicious look to it.

MOORISH MOONSET The author photographed the waning gibbous Moon as it set behind a Moorish castle located in Jimena de la Frontera, in southern Spain.

▲ **GOOD TO GO** With the exception of his mount's large tripod, everything David Dickinson needs for an astro-getaway fits into one carry-on suitcase.

Zealand while on hiking treks. No one would willingly pass up a chance to view the bountiful southern sky! (*Sky & Telescope* maintains a comprehensive list of international astronomy clubs at **https://is.gd/astroclubs**.)

Accessory Considerations

I find that border and security staff are always interested in my telescope, though I haven't had a problem transporting it in my carry-on luggage. Usually a brief inspection and short discussion is all that's involved. As my Malaysian colleague Shahrin Ahmad suggests, "The best practice is to be as transparent as possible and pack your equipment so that it can be easily opened and checked at customs."

While we tend to worry most about the big stuff, other items can also attract attention. If you plan on bringing an aerial drone, be mindful that some countries ban such devices. The website for UAV Coach lists current domestic and international drone laws (**uavcoach.com/drone-laws**). Laser pointers are another potential problem and will likely be confiscated at many borders. The U.S. Transportation Security Administration (TSA) currently allows laser pointers in checked and carry-on baggage, but I opt to leave mine at home when I'm on an astrophotography trip abroad.

Be aware that batteries can also be a concern. The TSA permits alkaline and rechargeable batteries (including lithium cells with "less than 100 watt-hours capacity") only in carry-on bags. Be sure to check with the TSA (**tsa.gov**) for the latest updates. You should also ensure there's enough power left in your batteries to briefly demonstrate that your devices function, if requested to do so.

Stay Safe at Night

No matter how far afield you travel, take sensible precautions and be aware that conditions may vary greatly from those you're accustomed to at home. In Morocco and Turkey, for example, it's not unheard of for drivers to travel at night without headlights! Some rural villages present hazards that include horse-drawn carts and livestock wandering around in the dark. This is another reason why connecting with a local astronomy group can be very valuable. They'll likely know the best places to safely set up, and you might even score an invitation to tag along. In any case, it's wise to employ a precaution used in the hiking community and tell someone where you're going and when you expect to be back. That said, I've never had problems while observing abroad.

Combining travel with astronomy can be a tremendously enriching experience. With a little advance planning and research, "getting there" really can be half the fun.

◀ **LOCAL TRAVEL** Not every astro-journey requires a passport. The author visited Bruneau Dunes State Park, in Idaho, where he shot this image of the Sagittarius Milky Way glowing above the park's observatory.

■ **DAVID DICKINSON** is a U.S.-based writer who travels the world with his wife, Myscha. He's the author of *The Universe Today Ultimate Guide to Viewing the Cosmos*, and the forthcoming *The Backyard Astronomer's Field Guide*, due this July.

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The Stellina "Observation Station"

This fully integrated system promises to bring astronomy to the masses. Does it deliver?

Stellina packs a lot of equipment — an 80-mm f/5 apochromatic refractor that integrates a color digital video camera, focuser, dew heater, motors, computer, and more — into a very small, very sleek package standing barely 2 feet tall. Don't bother looking for an eyepiece: Stellina transmits images via Wi-Fi to iOS and Android smart devices running the free *Stellinapp*.

Vaonis Stellina

U.S. Price: $3,999

vaonis.com

What We Like

Ease of setup and use

Good-quality color images

User-friendly (and free) mobile app

What We Don't Like

Lack of user input

Wi-Fi signal subject to interference

Bright blue power light

NO MATTER HOW EASY they make it for someone to point a telescope at a celestial object, if the view is disappointing that person is not going to stick with astronomy. In a typical backyard telescope, the appearance of almost everything beyond the Moon literally pales in comparison to color images from the Hubble Space Telescope, which are everywhere. When you show a nonastronomer a star cluster, nebula, or galaxy in your telescope's eyepiece, the last thing you want to hear is, "That's it?" — something I hear all too often.

