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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

SEPTEMBER 2021

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the Celestial Swan

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THE ESSENTIAL GUIDE TO ASTRONOMY

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NASA / JPL / USGS

ON THE COVER

Hubble image of the Witch's Broom portion of the Veil Nebula

CREDIT: NASA / ESA / HUBBLE HERITAGE TEAM

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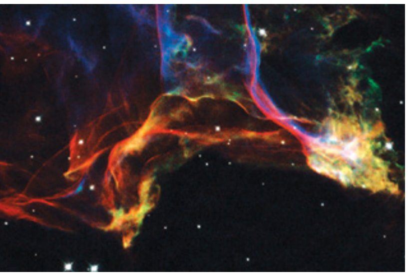
Behind the Veil

FOR SOMETHING THAT'S ESSENTIALLY NOTHING, the Veil Nebula has a bit of everything. This wispy expanse of gas and dust in Cygnus satisfies astronomers on so many levels that many bend over backward in their praise. Veteran observer (and *S&T* Contributing Editor) Steve Gottlieb has deemed it, for those with dark skies and the right equipment, "arguably the most spectacular telescopic object in the northern sky." Bob King, our Celestial Calendar author, has said the Veil "rightly elicits nearly as many wows as Saturn or your favorite globular cluster."

Why? For starters, it's breathtakingly beautiful, as our cover image shows. That's just one tiny portion of the Veil Nebula, or the Cygnus Loop as it's also known. To revel in the whole shebang, have a look at Howard Banich's article on page 28. As you'll quickly realize flipping through his piece, the Veil offers myriad sketching opportunities in the hands of a talented artist.



▲ Hubble image of filamentous structure within the Veil Nebula

NASA / ESA / HUBBLE HERITAGE TEAM (STSCI / AURA) / ESA / HUBBLE COLLABORATION / J. HESTER, ARIZONA STATE UNIVERSITY

For those like Banich who have access to ink-dark skies and big scopes, the Veil provides truly exquisite richness of detail. One can explore its intricacies as limitlessly as one might pore over, say, a high-resolution satellite image of Earth. Some of the Veil's ropelike strands even furnish a 3D effect. Yet you don't need a 28-inch telescope like Banich's. The Veil is visible in small scopes and even binoculars (see page 38).

To fully indulge in the Veil's labyrinthine subtleties, we can turn to superb images that astronomers have taken with the Hubble Space Telescope and other observatory instruments. Captured at different wavelengths — ultraviolet, infrared, and X-ray, among others — such pictures hint at the physical processes sculpting this profoundly complex object.

The science behind the Veil is as mind-altering as its beauty. What we see are the glowing results of shock waves from a supernova slamming into interstellar dust and gas. When the progenitor star exploded perhaps 20,000 years ago, alert Ice Age humans would have noticed a new star brighter than Venus overhead. Since then, the speeding remnants have expanded so far that a photon unleashed on one side of the Veil today would take 120 years to reach the other.

That ever-ballooning immensity, visible in its entirety through a wide-field telescope eyepiece, reminds us of our own origins. As Carl Sagan so memorably assured us, "We are made of star-stuff." We wouldn't be here if it weren't for collapsing stars seeding the cosmos with the elements that comprise us and everything else of substance.

"No wonder we all love this object," Banich concludes. Next time you visit a dark-sky site, lift the veil for yourself.

Editor in Chief

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Subscription Rates:
U.S. and possessions: $54.95 per year (12 issues)
Canada: $69.95 (including GST)
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▲ NGC 4618 in Canes Venatici is a barred spiral galaxy with only one arm. It's close enough to its neighbor NGC 4625 that the two galaxies influence each other.

Galaxy Hopping

I am an avid deep-sky observer with a 14½-inch (368-mm) Dobsonian and a pretty good rural observing site near Georgian Bay in Ontario. I read Scott Harrington's "Star-forming Regions in Faraway Galaxies" (*S&T:* May 2021, p. 22). Using the photos on page 25 and his description of NGC 4618, I easily found it and NGC 4625. Following his comments, I carefully looked between the nucleus of NGC 4618 and the 11th-magnitude star below it and traced the southern arm of the galaxy. I easily made out the nebulous enhancement, IC 3668, at the bottom of the galaxy. The high-quality observing articles in *Sky & Telescope* and excellent writers like Harrington have encouraged me to subscribe to the magazine for years. I look forward to every new issue.

Chris Malicki • Mississauga, Ontario

Conjunction Blues

Reading David Grinspoon's much needed and appreciated "The Cosmic Conjunction" (*S&T:* May 2021, p. 13) was bittersweet for me.

After all that 2020 dished out, at least I could look forward to the end-of-the-year applause. However, last December found me temporarily stuck inside a glacial valley in the Patagonian Andes. I may have been the only astronomer in the world for whom it was geographically impossible to see the event!

Thomas Hockey
Cedar Falls, Iowa

A Light Controversy

I enjoyed reading about the meritorious life of the 17th-century French-Italian astronomer Giovanni Domenico Cassini (*S&T:* May 2021, p. 58).

Astronomy historians have long disagreed about whether Giovanni Cassini or Ole Rømer was the first to discover the irregularity in the predicted timings of the eclipses of the Jovian moon Io and interpret that the cause was light traveling at a finite speed.

In my paper, "Paris 1676: The Discovery of the Velocity of Light and the Roles of Rømer and Cassini" (**https://is.gd/Velocity_of_Light**), published in the *Journal for the History of Astronomy*, I point out that Rømer was likely the first to discover the irregularity. He was also the first to interpret that light traveling at a finite speed was the cause of this discrepancy.

Both astronomers said that Rømer was the one who made the discovery. But the first mention of it is in a communication from August 1676, in which Cassini warned about the quality of the eclipse predictions he published just a few days earlier.

Cassini must have learned about Rømer's discovery in the intervening days, but this communication contained a couple of misunderstandings. When Cassini realized that Rømer only saw the irregularity in one of the moons and not the others, he rejected the speed-of-light hypothesis and continued to do so even as Rømer produced additional evidence.

Claus Fabricius
Barcelona, Spain

The Comet and the Rocket

In his 75, 50 & 25 Years Ago column, Roger Sinnott's remembrances from 1996 in "Spring Comet" (*S&T:* June 2021, p. 7) mention Bjørn Granslo's comparison of the brightness of Comet Hyakutake (C/1996 B2) to that of Arcturus on March 22nd. This reminded me of a photo that I took at nearly the same time.

I was in Titusville, Florida, to see the launch of NASA's Space Shuttle *Atlantis*, which occurred shortly after 3:00 a.m. on the morning of March 22, 1996. I arrived at my chosen viewing site early the previous evening. While waiting for the launch, I was able to do some binocular viewing of the comet despite the heavy light pollution.

The image below shows the brilliantly lit launch pad about four hours before liftoff. Arcturus is at the top of the image, and the fuzzy bluish head

▲ Comet Hyakutake (C/1996 B2) soars above the bright lights of the launch site of NASA's Space Shuttle *Atlantis*.

NGC 4618: ESA / HUBBLE / NASA / IGOR KARACHENTSEV; HYAKUTAKE: THOMAS FABER of Comet Hyakutake is below it. Both managed to shine through the skyglow!

Later, the light pollution increased dramatically as *Atlantis* leapt off its launch pad heading for Russia's Mir space station.

Thomas Faber
Alpharetta, Georgia

Professor of the Stars

What a delight to open my June issue of *Sky & Telescope* and find a letter from the inimitable Virginia Trimble!

I recall with pleasure the many articles she has written for this magazine. It only took reading the first paragraph, sometimes only the first sentence, to recognize the article as one only she could have written.

Many years ago, I attended a three-day course on the most recent discoveries in cosmology that was taught by Virginia Trimble. She remains one of the four or five best teachers I have ever had. She was crystal clear, informative, funny, smart, and a bit feisty just like her letter. It made my day.

Neal Sumerlin
Lynchburg, Virginia

Eclipse Watcher

Having been a reader and subscriber of *Sky & Telescope* for 54 years, I often think about the best of both the greatest articles and the most spectacular images. This publication provides the most detailed exploration of our world and our universe.

My favorite image of all time has been the photograph of the galaxy cluster MACS J0717.5+3745 from the Hubble Space Telescope's Frontier Fields project **https://is.gd/MACSJ0717**. With the arrival of the June 2021 issue, the image of MACS J0717.5+3745 slid into second place.

My all-time favorite image is now that issue's cover photo of an annular-eclipse watcher by Colleen Pinski!

Thank you for the greatest exploration life can provide.

Kreig McBride
Bellingham, Washington

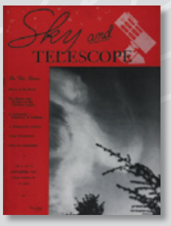
FOR THE RECORD

- The open cluster in the image at the top left of page 32 of the July 2021 issue of *Sky & Telescope* is NGC 436.
- The second column of the table on page 61 of "Halley's Comet: A Look Back and Ahead" (*S&T:* July 2021, p. 58) lists the distance between the comet and Earth in astronomical units.

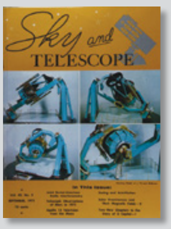
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Suite 300B, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1946



1971



1996

◖ September 1946

Lunar Aurorae "Professor Mohd. A. R. Khan, of Hyderabad, India, has [proposed] a decisive test on whether or not the moon has any atmosphere. '*If* there be any appreciable atmosphere on the moon, on account of its very tenuity it would give rise to auroral phenomena over that portion of the lunar surface that is lighted up by earthshine.' Of course, he grants it would be asking too much actually to observe auroral streamers and other such displays. He suggests, however, that a study of the spectrum of earthshine on the moon might reveal the presence of the stronger of the forbidden lines of oxygen and nitrogen characteristic of auroras."

In 1959, measurements made by the Soviet Luna 1 spacecraft showed that the Moon lacks a global magnetic field, a prerequisite for the spectacular auroral displays that take place on Earth and the gas-giant planets. Jupiter's Ganymede is the only moon where aurorae have been detected.

◖ September 1971

Supernova Match "The radio source 3C-58 in Cassiopeia is widely regarded by astronomers as a supernova remnant. [In several respects] it closely resembles the Crab nebula in Taurus . . . An English astronomer, F. R. Stephenson of the University of Newcastle upon Tyne, now proposes that 3C-58 is probably the remnant of a widely observed supernova in August, 1181. . . .

"In the Chinese records, the guest star of 1181 is said to have 'invaded' the asterism *Ch'uan-she*, a small group of 5th-magnitude stars including 10 Cassiopeiae. Dr. Stephenson points out that 'invaded' was a Chinese technical term meaning to be within about one degree of a star. . . .

"[C]oncludes the Newcastle astronomer, 'the absence of any other supernova remnant which could be associated with the guest star of 1181 makes the identification of 3C-58 as its remnant very convincing.'"

◖ September 1996

Biggest Blasts "Despite two decades of observation and study, gamma-ray bursts (GRBs) remain one of the deepest astronomical mysteries. These brief blasts of high-energy photons are seen about once a day by a handful of specially equipped spacecraft. Bursts have yet to be convincingly matched up with any object known to inhabit the cosmos. . . .

"For many investigators the Holy Grail of this tantalizing field is to catch a recognizable astronomical entity flaring up at the same time and place as a gamma-ray burst."

The picture sharpened, just a little, within a year after this overview article by Joshua Roth. Since 1997, large telescopes have occasionally recorded optical "afterglows" lasting a few days at some GRB sites. Their positions and redshifts clearly put them in remote galaxies — and given their stupendous energy, we can be thankful for that.

◀ The CHIME radio telescope consists of four massive cylindrical radio antennas roughly the size and shape of snowboarding half-pipes.

FAST RADIO BURSTS

Number of Fleeting Radio Bursts Triples

THE POWERFUL FLASHES of fast radio bursts (FRBs) are so fleeting, they're hard to find. Astronomers had detected only about 140 of them since 2007. But the first data release from the Canadian Hydrogen Intensity Mapping Experiment (CHIME), presented June 9th at the virtual meeting of the American Astronomical Society, more than tripled that number with 535 FRBs, including 61 bursts from 18 previously reported repeating sources.

After CHIME scans the whole sky visible from its location in British Columbia every night, astronomers use digital signal-processing to "focus" on individual signals. Yet the telescope only sees the tip of the iceberg: Based on the first year of data, collected between 2018 and 2019, the CHIME/FRB Collaboration calculates that some 800 bright bursts occur every day.

The radio flashes CHIME does see are spread out on the sky, which means that, as astronomers had already suspected, the sources of these mysterious flashes aren't concentrated in the Milky Way. But that spread isn't completely uniform. The team finds that FRBs correlate with galaxies between 3½ billion and 5 billion light-years away.

◀ An artist's depiction shows a hiccup in a magnetar's strong magnetic field.

Astronomers know at least some FRBs originate from the burnt-out stellar cinders known as *magnetars* (*S&T:* Sept. 2020, p. 10). These neutron stars generate strong magnetic fields that release energy when they tangle or snap. But astronomers don't yet understand exactly what makes FRBs, or why some sources repeat and others don't.

The CHIME data show that repeating bursts last slightly longer and emit more focused radio frequencies than single bursts. That could mean they're two distinct populations. Or, as CHIME/FRB team member Ziggy Pleunis (McGill University) suggests, they could represent two extremes of a spectrum. For example, if narrow bursts are rarer, then the narrowest bursts would appear to be one-off events.

The CHIME team is excited not only about the sources themselves but what can be done with them. "We are now in the era of using FRBs as cosmological probes," says team member Alex Josephy (also at McGill).

"The distortion of each signal carries a record of the structure it traveled through," explains Kiyoshi Masui (MIT). Ultimately, astronomers will be able to map out gas across the universe, showing the evolution of large-scale cosmic structures.

■ **MONICA YOUNG**

EXOPLANETS

Astronomers Challenge Barnard's Star Planet Claim

IN 2018, A TEAM OF ASTRONOMERS discovered a super-Earth about 6 light-years away, hidden in the meager light of its red sun, Barnard's star. Now, a new study to appear in the *Astronomical Journal* challenges that claim.

In the original study, Ignasi Ribas (Institute of Space Sciences, Spain) and colleagues analyzed two decades of radial velocity measurements, which showed the star's slight motions toward and away from us. Within those data, Ribas and colleagues saw the repeated signal of a planet's gravitational back-and-forth pull as it circled its star every 233 days (*S&T:* Mar. 2019, p. 9).

But in a new analysis, which includes observations from the recently minted Habitable-zone Planet Finder on the Hobby-Eberly Telescope in Texas, graduate student Jack Lubin (University of California, Irvine) and colleagues concluded that stellar activity might have masqueraded as a planetary signal.