Well, a new technological revolution in amateur astronomy is upon us, and it takes aim squarely at this problem. Several "smart telescopes" are entering the marketplace, all designed not only to find their way around the sky by themselves, but also to deliver colorful views of deep-sky objects roughly comparable to what you see on the pages of this magazine. Controlled via smart-device apps, these are telescopes for the internet age and are promoted by their manufacturers as making the universe accessible to all.

The first of this new breed to make it to consumers is Stellina, developed by the French company Vaonis. Billed as an "observation station," Stellina doesn't look — or behave — like any telescope you've ever seen. For one thing, it doesn't have an eyepiece, finderscope, or red-dot finder. Indeed, you don't look through Stellina at all — its built-in color digital camera sends celestial images directly to your smartphone or tablet through a Wi-Fi connection.

Introducing Stellina

At its heart, Stellina is an 80-mm f/5 apochromatic refractor married to a color video camera whose Sony IMX178 CMOS sensor has 3,096 × 2,080 pixels, each 2.4 microns square. Given the telescope's 400-mm focal length, the 6.4-megapixel chip offers a field of view of 1° by 0.7°, enough to accommodate the full Moon with room to spare, at 1.2-arcsecond resolution.

This shiny white, fork-mounted telescope would look right at home on a *Star Trek* movie set. The U-shaped base couples to an included Gitzo Systematic short tripod that holds the machine less than a foot off the ground. Light from the objective is reflected off an angled flat mirror through the altitude axis to a camera housed in one of the fork arms. The other fork has a compartment for the supplied 10,000 milliamp-hour (mAh) portable rechargeable battery and two USB ports.

Also built into the system are an electronic focuser, field de-rotator, dew heater connected with temperature and humidity sensors, a light-pollution filter, altitude and azimuth motors, and all the associated electronics, including a special-purpose computer. Stellina

VAONIS STELLINA: SEAN WALKER / S&T; ALL PHOTOS BY THE AUTHOR UNLESS OTHERWISE NOTED weighs about 25 pounds (11 kilograms) and measures about 19 inches (48 cm) tall, 15 inches wide, and 5 inches deep, not including the tripod.

How It Works

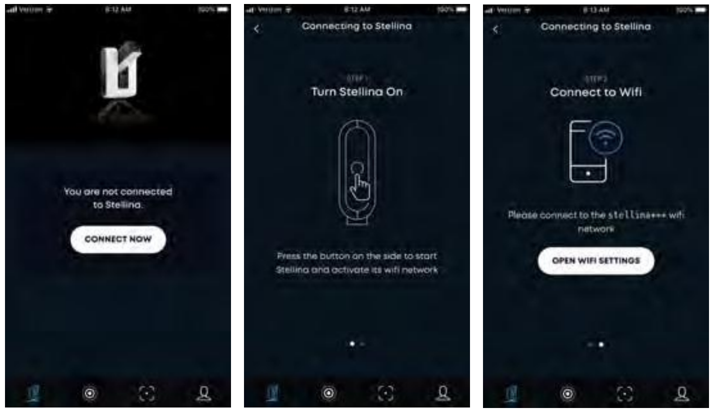
Before observing with Stellina, download and install *Stellinapp* on whatever devices you'll use to control it. I used an iPhone 8 and a 4th-generation iPad. You also need to charge the battery via the supplied USB charging cable.

Once Stellina is secured to the tripod, you set the assembly on the ground or on a sturdy table outside and level it. Open the battery compartment, insert the battery, plug it in using the included power cable, close the door, and press the big round power button, whose rim will glow blue — more about that later.

Next, launch *Stellinapp*. It'll prompt you to connect to the telescope via Wi-Fi, which you do the same way you connect to any other Wi-Fi network via your device settings.

As soon as you connect to Stellina, it determines your location and the current date and time via your mobile device's GPS receiver. If it's not yet dark, the app warns you that Stellina may not be able to initialize. My experience leads me to agree with Vaonis's recommendation that you wait at least one hour after sunset before you start observing.