The researchers analyzed 856 days' worth of data from the HPF spectrograph, but they didn't find the planet's signal. They also re-analyzed the data Ribas's team had published and showed that the signal had strengthened and weakened over time — something a planet's signal wouldn't do.

In fact, the researchers found that almost all of the signal was in 211 data points collected between 2011 to 2013. During this same time period, Lubin says, his team also found a chemical signature associated with stellar activity that also varied on a 233-day period.

CHIME RADIO TELESCOPE: ANDRE RENARD (UNIVERSITY OF TORONTO); CHIME COLLABORATION; MAGNETAR FLARE: NASA'S GODDARD SPACE FLIGHT CENTER / CHRIS SMITH / USRA / GESTAR

FAST RADIO BURSTS

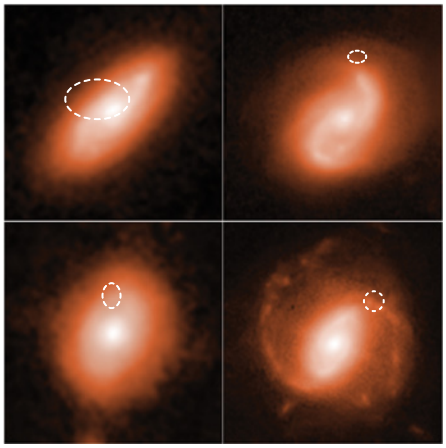
Radio Flashes Tied to Spiral Arms

NEW HUBBLE SPACE TELESCOPE observations have traced five enigmatic fast radio bursts (FRBs) to the arms of spiral galaxies, narrowing down the possible explanations for their sources. The study, led by Alexandra Mannings (University of California, Santa Cruz), will appear in the *Astrophysical Journal*.

While scientists have detected hundreds of FRBs (including those just announced by the CHIME/FRB Collaboration), they have only traced about 15 of them to specific sources. Some of these are repeating sources, which makes it easier to localize the brief radio flashes within their host galaxies. But single bursts are harder to pin down.

The Australian Square Kilometre Array Pathfinder (ASKAP) makes this job a little easier, by pinpointing FRBs' locations as they are detected. When an event triggers an automated pipeline, the receivers save all of the event's information, which then allows astronomers to pinpoint its exact location. Using Hubble, Mannings' team followed up on six FRBs that ASKAP had detected and localized, as well as two repeating sources seen by other radio telescopes.

In five of the eight cases, the flashes came from the host galaxy's spiral arms. That means they are probably not caused by neutron star mergers, which typically involve older stars residing outside the arms. But the sources are also not in the arms' brightest regions, where the most intense star formation occurs. Mannings and colleagues therefore ruled out supernovae of the most massive stars. The team suggests that highly magnetized neutron stars, known as *magnetars*, or core-collapse supernovae of more average-size stars, both of which would occur within the fainter regions of spiral arms, would be more likely sources of FRBs.



▲ Astronomers used the Hubble Space Telescope to trace fast radio burst sources (dashed ovals) to the spiral arms of galaxies.

Shami Chatterjee (Cornell University), who was not involved with the study, calls the results "a big step forward." But he adds, "many more such detections are needed before we have a definitive picture."

■ JULIE FREYDLIN

IN BRIEF

Orion Purchases Meade

Optronic Technologies, Inc., better known to backyard astronomers as Orion Telescopes & Binoculars, has announced the acquisition of Meade Instruments following approval in bankruptcy court. Peter Moreo, president of Orion (and now president of Meade), stated, "I am honored to have the opportunity to work with Meade employees, customers, and suppliers as the next phase of Meade's corporate journey begins." For more than four decades, Meade Instruments has been one of the world's largest designers and manufacturers of telescopes and accessories for amateur astronomers. In 2019, Orion Telescopes & Binoculars sued Meade, then a subsidiary of Chinese manufacturer Ningbo Sunny Electronic Co. Ltd, in an antitrust lawsuit that included several other manufacturers. The lawsuit found that Sunny had colluded with other Chinese manufacturers in a price-fixing scheme that formed a monopoly over the domestic consumer telescope market. In December 2019, Meade filed for Chapter 11 bankruptcy protection (*S&T:* Apr. 2020, p. 11). Moreo announced the formation of a new Orion subsidiary, Meade Acquisition Corp., that has acquired all relevant trademarks. He plans to continue the development, manufacturing, and distribution of products under the Meade brand. Meade Instruments will continue to honor its product warranties and, in conjunction with authorized dealers and distributors, will make reasonable efforts to provide customer support, repair services, and parts for their products that are not covered by warranty.

■ SEAN WALKER

Starspots might last for hundreds to thousands of days on Barnard's star. Combined with irregular observations from the ground, plus Earth's own motion around the Sun, such temporary stellar activity could have mimicked the planetary signal, the team suggests.

For now, Ribas stands by his team's detection, arguing that researchers must combine archival data carefully to avoid introducing or removing signals. Multiple groups are collecting additional data in current and near-future campaigns to help settle the debate.

■ MONICA YOUNG

An artist imagines the surface of a hypothetical super-Earth around a dim red sun; however, such a planet may not exist around Barnard's star.

FRB LOCATIONS: NASA / ESA / ALEXANDRA MANNINGS (UC SANTA CRUZ) AND WEN-FAI FONG (NORTHWESTERN); IMAGE PROCESSING: ALYSSA PAGAN (STSCI); BARNARD'S STAR'S PLANET: ESO / M. KORNMESSER

COSMOLOGY

Dark Energy Survey Catalogs Millions of Galaxies

▲ Distant galaxies teem in this deep image taken by the Dark Energy Camera.

ASTRONOMERS HAVE CAPTURED 226 million galaxies up to 7 billion light-years away in an area covering about one-eighth of the entire sky. This treasure trove of data provides the best-ever probe of cosmic evolution and illuminates the role of dark matter and dark energy in shaping the large-scale structure of the universe.

The Dark Energy Survey (DES) started back in August 2013. On May 27th, the international collaboration behind the survey posted 30 scientific studies covering the first three years of observations. These papers will appear in the *Monthly Notices of the Royal Astronomical Society.* (Although the Dark Energy Survey was completed in early 2019, the collaboration is still processing the last three years of data.)

To map out large-scale structure, DES scientists start with individual galaxies. Based on a galaxy's brightness at several visible and near-infrared wavelength bands, the team determines its *photometric redshift*, which yields a rough but reliable distance estimate. Using this technique, astronomers can discern the evolution of galaxy clustering and reveal the actions of dark matter and dark energy over cosmic time. Estimates of *cosmic shear* — distortions due to weak gravitational lensing — provide additional information about the distribution of dark matter.

The results support the dark matter–dark energy scenario, in which dark energy and slow-moving dark matter particles vastly overshadow the remaining 5% of "normal" matter that exists in galaxies, stars, planets, and people.

There's one nagging discrepancy: Like previous surveys, DES has found that the current universe is a few percent less "clumpy" than the standard cosmological model would predict. Nobody knows why.

Another galaxy survey officially took off a few weeks ago at the Nicholas U. Mayall 4-meter Telescope at Kitt Peak National Observatory in Arizona. The similarly named Dark Energy Spectroscopic Instrument aims to capture spectra (rather than images) of tens of millions of galaxies and quasars over the next five years. The European Space Agency's Euclid mission, slated for launch in 2022, will carry out an even more sensitive survey with similar cosmological goals.

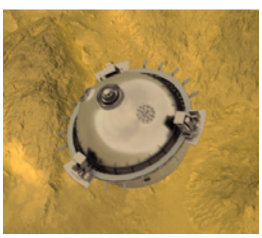
■ GOVERT SCHILLING

SOLAR SYSTEM

Three Missions to Head for Venus in Next Decade

NASA ANNOUNCED on June 2nd that it had selected two missions to launch for Venus in the 2028–2030 timeframe as part of the agency's Discovery Program: the Deep Atmosphere Venus Investigation of Noble gases, Chemistry and Imaging (DAVINCI+) and Venus Emissivity, Radio Science, InSAR, Topography, and Spectroscopy (VERITAS). These spacecraft mark NASA's first return to our sister planet since the Magellan mission, which ended in 1994. A week later, the European Space Agency announced it will also send its EnVision orbiter to Venus in the early 2030s.

All three missions will look at Venus's present conditions for clues to its past, to see if the planet might once have hosted a more habitable environment. DAVINCI+ will deploy a descent sphere that will sample gases and weather conditions during a 63-minute drop through the Venusian atmosphere. An orbiter will relay these data to Earth while also sticking around to obtain high-resolution ultraviolet and near-infrared measurements. These images will zero in on *tesserae*, Venus's most ancient terrain, while also shedding light on the planet's mysterious "ultraviolet absorber" that swallows up to half of the incoming solar energy Venus receives.



◀ An artist's concept shows DAVINCI+ approaching the surface of Venus.

VERITAS will construct a complete topographical map of the planet's surface in an effort to trace the history of the planet's plate tectonics. Meanwhile, EnVision will map Venus's gravitational field to probe its internal structure. Both VERITAS and EnVision will also be looking for signs in the atmosphere and on the surface to determine whether Venus is still volcanically active.

■ DAVID DICKINSON

DARK ENERGY SURVEY / DOE / FNAL / DECAM / CTIO / NOIRLAB / NSF / AURA; ACKNOWLEDGMENTS: T.A. RECTOR / M. ZAMANI / D. DE MARTIN; DAVINCI+: NASA / GSFC

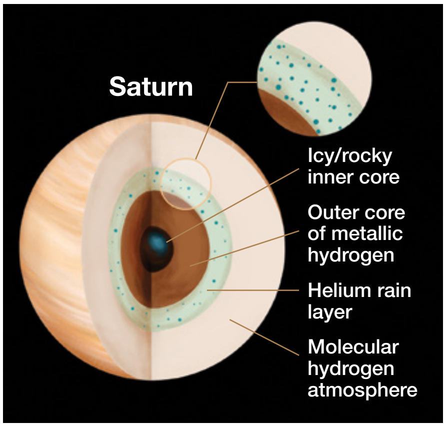
SOLAR SYSTEM

Helium Rain Might Shape Saturn's Magnetic Field

SATURN'S MAGNETIC FIELD aligns almost exactly with its spin, a unique quality that astronomers propose comes from a thick layer of helium "rain" within the planet. The new model appears in the June *AGU Advances*.

Saturn's magnetic field, like Earth's, probably comes from its convecting outer core. However, while Earth (as well as Jupiter, Uranus, and Neptune) spins on an axis tilted relative to its magnetic field, Saturn's rotation and magnetic axes are within 0.007° of each other. This unexpected alignment indicates something's amiss with our understanding of the planet's interior.

Chi Yan and Sabine Stanley (both at Johns Hopkins University) approached the problem the other way around, simulating aspects of Saturn's interior to calculate the magnetic field they produce. Information from the Cassini spacecraft's final passes, when the spacecraft came closest to Saturn's poles and made detailed measurements of the planet's magnetic field, helped narrow the range of conditions possible within the planet.



▲ This diagram shows Saturn's interior, including a thick layer of "helium rain," where helium blobs slowly settle against the core.

Astronomers think a convective outer core of metallic hydrogen and dissolved helium surrounds Saturn's inner core of rock and ice. The outer core produces the planet's dynamo. To keep this dynamo's magnetic field aligned with the planet's spin, Yan and Stanley's simulation incorporates a thick additional layer of helium rain. The pressure in this layer is lower than in the core but still roughly a million times Earth's atmospheric pressure at sea level. Here, helium does not dissolve into the dominant hydrogen but instead forms blobs that "rain" down and settle around the outer core.

The helium rain layer thus confines the core's magnetic dynamo in a way that, combined with heat flow within the layer, helps align the magnetic field to the spin axis. The helium layer may extend from the core to 70% of the way to the surface, Yan and Stanley say.

However, Stanley cautions that their model doesn't rule out other ways to explain Saturn's magnetic field. She adds, "We would love it if other people could find other solutions."

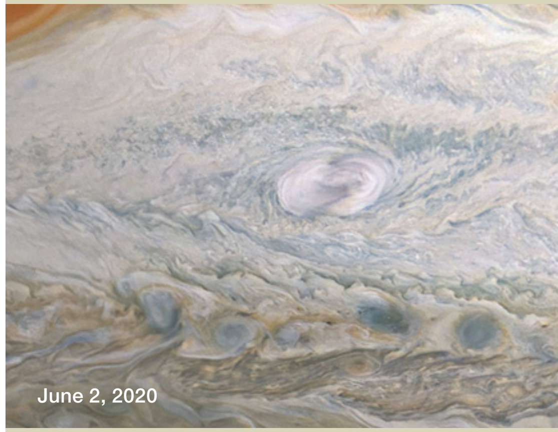
■ JEFF HECHT

IN BRIEF

OSIRIS-REX Heads Home

After nearly five years on mission, including more than two years spent exploring the 500-meter (1,600-foot) asteroid 101955 Bennu, NASA's Origins, Spectral Interpretation, Resource Identification, Security, Regolith Explorer (OSIRIS-REX) is coming home. The spacecraft fired its thrusters for 7 minutes on May 10th to set it moving 1,000 kilometers per hour (600 mph) relative to the asteroid, starting its 2½-year journey to Earth. OSIRIS-REX will orbit the Sun twice inside Venus's orbit before flying by Earth on September 24, 2023. On that date, the sample return capsule will separate from the spacecraft for a parachute reentry over the Utah Test and Training Range in the state's West Desert. If everything goes as planned, lots of fuel should remain post-flyby, so it's not out of the question that the spacecraft might head toward a second target.

■ DAVID DICKINSON



Clyde's Spot Unravels

Clyde's Spot, a distinctive white spot on Jupiter southeast of the Great Red Spot, received its nickname in honor of amateur astronomer Clyde Foster of Centurion, South Africa. He discovered it using his 14-inch Schmidt-Cassegrain telescope on May 31, 2020, two days before NASA's Juno mission was able to swing by for a closer look. The initial white spot was a plume of methane-poor cloud material erupting above the top layers of the Jovian atmosphere. Later, the white spot faded and left behind a darker spot still visible in amateur scopes. Now, a new image from Juno taken on April 15, 2021, shows that winds have stretched and pleated the spot into a *folded filamentary region*. Many atmospheric features are short-lived, disappearing quickly into the cloud decks, but due to its size this one might stick around for a while.