Under the night sky, the app reports "Starry star zone search" as the telescope points about two-thirds of the way toward the zenith, rotates a little in azimuth, and shoots an image. The app then displays "Field of star analysis" as Stellina's computer compares the image to its internal star atlas. (These messages are translated from French by someone lacking a good command of idiomatic English.) If the software doesn't recognize the star pattern, it moves the telescope and tries again on a different field. Most times it identified where it was pointing on the first try and went on to the next step: autofocusing the system by taking a series of images and adjusting the optics to minimize the star sizes. With that done, *Stellinapp* reports that it is ready and invites you to choose a target to observe.



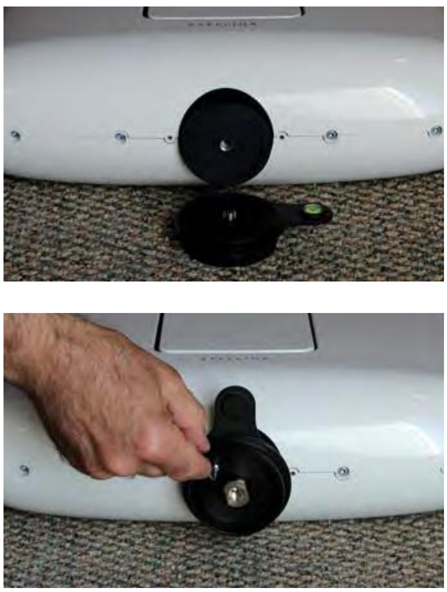
▶ After launching *Stellinapp* on your smart device and pressing "Connect Now," the app then provides step-by-step instructions for powering on the telescope and connecting to its Wi-Fi network via your device settings.

The app presents a short list of recommended targets, mostly Messier objects. When you tap an object, you get a bunch of information about it, including its various designations, a brief description, its "situation" (constellation), distance, size, magnitude, right ascension, and declination. If you tap the little blue triangle next to the item, you get more details — but not necessarily ones that a beginner would understand. For example, the app explains magnitude only as "a logarithmic measure of the brightness of an object in a defined passband" and, as far as I could tell, doesn't explain right ascension and declination at all.

Once you choose a target to observe, Stellina slews to where it expects to find it in the sky, with the app reporting "Pointing near target." Then Stellina shoots an image, compares it to the onboard database ("Checking pointing accuracy"), and refines the pointing as needed to center the target in the camera's field of view. Following "Tracking activation" Stellina begins shooting a series of 10-second images and stacks them to build up a long exposure.

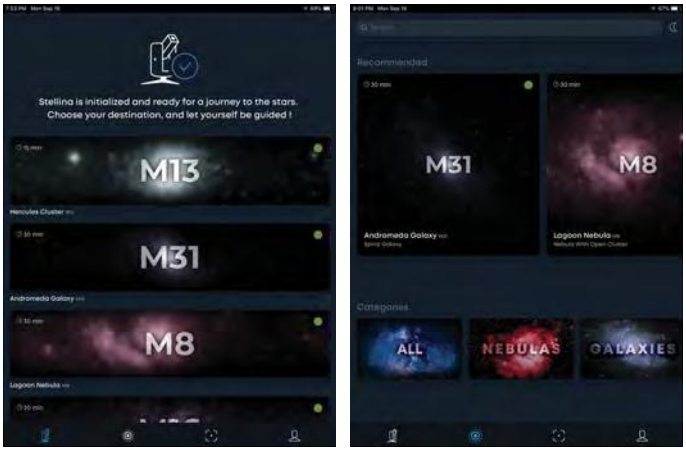
Effortless Astrophotography

I first asked Stellina to show me globular cluster M13 in Hercules. When the initial image appeared on my iPhone



▲ *Top:* Before you can place Stellina atop its short tripod, you need to attach the adapter and bubble-level plate. *Bottom:* After screwing the adapter into Stellina, you tighten a set screw with an included hex key.

▲ *Top:* Stellina rides atop a custom-designed, miniature Gitzo Systematic carbon-fiber tripod. *Bottom:* After attaching the bubble level and adapter to Stellina, guide the adapter into the tripod ring until it locks in place with a click.



Left: When Stellina is ready to begin imaging, the app presents a list of suggested targets. The green dots indicate that they're at least 20° above the horizon. *Right:* Want more choices? Scroll down to browse the full target catalog or lists of objects by type.

screen, it was perfectly centered and resembled a low-power eyepiece view. As each new 10-second exposure was added to the stack and the image brightened, I could see more stars in the cluster's outskirts. I noticed a slider next to the image that was keeping track of the exposure count; sliding it downward shows earlier versions of the stack, right back to the first image. This reveals that Stellina is not autoguiding but instead shifting and rotating each new image as needed to align with the previous one. As this process continues throughout the observation, non-overlapping areas get cropped out, such that the field of view shrinks a bit, which has the effect of slightly zooming in on the target.

I let Stellina accumulate 32 images of M13, for a total of 5 minutes 20 seconds of exposure time, and if I were a newcomer to astrophotography I'd be mighty impressed with the result. The focus was a bit soft, and the brightest stars in the image looked a bit like flying saucers, presumably because of slight inaccuracies in the image translation, rotation, and stacking. Still, not bad for a first try, especially since the entire process occurred without my having to do anything but tap my iPhone screen a few times.

Next I went after a more colorful target: M27, the Dumbbell Nebula in Vulpecula. Again Stellina got it nicely centered, and there were hints of red and green in the very first exposure. By the time I'd accumulated 15 images (2 min 30 seconds of exposure), I had a photo of which any beginning astrophotographer would be proud.

Fainter deep-sky objects didn't become visible on the screen until Stellina had combined several images, but they always appeared well centered. Even in full moonlight, I got a decent color image of NGC 6960, the Western Veil Nebula in Cygnus, in just 20 minutes.

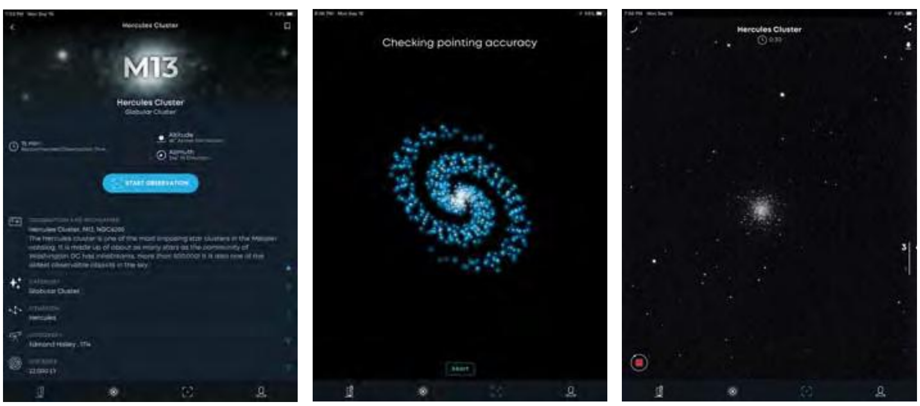
Solar system targets challenge Stellina in two ways. Vaonis acknowledges the first on its website: 400 mm isn't enough focal length to show the planets particularly well. Galileo would recognize Saturn in a Stellina image: It has "appendages," but it's not obvious they're rings. Second, the Moon and planets are bright, so Stellina images them with very short exposures — too short to record background stars. This means the image-stacking routine doesn't work, and this in turn shows the limitations of the telescope's tracking accuracy: Solar system targets drift from exposure to exposure. The Moon started out partway in the frame, then drifted fully in, then drifted out the other side. Given the Moon's large apparent size, of course, the images showed plenty of detail, but not as much as they would with sharper focus.

Stellina gives you three ways to save images. From within the app, you can save JPEGs to your device's photo gallery and/or to the app itself. When you do the latter, your images show up in the target list, replacing the placeholders that come with it. The third option, in addition to the other two, is to save FITS images to a USB key (thumb drive) that you plug into one of the ports in the battery compartment.