■ MONICA YOUNG

SATURN'S INTERIOR: YI ZHENG (HEMI / MICA EXTREME ARTS PROGRAM) / JOHNS HOPKINS UNIVERSITY; BEFORE/AFTER STORM ON JUPITER: NASA / JPL-CALTECH / SWRI / MSSS; IMAGE PROCESSING BY KEVIN M. GILL © CC BY

The Prime of Their Lives

The strange cycles of cicadas offer timely insight into the search for ET.

Brood X cicadas can not only *look* like aliens but can inform our search for their intelligent constituents.

AS I WRITE THIS, hordes of bug-eyed monsters are invading our nation's capital. Vast numbers of Brood X cicadas are swarming the trees and filling the air with their pulsing songs. So naturally I'm thinking about aliens.

As far as we can tell, life arose on Earth due to conditions that ought to exist on myriad planets, and it evolved into complexity and cognition through evolutionary processes that should also be universal. Many of us feel we're not likely to be alone in this universe.

Yet we would love to confirm this hunch with solid evidence. How will we recognize the hallmarks of intelligence in signals or artifacts? It's not enough to look for regular geometrical forms or repeating patterns. We know nature can make those in abundance — no minds needed. What kind of pattern would be an unmistakable sign of intelligence?

One popular idea is that an extraterrestrial intelligence could well construct a message using prime numbers, which are divisible only by themselves and by 1. There's no simple, formulaic way to generate primes, and it's often said that no natural process produces them. It has become canonical in the SETI field that investigators should seek prime numbers when searching for artificial signals. Astronomer Frank Drake constructed the famous Arecibo message, broadcast in 1974, in a sequence containing 1,679 bits, which any numerate alien would see is the product of two primes and thus begs to be displayed as a 73-by-23-bit image.

In Carl Sagan's novel *Contact*, astronomers deduce that a radio signal coming from near the star Vega is a message from an extraterrestrial intelligence because it contains a repeating sequence of primes. In the book, astronomer Ellie Arroway explains that "prime numbers are very specific, very artificial." Sequences of primes don't come from naturally occurring processes, she says.

Which brings us back to the cicadas. They favor prime numbers. Some species come up every year, but Brood X and the other periodical cicadas spend long intervals buried underground as nymphs sucking on tree roots. After 17 years for Brood X and several others, and 13 years for some other broods, they all suddenly crawl to the surface for a few weeks of sex and song. Their synchronous appearance is part of a survival strategy — with so many appearing all at once, enough will avoid being eaten and mate successfully.

But why the primes? The most promising hypothesis is that these intervals help the cicadas evade predators whose life cycles peak at smaller intervals. Primes have no small number factors, so no critters following two- or three- or five-year patterns will consistently overlap with these longer-term cicada broods. By evolving prime number cycles, these bugs avoid cultivating predators that can consistently lie in wait for them.

So much for the idea that primes must always be the hallmarks of a math-savvy civilization. They may be unlikely to arise from physics or chemistry, but they can evolve biologically.

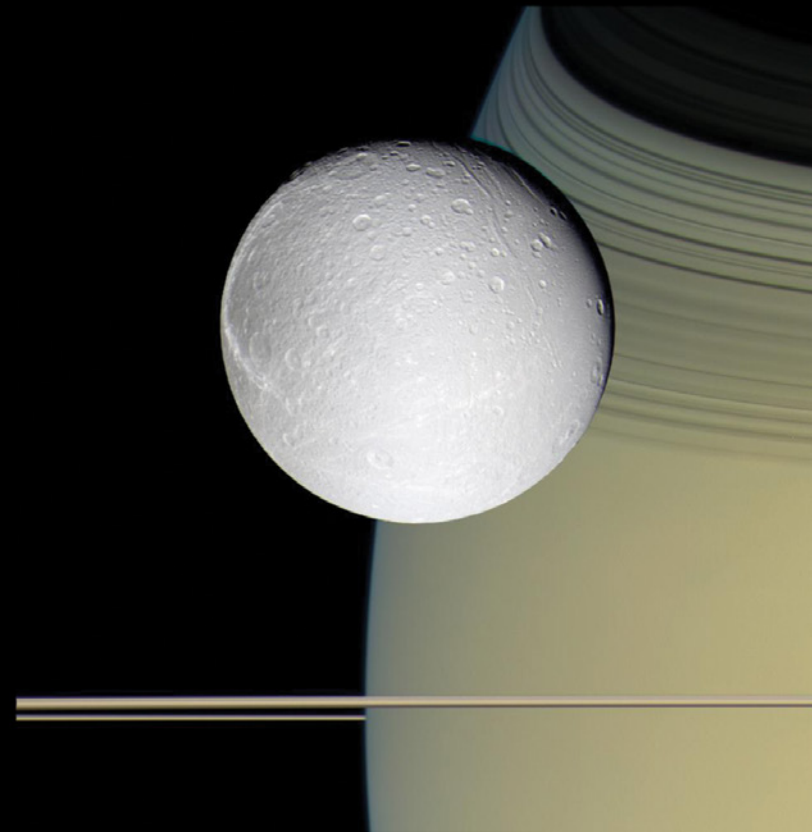
My point isn't that if we think we see a message with alien primes it could just be a brood of ET insects that have somehow commandeered a radio telescope. It's simply that everything we think we can surmise about technosignatures is still a web of educated guesses, and that "we'll know it when we see it" — however vague and unsatisfying — is still the best principle for recognizing that we've got company.

■ Contributing Editor **DAVID GRINSPOON** is an astrobiologist at the Planetary Science Institute (**psi.edu**).

CHIP SOMODEVILLA / GETTY IMAGES

 by Monica Young

How Old Are Saturn's Moons?



A deceptively simple question has caused planetary scientists to rethink some basic physics.

The Saturn system is beautiful, and beautifully weird. The magnificent rings inspire an "Oh wow!" when seen through even small telescopes, in part because they're so unexpected, almost as if the planet had sprouted ears. Every giant planet in the solar system has rings of some sort, but only Saturn's are so vast and so brilliant, composed almost solely of highly reflective water ice.

But the rings aren't the only unusual thing about this planet. The diversity of its extended family of satellites is unique among Saturn's giant brethren. Unlike Jupiter, with its four heavyweight moons and scores of small ones, Saturn has a third kind of companion: midsize moons, with diameters of 300 to 1,500 km (200 to 1,000 miles), or a tenth to almost half the span of our Moon.

Tucked between the lone heavyweight, Titan, and moonlets like ravioli-shaped Pan and Atlas, the midsize moons are varied mixes of rock and ice. Tethys, for example, is almost entirely made of ice — it would float if you could find a glass of water big enough. Meanwhile, Enceladus, although famous for its subsurface ocean, is more than half rock.

The riddles these moons pose promise insights into solar system history, if only scientists can solve them. While many of the gas giants' major moons probably formed in mini-solar systems around their planets billions of years ago, the midsize moons might have formed more recently, born from Saturn's rings. But attempting to answer the simple question

▲ **MIDSIZE MOON** This view from NASA's Cassini juxtaposes icy Dione against the golden hues of Saturn in the distance. The horizontal stripes at the bottom are the rings; sunlight casts their shadows on the planet.

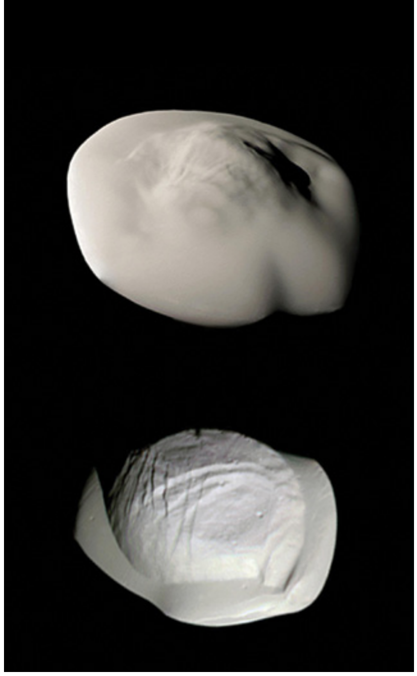
"how old are they?" has led to a metaphorical tug-of-war among both observers and theorists. Amidst the back-and-forth, astronomers have realized they need to completely rethink some basic physics in the Saturn system.

What's New?

Most things in the solar system are ancient: 4.57 billion years old, give or take a few million. So it's unsurprising that astronomers thought the same of the Saturn system. But since the Voyagers passed by the giant planet in 1980 and 1981, astronomers have been debating that view. Measurements of the rings suggested they might actually be quite young, the recent remnants of a collision between moons or between a moon and some other trespassing object.

Two pieces of evidence support the notion of young rings. First, measurements by both the Voyagers and later by the Cassini spacecraft revealed that for all their vast expanse — the E ring spans almost 10 times Saturn's diameter — the rings are lean: They contain less than half the mass of Mimas, the smallest of the midsize moons. And the less massive the rings, the theory goes, the younger they must be, because the rings are slowly disappearing. Interactions

NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE



◀ **RAVIOLI MOONS** Atlas (above) and Pan (below) are two of the smaller moons. The ridges around their equators are made of particles they sweep up as they orbit within Saturn's rings.

between ring particles cause the rings to spread out over time. Any material that expands far enough from Saturn, past the so-called *Roche limit*, can clump up into moons. Meanwhile, the rings' inner edges are constantly losing material to Saturn's gravity; the Voyagers and Cassini even observed this *ring rain* as it fell.

Second, the rings are extremely reflective, made of 90–95% water ice. "They look like fresh snow," says Luke Dones (Southwest Research Institute). And just as snow dirties within a day in a city, thanks to the carbon-enriched smoke from cars and trucks, interplanetary meteoroids should darken the rings over time. Jupiter, Uranus, and Neptune have darker rings for this reason, yet Saturn's rings are still bright.

Since less massive rings would darken more quickly, some scientists have suggested that they must be quite young — less than 100 million years old. That's recent enough that the Triceratops and other dinosaurs of the Cretaceous Period would have been roaming Earth when the rings form. Yet the precipitating event — a moon-size collision — would have been so rare that many scientists remain uneasy with the idea of young rings. Even those in favor of a past collision acknowledge this, such as John Dubinsky (then at University of Toronto), who qualified such an event in a 2019 study as "perhaps unlikely, but not wildly so."

There's also a more general sense of discomfort with the young-ring scenario. Despite the circumstantial evidence, Dones counters, "there's no direct evidence that the rings are young." In fact, Dones worked with Aurélien Crida (Côte d'Azur University, France) and others to outline why the rings could be light, bright, and still be primordial — no moon smash necessary.

Take the mass, for example. Crida's team acknowledged that the spreading effect would cause the rings to lose material. But because more massive rings spread faster, they argue, the rings would have lost most of their material early on, eventually converging to a mass very like the one Cassini measured. So the rings' current leanness could be a sign not of youth but of age.

It's even possible that the ring rain could preferentially "clean" the rings of organic material, leaving them looking shiny and new. Although the details of how this would work remain unclear, Cassini observations of the ring rain and of Saturn itself confirm that much of what is raining down consists of silicates and organics.

But Dones admits the debate is far from settled. "We've never really come up with a good reason why Saturn should be the planet that has a much more 'ginormous' ring system than the others," he says.

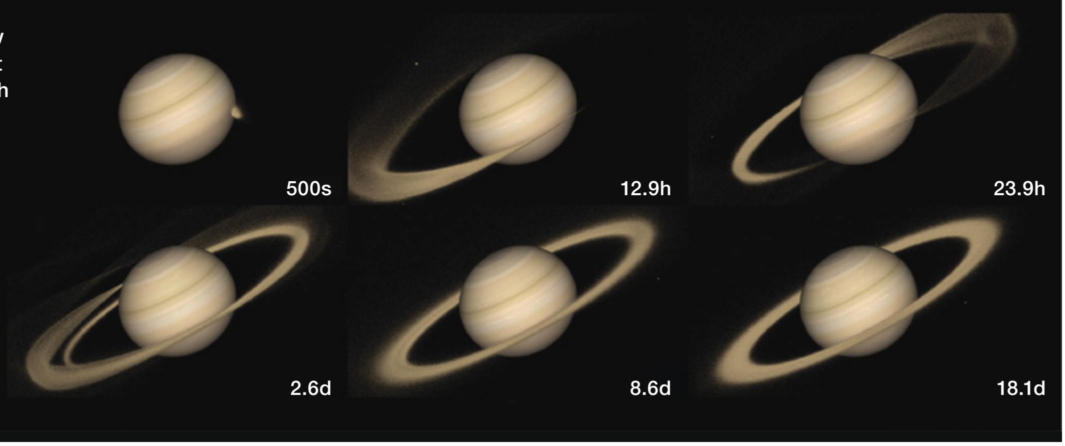
The unsettled age of the rings ties directly to the unsettled origin of the midsize moons, because the two structures are two sides of the same coin. Even as the rings' outer edges spawn new moons (including moonlets we've spotted in the act of forming), other moons donate material to the rings or even make them wholesale, in moon-destroying impacts. If the rings are young — and maybe even if they're not — then some of the midsize moons might be newcomers, too.

"Children of the Rings"

There's little doubt that Saturn's innermost moons are indeed "children of the rings," as first proposed by Sébastien Charnoz (then at Paris Diderot University). Observations bear this out. The ravioli shapes of Pan and Atlas likely come from the ice particles they've amassed as they orbit within and just

(continued on page 18)

YOUNG RINGS
These simulation frames show what would happen if a comet that happened to pass through the Saturn system smashed into a moon. The resulting debris would form wide, icy rings around Saturn, close to what we see now. However, the small likelihood of the smashup causes some scientists to doubt the scenario. (Watch the full animation at https://is.gd/newrings.)