I tested Stellina in the fall, when it tends to be very dewy. Several times I noticed the telescope dripping wet, but when I checked the objective, it was clear and dry. The built-in dew heater works very well!

Up to 10 smartphones and tablets can connect to Stellina simultaneously, and you can pass control of the telescope from one device to another, which could be fun with a group of friends, family members, or students. I tested this with my iPhone and iPad and was able to see images on both devices and to pass control from one to the other and back with no problems. This is where Stellina really shines — as an outreach tool. Instead of asking "That's it?"

Left: Choosing M13 from the target catalog brings up a page with information about it. *Middle:* Pressing "Start Observation" slews the scope to where it expects to find M13 in the sky, takes an image, and compares what it sees to its internal database. *Right:* A screen then opens where you can watch the image build up one 10-second exposure after another.



▲ Stellina's view of the September 2019 Harvest Moon. For solar system targets, Stellina shoots individual fraction-of-a-second exposures and doesn't stack them.

▲ *Left:* The first 10-second image in a sequence of exposures of planetary nebula M27, the Dumbbell, always has the object nicely centered. *Right:* As further exposures are stacked, non-overlapping areas are cropped out, effectively zooming in on the target. Here's the Dumbbell Nebula after 10 minutes of accumulated exposure time. Note that because of all the computer processing needed to align and stack 60 frames, the actual elapsed time of the observation was more than 1 hour.

people will be bowled over by the color images that this little Space Age gizmo literally puts in their handheld devices.

Shortcomings

For the most part Stellina does what Vaonis says it'll do, and because most of the "heavy lifting" is done by the internal computer or the app, the concerns I've raised so far — with the autofocus, tracking, and image processing — will no doubt be addressed in future software updates. But I encountered quite a few other problems as well, and not all of them are so easily remedied.

The most frustrating problem is the blue light around the power switch. It is so bright that you can't get dark-adapted in Stellina's presence unless you cover the switch with opaque tape. This is especially maddening when you discover that *Stellinapp* has a night (red-light) mode. Oh, the irony!

I had trouble maintaining my Wi-Fi connection to Stellina. When I asked the company about this, they suggested two possible reasons: Either I had wandered more than 10 meters (about 30 feet) from the telescope (I had not), or there might be another Wi-Fi signal interfering (there was). The problem went away when I turned off the wireless router in my observatory.

In addition to browsing Stellina's catalog by object type, you can choose to display all the targets in one long list. Well, not that long: I counted 127 — the Messier objects, a few bright NGC objects, and the Moon and planets. The target list is heavily weighted toward the Northern Hemisphere currently.

Worse, there's no way to add your own targets. Vaonis states it has no plans to add that capability, though it might invite users to suggest new objects to add during a software update. But if you want to shoot anything that isn't in the catalog — such as a bright new comet — you're out of luck.

Similarly, there is currently no way to manually change any of Stellina's settings. You can't tweak the focus, adjust the tracking rate, or change the way a target is framed, nor can you ask the computer to lighten up on the image processing. Vaonis says more manual control is in the works and should be implemented by the time you read this, though it may not provide as much control as an experienced amateur would like.

Final Thoughts

In its online FAQ, Vaonis writes, "Thanks to its ease of use, you could think that Stellina is for beginners, but you'd be making a serious mistake . . . it also meets all the needs of the advanced amateur astronomer." The ability to save FITS images is consistent with that latter statement, but except for the purpose of sharing astronomical experiences with the uninitiated, I don't think serious amateurs will find Stellina particularly satisfying.

▶ Stellina's power switch is illuminated by a ring of blue light that is so bright it makes dark adaptation impossible.

Is Stellina worth its hefty price? If you were to buy a high-quality 80-mm ED refractor and trick it out with all the gear that's built in to Stellina, you'd spend a good fraction of that amount. Yes, you'd have access to every interesting object in the sky, both visually and photographically, but you'd also have a lot of work ahead of you to get everything operating properly — and, as the saying goes, time is money.