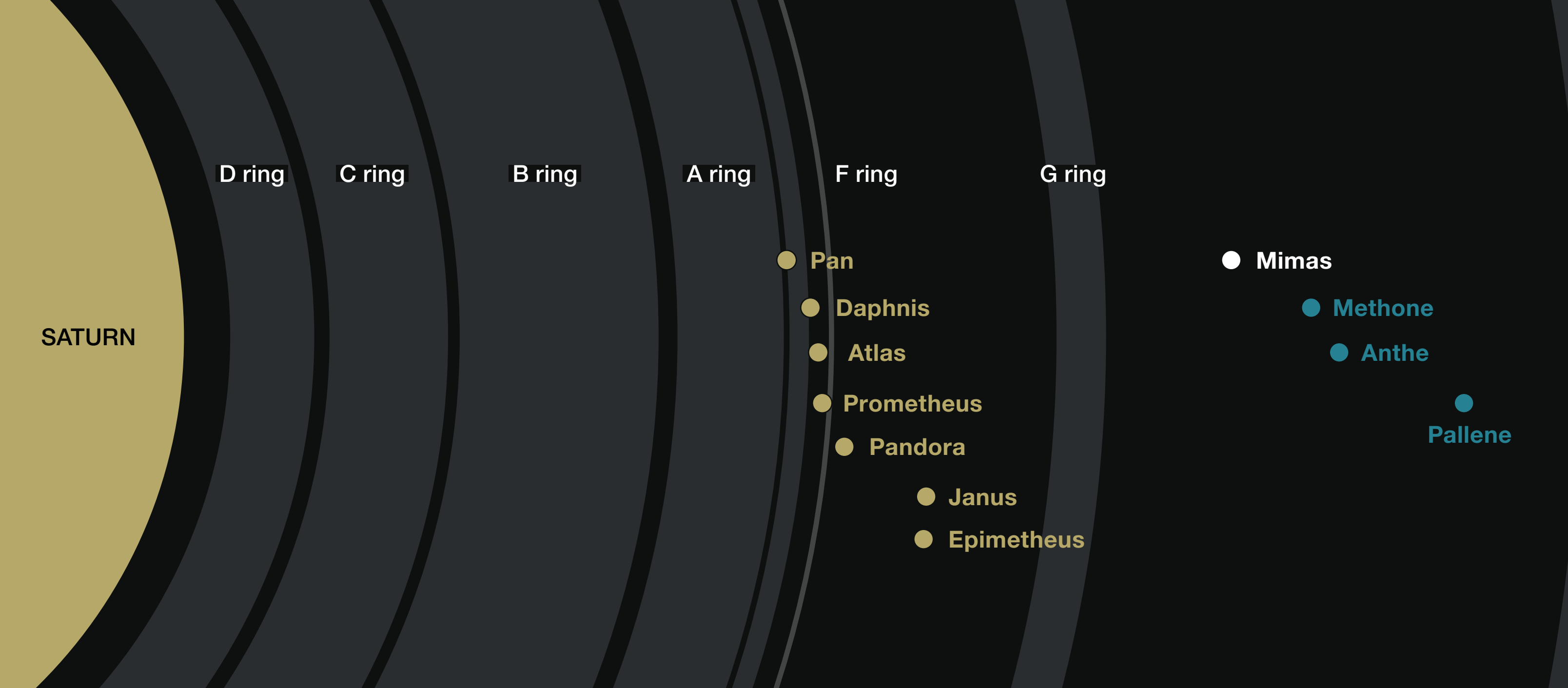


PAN AND ATLAS: NASA / JPL / SPACE SCIENCE INSTITUTE; RING SIMULATION: JOHN DUBINSKI / *ICARUS* 2019

WELCOME TO THE FAMILY

This diagram shows Saturn's rings (labeled in the order of their discovery), ring-shepherding moons, and icy midsize moons. (Technically, Iapetus is also a midsize moon, but its orbit lies outside Titan's, so it doesn't interact with the others and may have a different origin.) The orbits are shown to scale, but the moons' sizes are not. Moons smaller than a kilometer across are omitted.

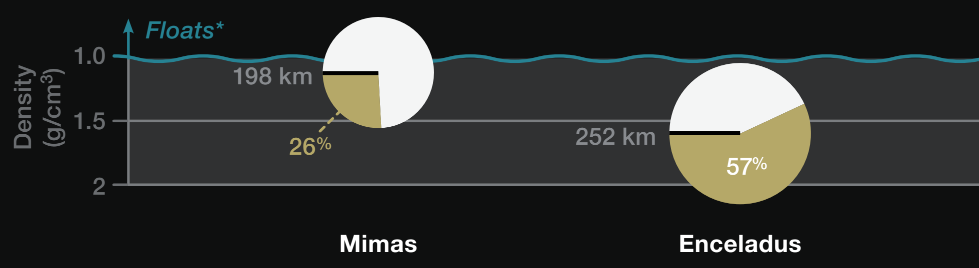
- Ring shepherds
- Midsize moons
- Trojans/companions



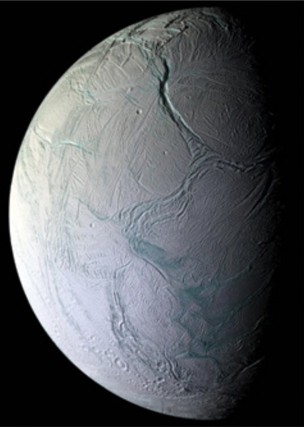
MIMAS This moon came to light as a dot in the telescope of William Herschel in 1789, long before the Voyagers and Cassini obtained closer views. Cassini's photo features the eponymous Herschel Crater that gives this geologically dead moon the appearance of the Death Star in *Star Wars*.

WOULD THEY FLOAT?

The five midsize moons inside Titan's orbit exhibit a diversity of densities (and therefore compositions) that has long defied explanation.



Density of water is 1 g/cm³



ENCELADUS This Cassini image highlights the icy moon's *tiger stripes*, fractures from which the spacecraft observed water from an underground ocean geysering into space. The surface and activity make this moon strikingly different from Mimas, despite the two moons' similar sizes and orbits.

TETHYS Ithaca Chasma, which snakes to the right in this image, runs nearly three-quarters of the way around Tethys, the iciest of the midsize moons.

MOON SHAPES

Gravity rounds the shapes of more massive moons, while less massive ones remain lumpy. But origins matter, too: Moons forming in the rings collect icy material along their equators, giving them a distinct ravioli appearance.

POTATO		RAVIOLI	ROUND
Prometheus	Anthe	Pan	Mimas
Pandora	Telesto	Daphnis	Enceladus
Janus	Calypso	Atlas	Tethys
Epimetheus	Helene		Dione
Methone	Polydeuces		Rhea
Pallene			

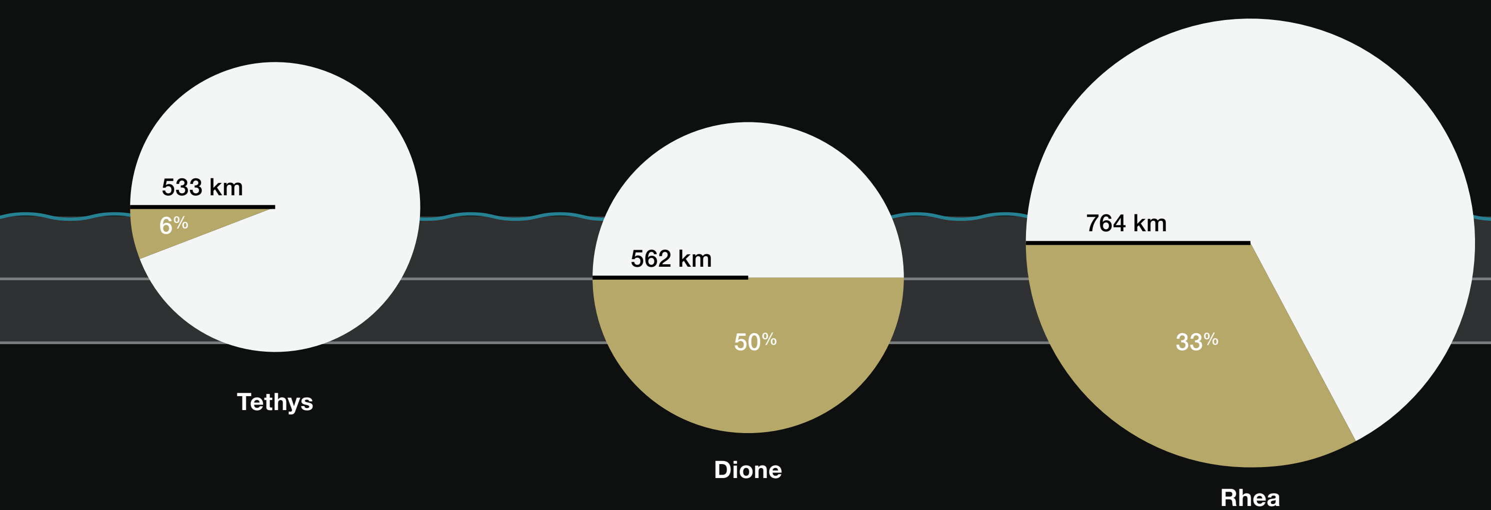
E ring

Enceladus

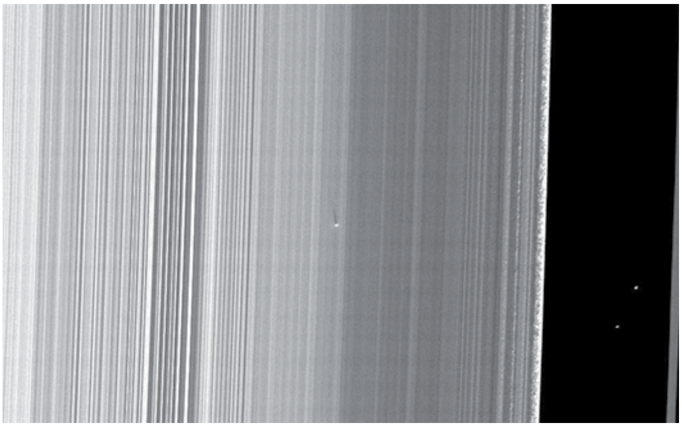
Tethys
Telesto
Calypso

Dione
Helene
Polydeuces

Rhea, Titan, Hyperion, Iapetus,
and other moon families are farther out →



INFOGRAPHIC: TERRI DUBÉ / S&T; MIMAS, ENCELADUS, TETHYS, AND RINGS: NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE



▲ **MOONLET** Cassini caught a moon, designated S/2009 S1, in the process of forming within the B ring. The moonlet casts a shadow that stretches 36 kilometers (22 miles) across the rings, which suggests the object itself protrudes 150 meters above the ring plane.

(continued from page 15)

outside Saturn's A ring, respectively. Likewise, Prometheus and Pandora have been observed shepherding and frolicking with the faint and narrow F ring. One tiny world — a moonlet named S/2009 S1 — was even caught in the act of forming within the B ring.

But Saturn's midsize moons present more of a puzzle: Mimas, Enceladus, Tethys, Dione, and Rhea are surprisingly icy compared with Titan, but nowhere near as icy as the rings. In fact, the rocky fractions of their compositions range widely (between 6% and 57% silicates) in a way that doesn't seem to be tied to their distance from Saturn or even to their size.

Their geological activity is likewise diverse: Small Enceladus harbors a subsurface ocean that geysers into space (*S&T:* Aug. 2020, p. 32), while similarly sized Mimas is as geologically dead as the Death Star it resembles.

Small Enceladus harbors a subsurface ocean that geysers into space, while similarly sized Mimas is as geologically dead as the Death Star it resembles.

How astronomers explain this riddle of diversity depends very much on how old the moons are.

Scenario A: The Moons Are Young

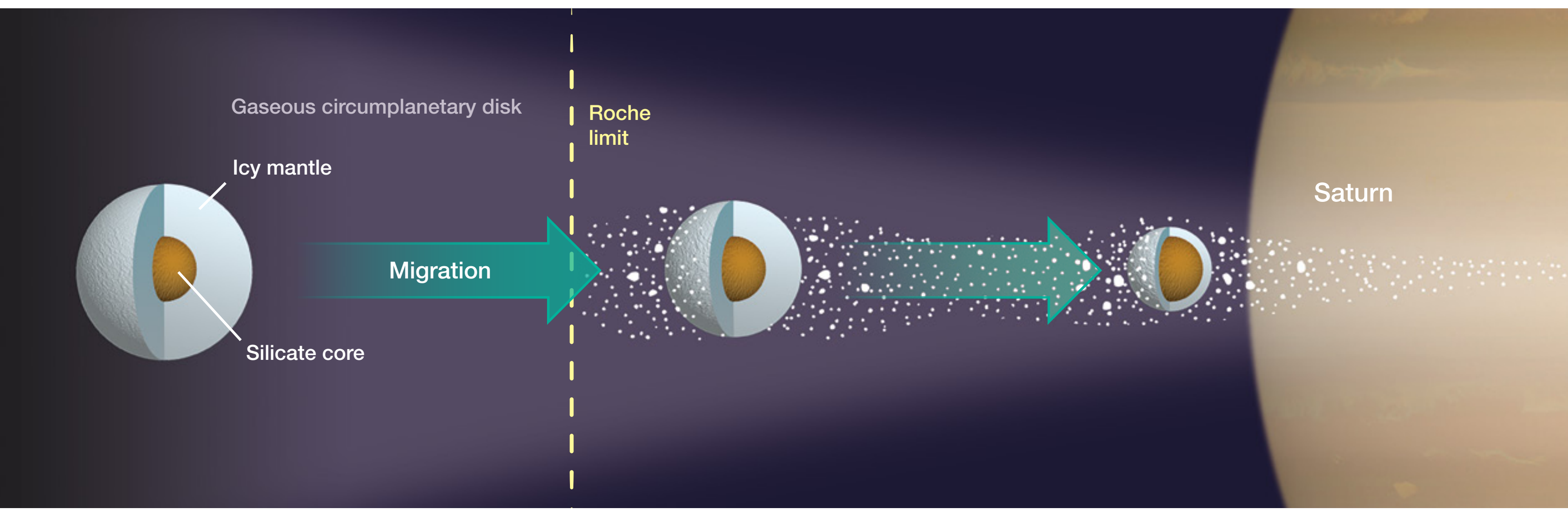
There are two key observations that open the possibility of young midsize moons. First, there's their craters. Astronomers use craters as timekeepers, and they initially thought the moons were ancient because of all the craters that spot their surfaces (at least those not resurfaced by ice).

But more extensive analyses have revealed oddities that don't line up with the crater record on the Moon or elsewhere in the solar system. Many astronomers now think that most of the moons' craters could have come not from comets or asteroids circling the Sun but from objects within the Saturn system. If that's the case, then the moons could have been heavily cratered in a one-off event, throwing off the only reliable dating measurement that astronomers have.

"There's just no real way to understand how busy it has been around Saturn," explains Marc Neveu (University of Maryland). "The fact that there's a giant planet throws a wrench in things."

The second key observation was of the moons' orbits, which change over time due to tides. According to the classical idea of how tides work, each moon pulls on Saturn, deforming it ever so slightly into an oblate shape. (The Moon

▼ **PRIMORDIAL RINGS** Under Robin Canup's proposal in 2010, a just-formed Titan-size moon would migrate inward toward Saturn due to interactions with the gaseous disk around the planet. Once the moon crossed the Roche limit, Saturn's tidal gravitational pull would remove the less-dense outer layer of ice, distributing it in a massive ring around the planet. The rocky core would ultimately plunge into Saturn.



MOONLET: NASA / JPL / SPACE SCIENCE INSTITUTE; ICY MOON GRAPHIC: GREGG DINDERMAN / S&T

does the same to Earth, though it's our planet's water that bulges.) The force of gravity directs the bulge toward the moon that's pulling it, but both the planet and the moon are in motion — and while Saturn spins every 10.7 hours, the moons take days to orbit once around. So gas must constantly reflow to reshape the planet as it spins, and friction hinders the bulge from ever catching up.

This never-ending tension torques Saturn, slowing its spin. It simultaneously transfers angular momentum to the moons, expanding their orbits. (The same happens on Earth, causing our day to lengthen by 23 microseconds every year and the Moon to back away by some 4 cm every year.)

Initially, when scientists assumed Saturn's moons were primordial, they figured that for Mimas to take 4.5 billion years to reach its current location, Saturn must dissipate only a little energy through tidal interactions.

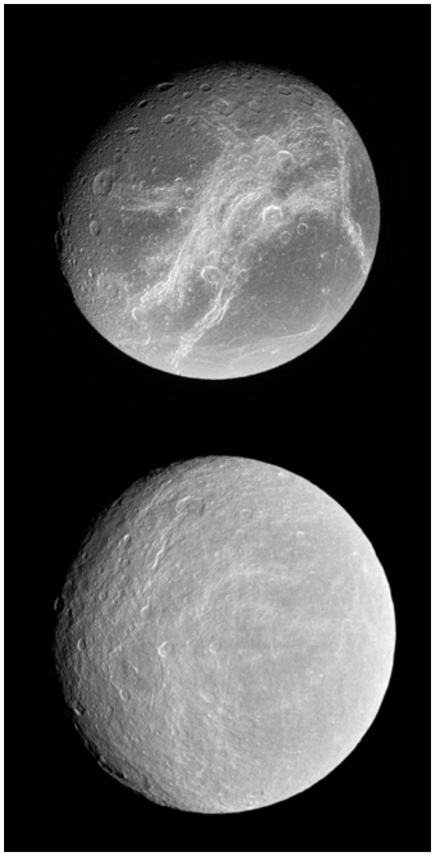
Energy dissipates in complex and varied ways depending on the planet. Scientists lump these processes together under something called a *quality factor*, or Q for short. In simple terms, a higher Q means the planet's gas is slippery and can deform without much friction. A lower Q, on the other hand, indicates a body with "stickier" gas that experiences more friction and thus dissipates more energy.

For decades, scientists had assumed Saturn was fairly slippery, with a Q of at least 20,000. But that's not what Valéry Lainey (Paris Observatory) found. Studying observations of the moons' positions collected since 1886, including the extremely precise data collected during Cassini's 13-year run, Lainey and his colleagues realized that Saturn's Q factor is an order of magnitude lower than expected. In other words, the gas inside Saturn is surprisingly sticky and generates a lot of friction.

Even more surprising was the implication for the midsize moons. It turns out their orbits are expanding more quickly than expected, especially Rhea's, which Lainey found was moving outward 10 times faster than previously thought. Run time backwards, and the midsize moons would fall into the planet a billion or so years ago.

Scenario B: Long Live the Moons

However, theorists have struggled to explain young midsize moons. Ancient moons, on the other hand, develop naturally in simulations that follow the evolution of Saturn's rings.



DIONE *Top:* The surface of this icy moon is both heavily cratered and fractured.

RHEA *Bottom:* Saturn's second largest moon (not shown to scale here), Rhea is nevertheless only a quarter as wide as Titan. This view shows the cratered plains on its trailing hemisphere.

NASA / JPL / SPACE SCIENCE INSTITUTE (2)

In 2010, Robin Canup (Southwest Research Institute) considered what would happen if Saturn had originally had more Titan-like moons, just as Jupiter has four Galilean heavyweights now. The multiple Titans, each with a rocky core surrounded by a thick layer of ice, would have orbited in the disk of dust and gas surrounding the newborn giant planet. Interactions with that disk would have dragged the massive moons inward over time, and one or more such moons might have ventured too close, inside the Roche limit. Since ice is less dense than rock, Saturn's tidal gravitational pull would have stripped off the moon's icy surface layers first. These would have settled into pure-ice rings much more massive than the ones we see today. The remaining rocky core would have plunged into Saturn.

"[This] is still the leading theory of how the rings formed," Dones says. The theory also explains why Saturn has only one heavyweight moon: It ate the others.

> **The theory also explains why Saturn has only one heavyweight moon: *It ate the others.***

Under Canup's proposal, the newly formed rings would in turn have spawned smaller moons off their outer edges while still in the early days of the solar system. That process, she contended, could have created Tethys and those midsize moons inside its orbit, but not the heftier and farther-out Dione and Rhea.

Charnoz and others modified and extended Canup's idea. If some rock chunks remained in the rings, then *all* of the midsize moons could long ago have spun off the rings' outer edge. The size of the rock-chunk cores would have varied greatly, thereby explaining the variety of compositions: Tethys, for example, might have formed almost solely from ice chunks where no rock was available.

Charnoz and his colleagues explicitly tie the moons' origin to the rings, which they estimate could have formed anytime between 2.5 and 4.5 billion years ago. Mimas, the innermost and smallest of the bunch, is the exception, forming up to 1.5 billion years after Rhea.

Other variations on the moons-from-leftovers theme come to a similar conclusion: The midsize moons seem to be old, if not necessarily primordial.

Mimas Come Lately

But recently, some theorists have gone a step in the other direction, suggesting that at least some of the moons are geological infants.

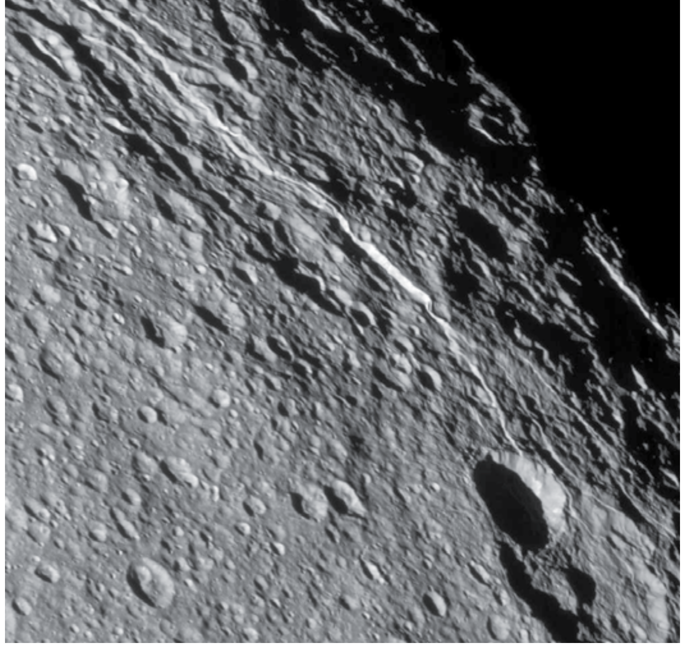
Matija Ćuk (SETI) and his colleagues modeled the system's evolution to look for resonances between the moons' orbits. What they found was that as the orbits of Dione and Tethys expanded away from Saturn following the moons' formation, they ought to have gone through a stable 3:2 resonance, in which Dione would have orbited Saturn three times for every two times Tethys went around. But that inevitable resonance never happened.

"Tethys and Dione should have gone through this resonance 100 million years ago or so," Ćuk says. That resonance would have tilted their orbits, he adds, and they're not tilted enough. Moreover, there's no evidence of a major impact or another significant event that could have knocked the moons out of resonance. As a result, there's a limit on how old these moons — and thus their compatriots — could be, a limit that happens to line up nicely with the age that had been proposed for the young rings: on the order of 100 million years.

Perhaps not surprisingly, the finding was controversial. "I think it was provocative," Neveu says, "but it's another way to look at the issue."

Neveu put out his own proposal, based on numerical simulations of the midsize moons' orbits and interiors, that Mimas might be a child of the rings, born between 100 million and 1 billion years ago. But these same simulations only work if the other midsize moons are old.

A young age for at least Mimas might explain why it has no ocean. Enceladus supports its underground ocean by heat generated from tidal stresses. Mimas should experience similar tidal stresses, being roughly the same size and distance from Saturn. But if it's young, it wouldn't have enough residual heat to soften the ice to a point where tidal stresses could fully melt it.



▲ **CRATER AGES** Heavily cratered terrain, such as on the surface of Rhea, suggests that the midsize moons are old. But that conclusion holds only if the impactors came from the solar system at large — if they originated within the Saturnian system, craters become less reliable indicators of age.

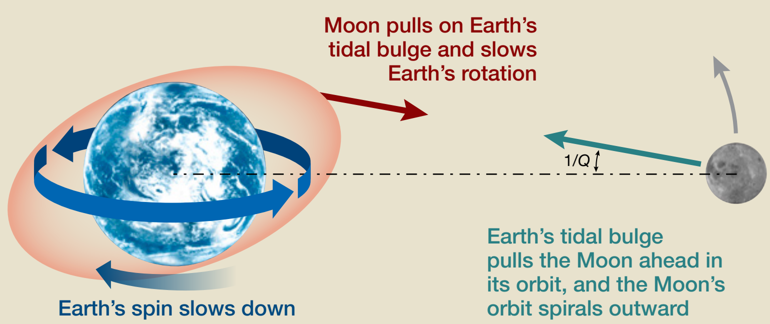
A Sea Change

The flood of studies coming from observers and theorists alike in previous decades did little to settle the origins of the Saturnian system. Part of the trouble was that everyone assumed we understand how a concept from freshman physics works on Saturn: tides.

Scientists rely on tides to explain everything from the behavior of moons' orbits to the heating of their internal oceans. But Lainey's research hinted that Saturn's interior behaves differently than expected, causing Rhea to back away more quickly than thought. Another researcher, Jim Fuller (Caltech), realized he might have the answer — not from planetary science, but from his studies of tides in close pairs of stars. That work had taught him a key lesson: When it comes to giant gaseous bodies, everything we thought we knew about tides is irrelevant.

"When you tidally distort a planet, it doesn't just distort into a nice egg or oval shape," Fuller explains. His simulations show that a gas planet actually oscillates, and it does so at many different frequencies at the same time. He compares the vibrations to an earthquake, but one with such low frequencies that any back-and-forth motion would be gradual, on timescales of hours. That motion likely comes in the form

CLASSICAL TIDES The gravitational pull of a moon causes a planet's water (or gas) to bulge in the shape of a rugby football. The angle between the tidal bulge and the moon is equivalent to $1/Q$. If there were no friction inside the planet, the angle would be zero and Q would be infinity. But there is some friction, so the bulge can't instantaneously change its shape. Since the planet spins faster than the moon revolves, its bulge always points slightly ahead of the moon, pulling it along in its orbit. And as the moon speeds up, its orbit enlarges. The moon in turn pulls on the bulge, slowing the planet's rotation.



CRATERS ON RHEA: NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE; TIDES DIAGRAM: GREGG DINDERMAN / S&T

of waves traveling through the planet's gaseous interior.

As the moons orbit the pulsating planet, their orbital periods by chance might resonate with the frequencies of some of those pulsations. When that happens, the resonance amps up the volume. "It's like the moon is pushing on Saturn just at the natural frequency of the note it wants to play, so it makes the planet play a very loud note," Fuller says.

Once a moon's orbit hits the resonant frequency of the oscillations inside the planet, it will suddenly find itself migrating outward much faster, like a surfer catching a wave. The moon rides that wave, its orbit and Saturn's interior evolving in lockstep until the wave eventually breaks.

There are two related implications to come out of this *resonance locking*. First, just because a moon is migrating out quickly now doesn't mean it always has been — the dissipation of tidal energy isn't constant over time.

Second, the friction that tides generate still depends on distance — but in the opposite way than previously thought. While classical theory would tell you that farther moons should migrate outward more slowly, resonance locking instead suggests that farther moons migrate outward *faster*. In terms of an individual moon, that suggests its rate of migration was slow to begin with, but it sped up once it caught the resonant wave.

The expected difference in a moon's behavior depending on its distance from Saturn became a test, one that resonance locking passed with flying colors.

"One of the predictions of our paper was that Titan might be migrating out much faster than people expected," Fuller says. And that's exactly what Lainey found. "In fact, [Lainey] said he'd already seen it, but he didn't believe the results until he looked at the predictions," Fuller adds.

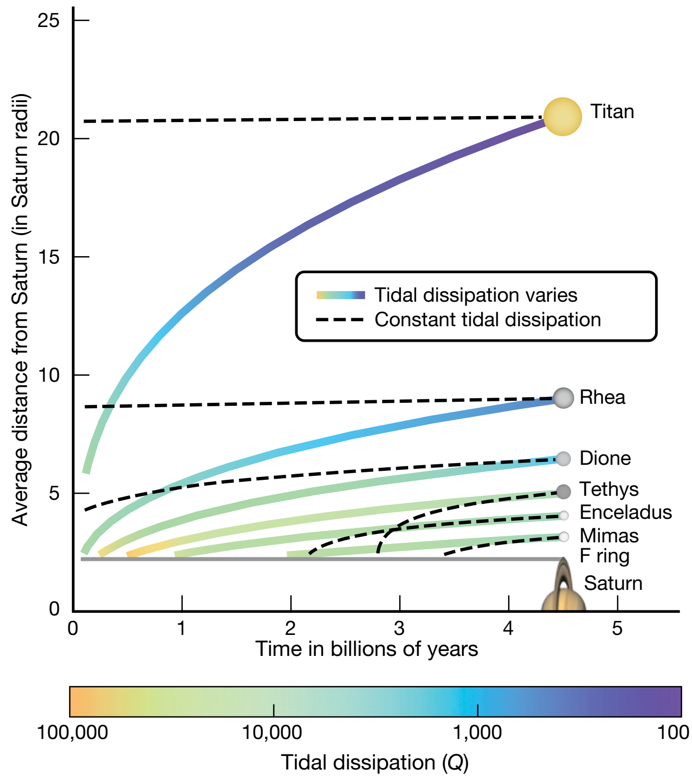
In 2020, Lainey and collaborators reported in *Nature Astronomy* that Titan was receding from Saturn at a surprising rate of 11 cm per year — 100 times faster than previously thought. Another team, including Neveu, is now looking to confirm that result independently.

The new understanding of tides caused the scientists involved to re-evaluate the midsize moons' origins: While their fast migration rates had pointed to young ages, now they only mean the moons are migrating fast today — the past is a different story. Likewise, theorists can no longer use predicted moon-moon resonances to date the moons, unless those simulations also take into account the effect of varying tides on orbital matchups.