There are two photos on Vaonis's website that give me pause. In one, a young couple sits outside on a deck, under a bright light, looking down at a tablet while Stellina sits a few yards away looking up at the sky. In the other, people huddle inside a closed and well-lit tent, presumably looking at their phone or tablet, while Stellina sits outside under a star-spangled sky. Is this the future of stargazing? In a world where so many people experience reality (or what they think is reality) through their handheld screens, and where the majesty of an unspoiled night sky continues to fade beyond reach for most of Earth's inhabitants, I guess I'll take it if the alternative is nobody paying attention to the universe at all.

■ **RICK FIENBERG** served as this magazine's Editor in Chief from 2001 to 2008 and is now Press Officer of the American Astronomical Society.

Art Gamble's "Final" Masterpiece

A veteran telescope builder achieves his own personal Nirvana.

▲ Art Gamble's latest telescope uses a fiberglass tube and lazy Susan bearings to achieve a masterpiece of form and function.

WHEN ART GAMBLE sent me a photo of his latest telescope, he wrote, "Please, please, know that I am not campaigning to have more of my gear featured in *S&T*. I feel pretty sure that your readers have seen more than enough of my low-tech, funny-looking telescopes." I wasn't even tempted to obey his wishes. This telescope was simply too amazing not to write about it.

Okay, it is indeed low-tech and funny-looking, but that's one of the things I love about it. That, and that it's a telescope-making tour de force. I asked Art the story behind this marvelous construction, and after giving his consent to present it here, he told me what I'm about to tell you.

First off, that beautiful wood-grain-looking tube and pier isn't wood at all. It's fiberglass. I kid you not. In fact, it was a reject from a local fiberglass tube manufacturer, probably because of the very color and texture that makes it so beautiful. And it's a perfect fit for the 1985 vintage Jaegers 6-inch f/5 achromat objective lens. Art chose not to paint it for two reasons: "First, it's so durable I don't have to worry about damaging a paint job every time I carry it in and out of the house. Second, I like the look of the fiberglass. So I sanded it smooth and left it like that. The color and pattern complement the wood used elsewhere on the scope."

I'd have wanted to show this scope to the world even if that was the only thing interesting about it, but there's hardly a thing here that's not. Take the diagonal and focuser, for instance. Most refractor builders put the focuser in front of the diagonal, but Art thinks outside the box, and inside the tube. Since there's no worry about image obstruction with a refractor, he simply put a 3-inch diagonal partway down the tube and stuck his focuser on the side. The result: a dramatically shorter telescope than if he'd done it the traditional way.

Then there's the altitude and azimuth bearings. One of the common problems with homemade mounts is that the mating surfaces are often so small that any play translates into unacceptable vibration at the eyepiece. Not a problem with 12-inch lazy Susan bearings! Many ATMs use them for azimuth bearings on Dobsonian scopes; Art reasoned that they would work just as well for altitude bearings, and they do.

Except for one problem: Lazy Susan bearings themselves are too smooth to allow for eyepiece changes. So Art installed a bolt and a wingnut in the center of the altitude bearing to let him adjust the tension.

You'd expect the scope to be a bit side-heavy with the tube offset like that and no counterweight, but Art solved that problem with simple over-engineering: long, beefy legs made of 2 × 6 pine.

While you're admiring this scope's legs, take a moment to admire the tracking mechanism. Yes, that's a strap hinge

▶ *Left:* Two 12-inch lazy Susan bearings provide smooth, rock-steady altitude and azimuth motions. Note also the mirror behind the Telrad — no leaning over necessary! *Right:* The base is made of solid 2 × 6 pine boards and features Art's signature "G-Tracker" tracking mechanism.

ART GAMBLE (4)

▲ The lazy Susan bearing surface is smooth aluminum with stainless steel rollers. No play or roughness here!

and a screw with a long, flexible shaft that lets you turn the screw while you observe. I wrote about that "G-Tracker" in my June 2018 column (p. 72).