But does that mean all of the moons really are ancient? "I don't think it provides a definitive answer either way," Fuller muses, "but it allows them to be older than people have previously assumed."

The Way Forward

While the new understanding of tides has completely changed the study of the Saturnian system — and even rendered some previous studies obsolete — it hasn't settled the debate. If anything, there's only more to consider now.



▲ **CHANGING TIDES** This plot shows how the evolving "stickiness" of gas within Saturn affects the orbits of its moons. Many of the midsize moons are migrating outward fast enough right now that, if time were rewound, those moons would fall within the rings not that long ago. But that's only true if Saturn's tides always dissipated the same amount of energy. If tidal dissipation evolves with time, then migration rates might have been slower in the past, and the moons could be much older.

GREGG DINDERMAN / S&T; SOURCE: LAINEY ET AL. / *NATURE ASTRONOMY* 2020

Young moons still have adamant advocates. Pointing to the observations of Titan's migration, Ćuk says, "Every time you add motion to the system, it makes old moons harder to have." Neveu also notes that changing tides could make collisions between moons more likely. And even Fuller's calculations show that some moons might yet be young.

Putting his idea into detailed numerical simulations will be difficult, Fuller says, because no one really understands Saturn's interior or how it has changed over time.

But there are ways to chip away at the problem. Several groups still work with the scads of exquisite data that Cassini returned during its years at Saturn. Fuller, for example, is using those data to turn the rings into a kind of seismometer to probe the planet's interior. Others continue to examine (and re-examine) the moons' migration.

Meanwhile, theorists are trying to find ways to incorporate the new physics into their simulations — it's an unexpected wildcard that has changed the game. But while this beautifully weird system may be keeping its cards close, that doesn't mean we'll stop playing.

■ News Editor **MONICA YOUNG**, award-winning science journalist, is on a first-name basis with Saturn's eclectic moons.

THE FIRST 10 SE

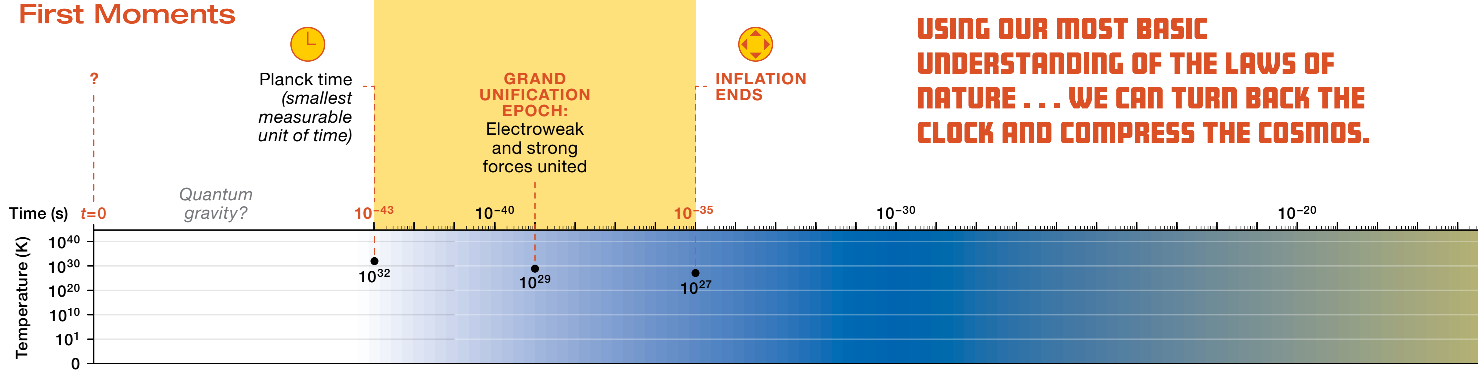
Scientists are using their knowledge of fundamental physics to study the universe's earliest moments and the origin of the first magnetic fields.

The universe is a complicated place. Crashing galaxies, exploding stars, lava-erupting worlds — the cosmos is messy. Go back 13.8 billion years, though, and things were a lot simpler. All that existed was hot plasma. Energetic particles filled this primordial soup, interacting in conditions so extreme that we are just now beginning to approach them in gigantic particle colliders on Earth.

This statement naturally leads to the question, "How do we know what the universe was like 13.8 billion years ago?" For humans, anything older than a few thousand years is prehistoric. We know about things like the U.S. Space Shuttle program directly from people who worked on it. We know about the U.S. Civil War because of the documents left by those who lived through it. But when it comes to older history — like the migration of the first humans to leave Africa or the extinction of the dinosaurs — we have to rely on fossil records to tell the story. Understanding the early universe is even more difficult than that.

Our oldest fossil is the *cosmic microwave background* (CMB), the radiation released when the early universe cooled down enough for photons to travel freely. People often refer to the CMB as the universe's baby picture. But the CMB comes from a time when the universe was about 380,000 years old: It's a snapshot of a moment long after the universe was a newborn. To really gain an understanding of what the early universe was like, we need to use an even more powerful tool. Perhaps the most powerful tool humans have ever created. Physics.

The Universe's First Moments



USING OUR MOST BASIC UNDERSTANDING OF THE LAWS OF NATURE . . . WE CAN TURN BACK THE CLOCK AND COMPRESS THE COSMOS.

BACKGROUND IMAGE: JONATHAN KNOWLES / GETTY IMAGES; TIMELINE: TERRI DUBÉ / S&T

CONDS

What Was the Early Universe Like?

Normally, we study our universe by looking out into the vast expanse. Because we have shown the speed of light to be constant and finite, we assume that light has traveled at a consistent speed since the beginning of time. So the further out in space we look, the further back in time we are seeing. Light's finite speed has allowed us to make many discoveries, like the fact that our universe appears to be expanding and that it was much smaller, hotter, and denser in the past.

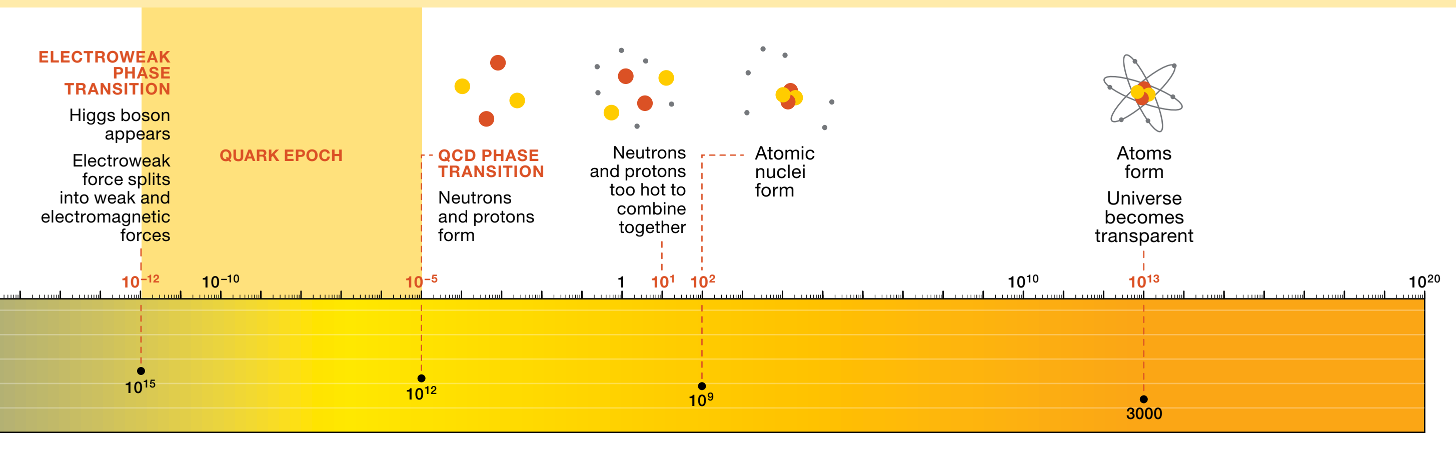
This knowledge, however, implies that we can only look so far into the past because at some point, the universe must have been too hot and dense for light to freely travel without scattering. We identify this *surface of last scattering* as the birth of the CMB, which suffuses our universe.

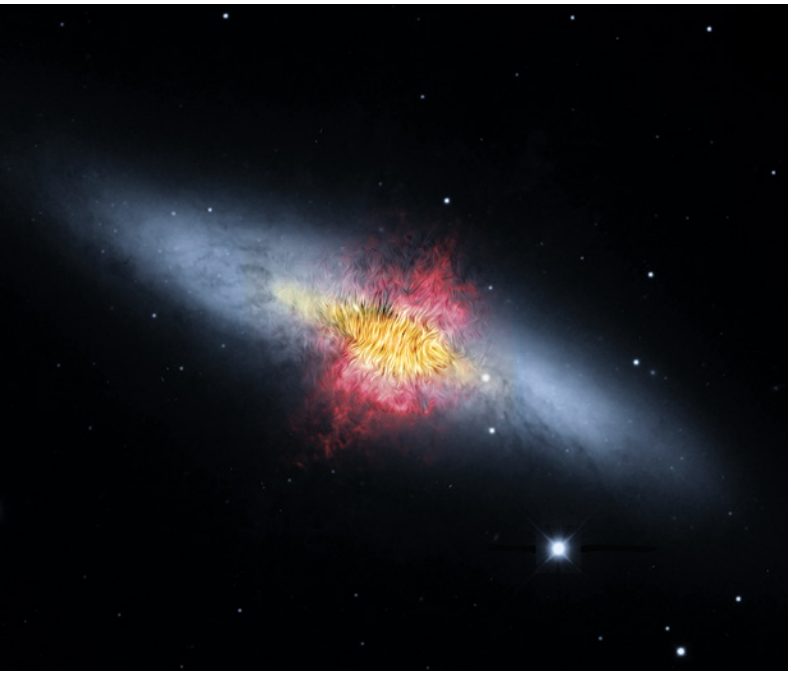
To know what happened even earlier in our universe's history, we must extrapolate backwards in time. In order to do so, we must make certain assumptions, and we need to be completely clear as to which assumptions we are making. First off, we assume that the laws of nature essentially work the same now as they did when the universe was young. Second, we assume that no particular part of the universe was special — that is, that the physical conditions were basically the same everywhere.

Beyond these two fairly standard assumptions, we also tend to make often-overlooked assumptions. For example, we understand the dynamics of fluids and laboratory plasmas fairly well, so we tend to assume that the highly energetic plasma in the early universe behaved similarly. We also assume that the fundamental physics we study in the low-gravity, vacuum conditions at the Large Hadron Collider (LHC) functioned the same way when the universe was hotter and denser, and gravity was much stronger. In addition, we assume that ripples in spacetime called gravitational waves didn't play a major role in the evolution of our universe.

None of these assumptions may be right. Even so, we can still develop a good idea of what the early universe was like. Using our most basic understanding of the laws of nature, developed through years of theory and experimentation, we can turn back the clock and compress the cosmos. As we do so, the universe changes from a collection of stars and galaxies into a cloud of neutral atoms not yet bound into structures by gravity. Going back even further, the particles would have been too hot to form neutral atoms and instead would have resembled a plasma, a sea of charged electrons and atomic nuclei. The soup of charged particles would have reacted strongly to any magnetic fields present, so the dynamics of this plasma would have been much different than that of a collection of neutral atoms. This particle soup filled the universe just prior to the CMB's release.

Going back further, to when the universe was less than 10 seconds old and the average temperature was more than a billion kelvin, the plasma's energy would have been so high that it's impossible to model the motion of its particles without using Einstein's special theory of relativity.





◀ **MAGNETIC GALAXY** This composite image reveals strong magnetic fields (lines) in the outflow created by abundant star formation in M82, the Cigar Galaxy. The image combines observations of visible starlight (gray), hydrogen gas (red), and infrared starlight and dust (yellow). Data from the flying SOFIA telescope indicate that the magnetic field in M82's center is 2–3×10^{-4} gauss — 10 to 100 times stronger than the large-scale fields in more sedate galaxies.

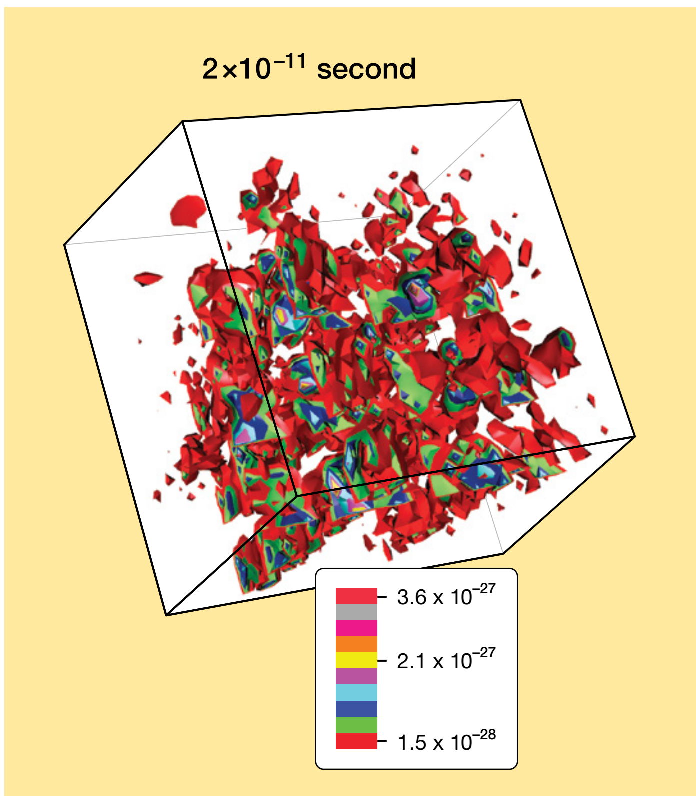
This medium is referred to as a *relativistic plasma*, and it's not something often seen on Earth or even in our Sun. It's the state of matter that we expect to see inside a neutron star or in the gas near a black hole. Like the plasmas that we observe in the laboratory, the electrons and nuclei are unbound; however, in relativistic plasmas, less-intuitive things — like the mass increase, time dilation, and length contraction that come with relativistic conditions — can significantly alter the dynamics.

In addition, in a few-seconds-old universe, there was still a significant amount of antimatter, which unleashed large amounts of energy through collisions with normal matter. In fact, there were near-constant, high-speed collisions between all particles in the hot, dense environment: Every part of the universe resembled the inside of the LHC, but with a much higher density and more collisions. For this reason, protons and neutrons had so much energy that they just couldn't stick to each other.

When the average temperature in the universe was about a trillion degrees, about 10 millionths of a second after the universe began, we reach the earliest time that particles like protons and neutrons (called *hadrons*) could exist. Before this time, hadrons would have been ripped apart by the motions of their constituent particles. This marks a transition between an earlier universe composed mostly of these subatomic particles to a later universe composed mostly of hadrons, known as the *quantum chromodynamic (QCD) phase transition*. The transition was similar to when water freezes. It occurred in random places, stirring the plasma until it was entirely converted into the new form. The stirring motions mean that, in addition to the relativistic plasma dynamics, the early universe was also turbulent. Although turbulence is everywhere in our lives — from water pouring down a drain to clouds moving through the sky — we still have yet to really understand it physically.

Amazingly, when you go back even further, there was another major phase transition. Today, four fundamental forces govern our physical world (gravity, electromagnetism, and the weak and strong nuclear forces), each transmitted by different particles. For example, electromagnetism's particle is the massless photon. But when the universe was less than around a trillionth of a second old, the weak force's

▶ **MAGNETOGENESIS** To understand where the universe's large intergalactic magnetic fields came from, scientists use computer simulations to explore the universe's earliest moments. These visualizations by undergraduate student Catherine Wood track the creation of seed fields within a fraction of a second after the Big Bang. Swirling motions generate weak fields, which then coalesce in locations where the plasma's characteristics are just right (blobs in left panel, fields are stronger in cores). As time progresses *(from left to right)*, the fields first increase due to strong turbulence, then decrease as the fluid motions slow and the universe expands and cools. Each cube translates into approximately 3 million light-years wide in today's universe (factoring in cosmic expansion), and because of the expansion-induced scale changes, the panels give the impression of watching an explosion in slow motion.



M82 MAGNETIC FIELDS: MAGNETIC FIELD: NASA / SOFIA / E. LOPEZ-RODRIGUEZ, INFRARED: NASA / SPITZER / J. MOUSTAKAS ET AL., VISIBLE AND HYDROGEN: KITT PEAK OBSERVATORY; VISUALIZATIONS: CATHERINE WOOD particles were also essentially massless, which made the two forces indistinguishable. The existence of this *electroweak force* implies that photons as we know them didn't exist yet at this point in cosmic history.

During this *electroweak phase transition*, the famous Higgs boson came into the picture. When the universe had cooled to around a quadrillion kelvin, the Higgs boson "froze out" of the primordial plasma and acted on some of the particles, including those carrying the weak force. That interaction gave the particles mass and caused the electromagnetic and weak forces to split. Like the QCD phase transition after it, the split stirred up the plasma and created a major change throughout the universe. We've seen physics similar to what may have occurred during both transitions experimentally, using instruments like the LHC.

We think other events occurred before the electroweak phase transition, but although they're part of our best and most consistent theories for understanding the beginning of the universe, these are things we've never seen experimentally. One event is inflation, in which the universe suddenly expanded by several orders of magnitude in an incredibly short amount of time. Another event is *grand unification*, a time when we think the strong and electroweak forces were unified as one force.

Finally, there is the Big Bang itself. When the universe's temperature exceeds conditions for which we can describe basic measurements like length, time, and mass — a fundamental limit called the *Planck scale* — physics as we know

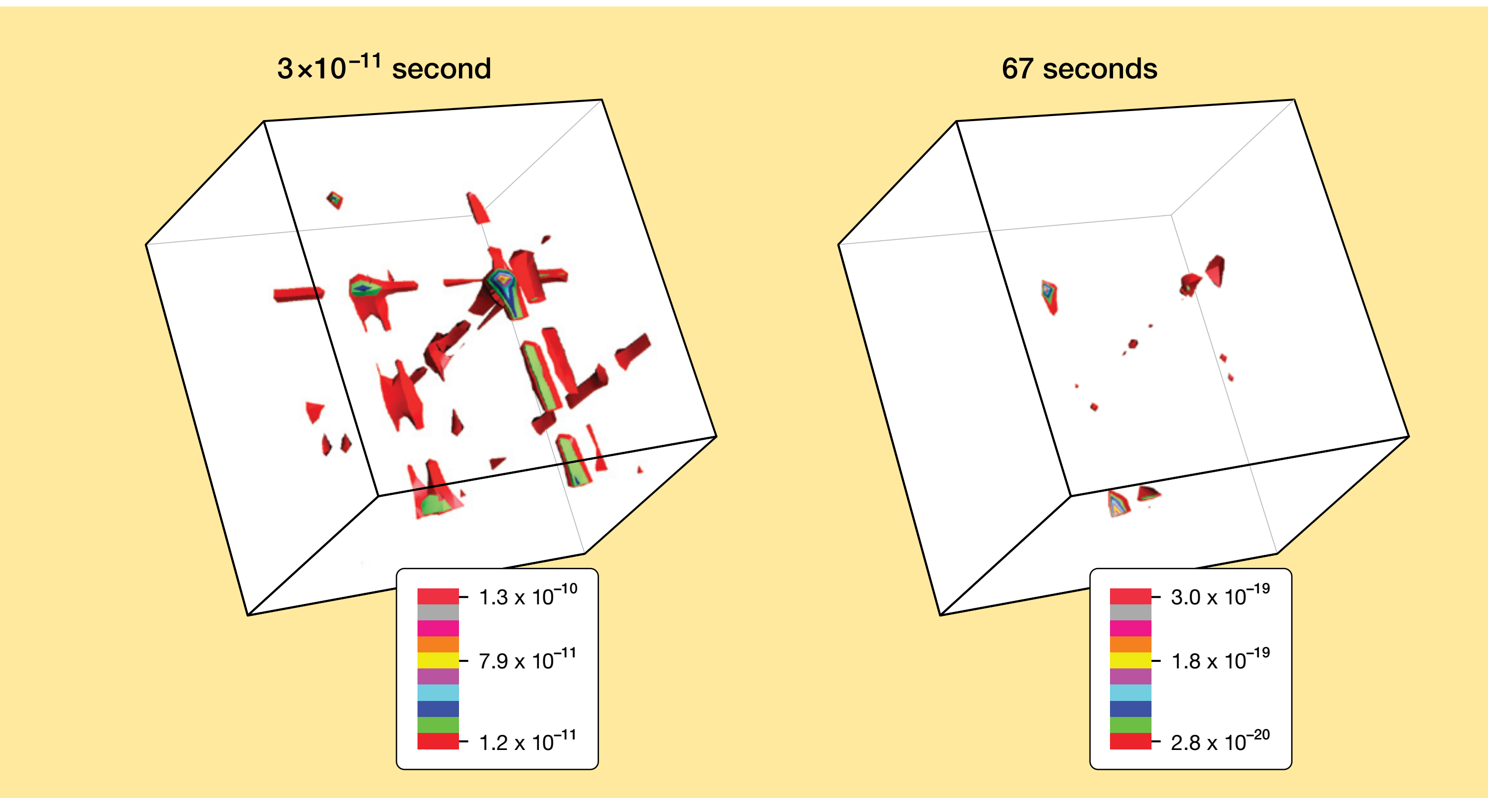
WE TEND TO LOOK AT ISOLATED SUBSYSTEMS AND ASSUME THAT THEY CAN TELL US ABOUT THE LARGE-SCALE STRUCTURE OF THE EARLY UNIVERSE.

it breaks down. This is the literal end of physics. It requires us to develop new theories in order to explain the universe at that point in history. The Big Bang should have occurred somewhere near this scale.

Do We Really Know What We Think We Know?

As impressive as it is that scientists can say anything about the universe's earliest moments, we are actively trying to learn more. One thing physicists do to probe the plasma of the early universe is smash protons and atomic nuclei within the massive LHC. This technique is pretty representative of how scientists often approach the problem: We tend to look at isolated subsystems and assume that they can tell us about the large-scale structure of the early universe. This is as true in simulations as it is in carefully controlled lab experiments.

The shortcoming of this approach is clear: It oversimplifies the problem. This is a common issue with physics. Every person who has ever sat through an introductory physics class remembers the problem of a frictionless block sliding down an inclined plane. The objective of this problem is to calculate

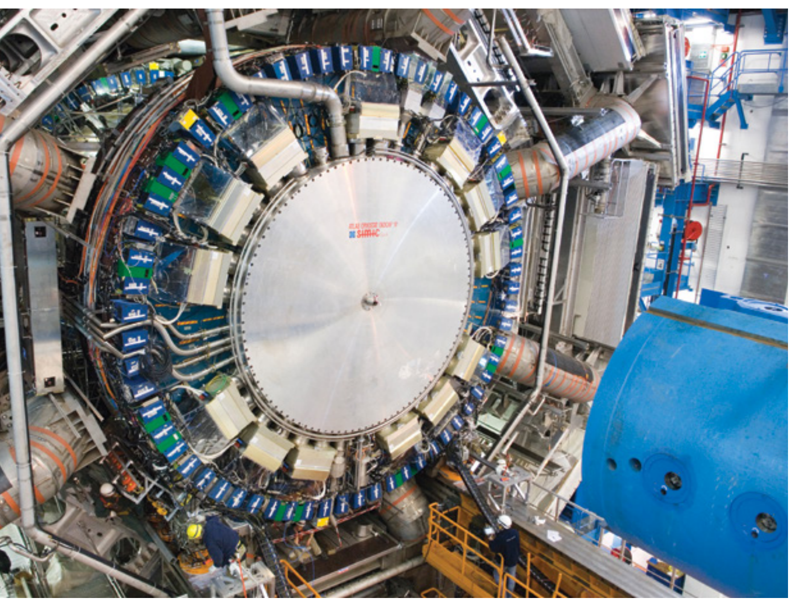


some quantity, such as the time it takes for the block to reach the bottom of the incline or the speed it has when it reaches the bottom. But students who repeat this experiment in the lab often find that the real-world results are at least a little different from their calculations. Later, they learn to add friction . . . only to find they had also neglected air resistance.

We see this process play out with physics problems at all levels. Over time, as we grow as physicists, we learn which elements of a problem are "negligible" and which are "essential." We accept the (supposedly) small errors that result from neglecting insignificant factors. This approach tends to work well, especially for *linear systems*, those with simple proportional relationships. For more complex *nonlinear systems*, the situation is more complicated, and an entire science has developed around understanding nonlinear dynamics and chaos. In addition, the idea of *emergence*, in which the behavior of the whole is significantly different than the summed behavior of its parts, implies that focusing on isolated subsystems may not be the best way to understand the early universe.

The problem with our picture of the early universe is that we constructed it by looking at its components in isolation. For example, we can extrapolate the size of density perturbations in the early universe from how big the temperature variations are in the CMB, but these calculations will be several orders of magnitude off if we don't account for how much the phase transitions disrupted the plasma. How magnetic fields and gravitational waves impacted the development of the universe is still a mystery. Also, what is dark matter, and what role does it play in all this?

▼ **SOUPED-UP PHYSICS LAB** This is one of the end-cap calorimeters for the gigantic ATLAS experiment at the Large Hadron Collider. The calorimeters detect hadrons emitted when proton beams smash together. ATLAS scientists conduct a wide range of studies, from investigating the Higgs boson to recreating the early universe's conditions. Notice the hardhatted people for scale.



One of the issues cosmologists grapple with is *magnetogenesis*, the origin of the first magnetic fields. Magnetic fields are extremely important in plasma physics because they act like puppet strings, directing how plasma's charged particles move. For example, large nuclear fusion projects and advanced space propulsion systems use magnetic fields to control plasmas. Because the early universe was filled with plasma — and, even today, plasma makes up most visible mass — magnetic fields should be extremely important to how the universe evolved.

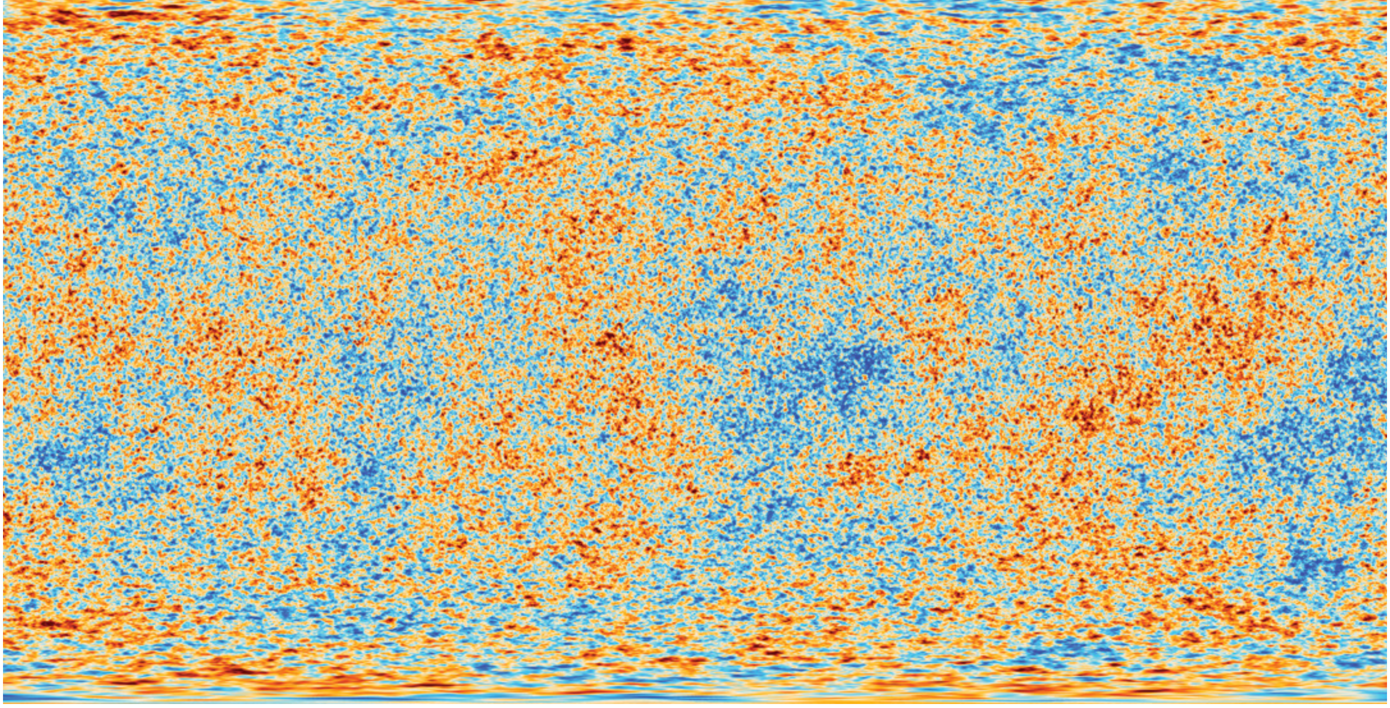
In addition, we see magnetic fields all over the universe, from stars to galaxies. Although moving charged particles can create tiny magnetic fields from scratch, they easily cancel one another out. It's difficult to generate coherent fields on the scale of galaxies and clusters without a seed field and a dynamo mechanism to amplify it. So whatever caused magnetogenesis may ultimately be the same thing that created magnetic fields in every galaxy in the universe. We want to know where they came from and when they first developed.