Lastly, check out the finder. That's a standard Telrad, but with an Art Gamble twist: a bicycle rearview mirror suspended at a 45° angle in back of the glass window lets him look through the Telrad without bending down. Given how my back aches after a long night of leaning sideways to look in a finder, I think this may be the biggest stroke of genius on this whole project.

Overall, Art is very happy with this scope. In fact, he says, "I started grinding mirrors and building telescopes in the mid-'80s. This is mount number eleven. I feel sure this will be the last. Out of all the telescope mounts I've built, this is the only one that has truly exceeded my expectations. It's heavier and bulkier than I had planned, but it is silky smooth and rock solid. It's a joy to use. There is always compromise; I'm never 100% satisfied with my telescope optics or mounts, but I think I am as close as I'll ever get with this one. I'm stopping here."

I sense a James Bond "Never say never" moment here, but I do agree with Art in this: I think it's one of the neatest scopes I've seen in quite a while. And a fitting grand finale, if indeed it turns out to be that.

For more information, contact Art at **artgam1946@gmail.com**.

■ Contributing Editor **JERRY OLTION** has built a couple of fiberglass scopes, too, but none as beautiful as this.

◁ NEBULOSITY IN CYGNUS

Ron Brecher

Several large emission nebulae dominate this popular section of the constellation Cygnus, including NGC 7000, the North America Nebula (top left); IC 5067, the Pelican Nebula (right); IC 5068 (bottom right); and LBN 332 (bottom).

DETAILS: *Takahashi FSQ-106EDX4 astrograph with QHY367C CMOS camera. Total exposure: 14⅔ hours through an Optolong L-eNhance filter.*

△ BULLISH STELLAR NURSERY

Kfir Simon

Dark nebula Barnard 18 in Taurus is part of the much larger Taurus Molecular Cloud, a stellar nursery that conceals hundreds of newly formed stars. Several hot young suns with strong stellar winds are seen in the process of blowing away their embryonic cocoons at center right in an area designated LBN 812.

DETAILS: *Dream Aerospace Systems 16-inch f/3.75 astrograph with Apogee Alta U-16M CCD camera. Total exposure: 4 hours through LRGB filters.*

▷ LITTLE SILHOUETTE

Chirag Upreti

Slightly larger than Earth's Moon, Mercury appears minuscule passing in front of the featureless Sun during the transit on November 11, 2019.

DETAILS: *Sony α7R III Mirrorless camera with 200-to-600-mm zoom lens and 2× teleconverter. Total exposure: 1⁄250 second through a Thousand Oaks solar filter.*

▽ DOUBLE-BARRELED SPIRAL

Ian Gorenstein

The barred spiral galaxy NGC 266 in Pisces displays two distinct spiral arms containing surprisingly few star-forming regions.

DETAILS: *Celestron EdgeHD 14 Schmidt-Cassegrain telescope with Atik 460 EX CCD camera. Total exposure: 13.7 hours through LRGB filters.*

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BASELINE STARE

Les Allert

This dish of the Very Long Baseline Array near Big Pine, California, tracks its target to the east on the evening of November 29, 2019.

DETAILS: *Olympus OM-D E-M1 Mark II DSLR camera with Rokinon 10-mm lens. Total exposure: 30 minutes (120 × 15 seconds) at ISO 3200.*

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INSIDE This Issue

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

Product Locator

AD INDEX

Event Calendar

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

January 31 – February 1
EUROPEAN ASTROFEST
London, England
facebook.com/AstroFest

February 17–23
WINTER STAR PARTY
West Summerland Key, FL
scas.org/winterstarparty

February 21–22
DEATH VALLEY STAR PARTY
Furnace Creek Resort, CA
https://is.gd/lvasevents

March 7
TRIAD STARFEST
Jamestown, NC
observatory.gtcc.edu/tristar

April
GLOBAL ASTRONOMY MONTH
Everywhere!
https://is.gd/astronoborders

April 4–5
NORTHEAST ASTRONOMY FORUM
Suffern, NY
rocklandastronomy.com/neaf.html

April 15–21
INTERNATIONAL DARK SKY WEEK
Everywhere!
darksky.org/dark-sky-week-2020

April 22–25
MID-SOUTH STAR GAZE
French Camp, MS
rainwaterobservatory.org/events

April 23–26
SOUTHERN STAR
Little Switzerland, NC
https://is.gd/southernstarcon

April 24–26
MICHIANA STAR PARTY
Vandalia, MI
michiana-astro.org

May 2 (also September 26)
ASTRONOMY DAY
Events across North America
https://is.gd/AstronomyDay

May 17–24
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

June 5–7
RASC GENERAL ASSEMBLY
Coquitlam, BC, Canada
rasc.ca/ga2020

June 13–20
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCSP2020

June 17–21
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 18–21
CHERRY SPRINGS STAR PARTY
Coudersport, PA
cherrysprings.org

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

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Plane Amazing

Chances were slim that day in a Maryland park, but the wish of two young observers came true.

▲ Capturing an airliner crossing the face of the Sun, such as occurred when this jet passed high over Manhattan on April 13, 2016, is a true treat — especially when unplanned.

ALEXANDER KRIVENYSHEV

BALTIMORE'S SHERWOOD GARDENS is a secluded, six-acre park that each spring attracts many visitors to admire its colorful tulip beds and azalea bushes and to picnic on its well-tended lawns. It's also a magnet for landscape artists and photographers.

Sometimes, mainly when sunspots are present, I'll set up my 3-inch refractor in the middle of the park. I'll invite passersby to safely view the white screen on which the telescope projects an image of the Sun — the ultimate nourisher of all those gorgeous plants.

I originally bought my 3-inch in 1978 from University Optics for nighttime observing. When it arrived with a bracket and screen accessory for solar projection, I felt I'd been snookered into paying for something I'd never use. In 1981 I purchased a Meade 8-inch Schmidt-Cassegrain for nighttime use and, later, a Tuthill Solar Skreen filter for observing the Sun. My 3-inch went into the basement.

Eventually I began specializing in public telescoping, and it slowly dawned on me that for solar viewing by groups, especially in school venues, projection with my 3-inch would be a far superior way of sharing views of the Sun than having everyone peering individually through an eyepiece. So, using red stick-on letters along its tube, I christened my 3-inch SUNSCOPE and have now used it dozens of times for solar observing, including for sunspots, partial eclipses, and two transits of Venus.

One Sunday afternoon in Sherwood Gardens, two boys came over to my sunscope. Probably brothers, they looked to be about eight and ten years old. As they gazed at the Sun's round image on the screen, across it glided the silhouette of a high-flying bird. The sight excited them considerably, whereupon I said, "Sometimes an airplane flies in front of the Sun." Instantly, they decided to stay put until they saw an airplane fly across our star. I warned them that the chance of its happening was very slim, but they were determined.

Maybe 30 minutes had passed when one of the boys pointed eastward and shouted, "There's an airplane!" It was there alright, the tiniest speck just above the distant treeline. I once again warned of the improbability of its passing in front of the Sun and then joined them in watchful waiting. Gradually, the plane grew closer and larger and at least seemed to be coming in our general direction.

A few moments later I realized, if nothing else, this was going to be a close call! I instructed the boys, "Don't take your eyes off the screen. I'll watch the airplane." Seconds later the nearly unimaginable happened: A giant jetliner shot across the Sun's projected image, leaving in its wake a silhouetted trail of dark, writhing engine exhaust.

The brothers never looked back. They darted off to tell their parents of the incredible sight they'd just witnessed. I last glimpsed them standing beside two adults, excitedly gesturing in my direction.

While it's been at least five years since the incident, I'm sure the brothers haven't forgotten their elation at seeing an airplane fly over the Sun — I certainly haven't. Indeed, I've had the pleasure of retelling the story when I'm out with my sunscope and, as sometimes happens, a pedestrian is surprised by seeing a bird, plane, or even a child's escaped balloon pass across the Sun's image on my screen.

■ **HERMAN HEYN** recently retired from street-corner astronomy in Baltimore, Maryland, after 31 years.