Researchers predict that a magnetic field as weak as 10^{-20} gauss on a scale of a few million light-years would have been enough to spark the modern universe's fields. This is extremely tiny compared to what we see on Earth: Our planet's magnetic field is about 0.5 G at the surface, and a fridge magnet is 100 G. Galaxies themselves have fields on the order of 10^{-6} G.

But there's no consensus yet as to how the first magnetic fields came to exist. Something must have set charged particles moving in the right way to create a field. Some scientists think magnetogenesis happened during inflation; others, during one of the phase transitions. Still others point to much later in cosmic history, when the first stars formed.

My own research focuses in part on the development of magnetic fields during the phase transitions. A major objective of my team's work is to study the evolution of our universe without introducing any more assumptions than are absolutely necessary. We do this by essentially building tiny universes inside a computer and watching them develop. Some of these universes seem to have the potential to grow into something that looks like ours, while others fizzle out quickly. We've developed software that can model most of the physics one may expect to encounter in the early universe. Our code can solve Einstein's equations of general relativity as well as the relativistic plasma physics equations for a compact early universe, all at the same time — something that was long impossible before recent advances in high-performance computing. It also uses a special time-stepping routine so it can simulate large or small portions of time, depending on the physical situation. It took a lot of testing to ensure the code could correctly simulate things like expansion, shocks, and gravitational waves.

We simulate a relativistic plasma containing every species of particle thought to exist during that time in history, plus dark matter, gravitational waves, a cosmological constant, and perturbations in temperature, density, and magnetic



ESA / PLANCK COLLABORATION

▲ **THE CMB** This view of the cosmic microwave background comes from the final data release of the Planck mission. The CMB's tiny temperature fluctuations correspond to regions of slightly different densities extant in the universe when it first became transparent to light. These regions became the seeds of future cosmic structure. Orange is warmer. (Due to projection effects, the fluctuations are distorted closer to the poles.)

fields, as well as the interactions among all these elements. It is a virtual lab specifically designed to study the early universe by witnessing how changes in initial conditions can lead to different outcomes.

We've run simulations to see how the plasma environment would have changed from just before the electroweak phase transition through the QCD transition, depending on the conditions we start off with. Along the way, we played with things such as varying how fast the plasma sloshed around and removing all dark matter, to see how that changed the system's behavior.

Based on our simulations, dark matter seems to stabilize the primordial plasma, keeping density perturbations from becoming too large and sending our universe to a premature death. We've also found that the dynamics of relativistic plasma don't match what would happen in a non-relativistic plasma; given these differences, magnetic fields might more easily arise in relativistic plasmas. If the stirring created by the phase transitions is strong enough, the electroweak and QCD phase transitions may be enough to produce the magnetic fields we expect in the early universe. If the stirring is weak, however, initial magnetic fields from inflation may have been necessary.

How Will We Really Know?

To steal a phrase from one of my fellow scientists: Theory without experiment is philosophy. It's not enough to calculate what the early universe was like — we need to see our predictions verified by the cosmos we see around us. This requires observation.

100 GAUSS
Strength of a fridge magnet

10^{-6} GAUSS
Strength of the magnetic field in a Milky Way–like galaxy

10^{-15} GAUSS
Strength of the magnetic field in intergalactic space

(values approximate)

But we started out by saying that the CMB only shows us what the universe was like when it was 380,000 years old. We need an even older signal.

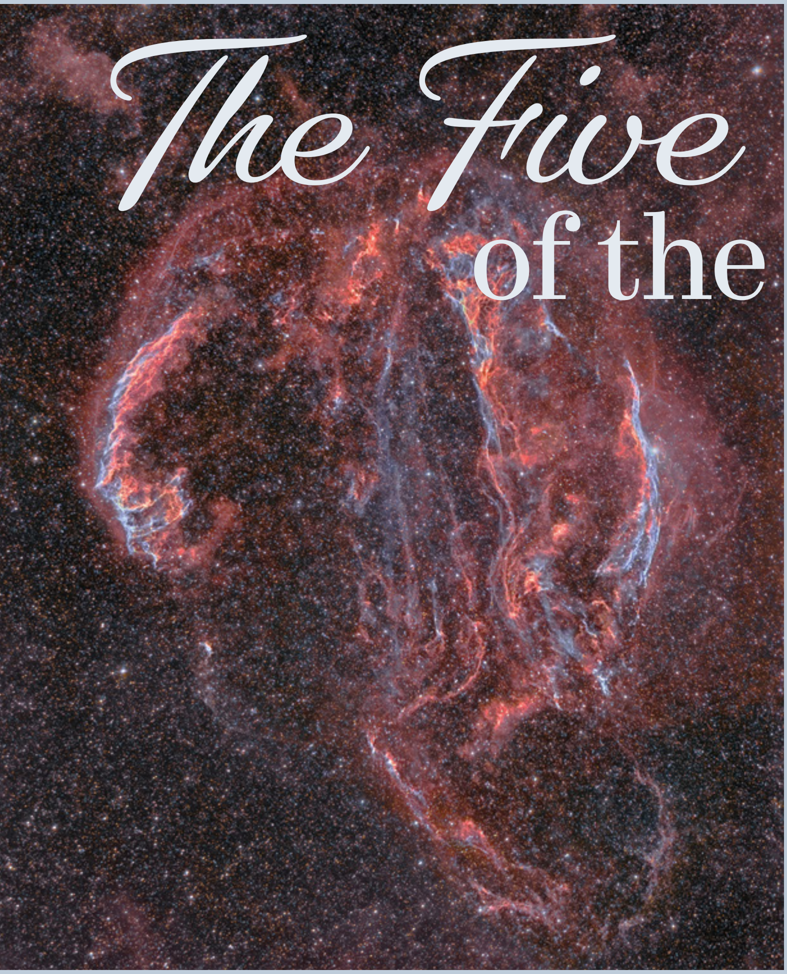
Primordial gravitational waves are our best candidate for that signal. These are waves in the fabric of spacetime that we think were produced in the first few instants of the universe by inflation and the turbulent plasma of the phase transitions. They may have left an imprint on the CMB (*S&T:* Oct. 2013, p. 22) or even a background echo that we could directly detect with future gravitational wave observatories, such as pulsar-timing arrays or the planned LISA spacecraft. These waves would have been faint, less than 5% of the tiny temperature fluctuations seen in the CMB. Still, they might be "visible" with the right technology.

The payoffs for observing these waves would be significant, since they could tell us precisely what the conditions were in the early universe. Knowing the waves' sizes and strengths would enable us to distinguish between the different scenarios that I and other researchers explore, because these waves are part of the conditions that explain magnetogenesis. Right now, all we have from observations are upper limits, and the waves might be too tiny to measure. But if we can predict the characteristics of these waves and if they can be detected, we will finally know the universe's earliest moments.

■ Physicist **DAVID GARRISON** is a professor and associate dean at the University of Houston–Clear Lake. He founded the university's physics program.

The Five Veils of the Cygnus Loop

Immerse yourself in the ethereal supernova remnant in Cygnus.



Amateur astronomers love the **Veil Nebula** because it's one of the most visually impressive deep-sky objects. As one of the nearest and brightest supernova remnants, it's an extraordinary object to professional astronomers too, but they refer to it as the **Cygnus Loop**.

Cygnus Loop or Veil Nebula, it's a rose by any other name — the result of a massive star that blew itself up in a supernova explosion long ago. An intriguing mystery is associated with the Loop: Repeated searches for the neutron star that should have resulted from the supernova event have come up empty, even after several decades. Based on indirect evidence, the progenitor star may have been approximately 15 to 20 times more massive than our Sun. It would have exploded as a core collapse supernova, which *ought* to have left behind a neutron star.

Be that as it may, recent research suggests the Cygnus Loop is approximately 2,400 light-years away, about 120 light-years in diameter, and may be as old as around 21,000 years in age. The interior of the Loop was cleared by the strong stellar wind of the progenitor star before it exploded, and the blast from the supernova continues to expand into a relatively dust-free neighborhood. This shock wave only encountered the surrounding denser interstellar clouds of dust and gas along the current supernova remnant's boundaries within the last thousand years or so. Before the shock wave reached these clouds there may not have been much to see.

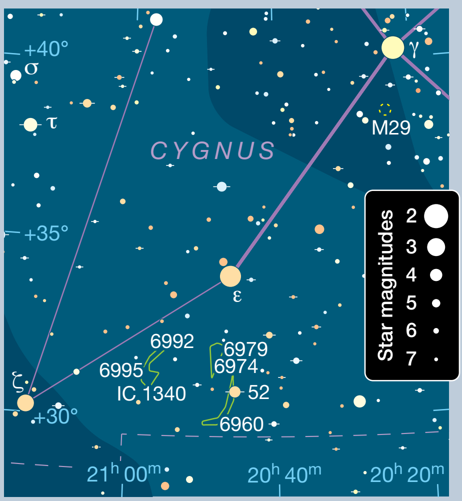
The optical emission now visible is the result of radiation from the supernova shock wave heating material in the interior of the Loop, photoionizing the dust and gas within. It radiates quite strongly in O III, which is why an O III nebula filter works so well on this object.

▲ **CELESTIAL VEILS** The full Cygnus Loop extends some 3° in the east-west direction and 4° north-south. The boundary of the supernova shock wave is marked by the faint outer streamers, with the much brighter visual elements making up what amateur astronomers call the Veil Nebula. North is at top, east to the left.

The Five Veils?

The Cygnus Loop comprises five main sections. Surprised? Me too! The two brightest arcs are the western and eastern sections, which understandably draw the most attention at the eyepiece because of their relatively bright, impressive details and mesmerizing shapes. Most observers are somewhat aware of a fainter section between the arcs, but in fact there are two, side by side. In addition, there's a little-known southern section connecting the southern ends of the two central regions. These five parts together make up the visible portions of the Cygnus Loop.

Through the course of my sketching project (see the sidebar on page 32), I've unofficially come to think of each section as an individual "Veil" and the entire complex as the Cygnus Loop. The visual intricacies of each Veil give them distinct personalities, making all five worthy of exploration.



◀ **UNDER THE CELESTIAL SWAN'S WING** Start your exploration of the Cygnus Loop by finding 52 Cygni. See page 36 for a chart of the whole constellation and refer to the author's sketches for the positions of the other features he covers in the text.

J.-P. METSÄVAINIO

The First Veil — NGC 6960

Let's begin our survey of the Veil starting with the western side of the Loop and working eastward. To see the nebula at its best, a narrowband eyepiece filter (such as an O III) and dark, moonless skies are essential.

Bright enough to be a fairly easy naked-eye star, 4.2-magnitude **52 Cygni** is the perfect place to start exploring the Cygnus Loop. No star-hopping or Go To mount is needed — just look up and point your scope at the star. If you need help, start at Epsilon (ε) Cygni, then drop about 3° due south to find 52 Cygni and the westernmost portion of the Loop.

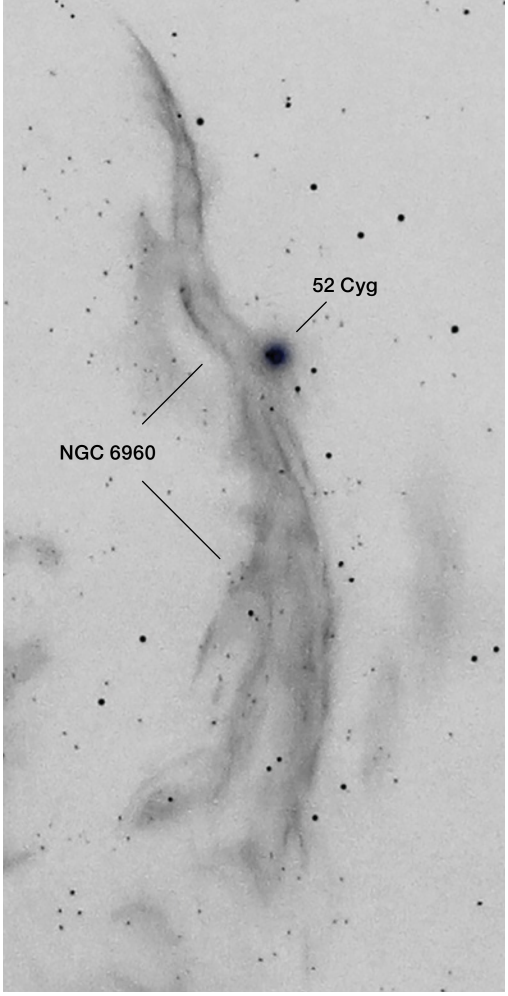
The star is seemingly poised just off the western edge of nebulosity, but is only about 200 light-years away — approximately 12 times closer than the Loop. Many observers miss the fact that 52 Cygni is also a lovely double star, designated ADS 14259. However, the fainter secondary star is obscured by an O III filter. Without a filter, the lovely soft-yellow primary is offset by its magnitude-8.7 secondary star 6.4″ due east.

Sometimes called the Witch's Broom, **NGC 6960** comprises curved, elongated wisps that gradually spread apart toward the southern end. A collection of arcs contributes to the brightest parts of NGC 6960. There are several short, relatively bright streamers along the outer western edge that are fascinating to trace along their overall length and help give this particular Veil its distinctive character.

The well-defined northern section is bright, thin, and highly detailed in a big scope, reminiscent of a monochrome photo. This part of NGC 6960 has fairly bright edges enclosing thin wisps that can sometimes impart a 3D cylindrical appearance. When north is down in the eyepiece, it looks somewhat like an ethereal tornado with 52 Cygni at its top. It has two radii, one pointed east, the other west.

The southern arcs continue branching out from one another, promoting the image of an old-fashioned straw broom, hence its popular moniker. The arcs are also richly detailed but gradually fade as they reach southward.

Even farther south is an area of vague feathery swirls and jumbled nebulosity that extends the general curve of NGC 6960. It takes a good night and some patience to see these features, but they make up about a third of the total length of the western side of the Loop. How far you can trace these faint features depends on the size of your scope and the quality of the observing conditions.



◀ **VEIL #1** Finding 52 Cygni should bring you right to the nebulosity of NGC 6960. Spend some time identifying the various arcs that make up this westernmost part of the Cygnus Loop.

The Second Veil — Fleming's Triangle

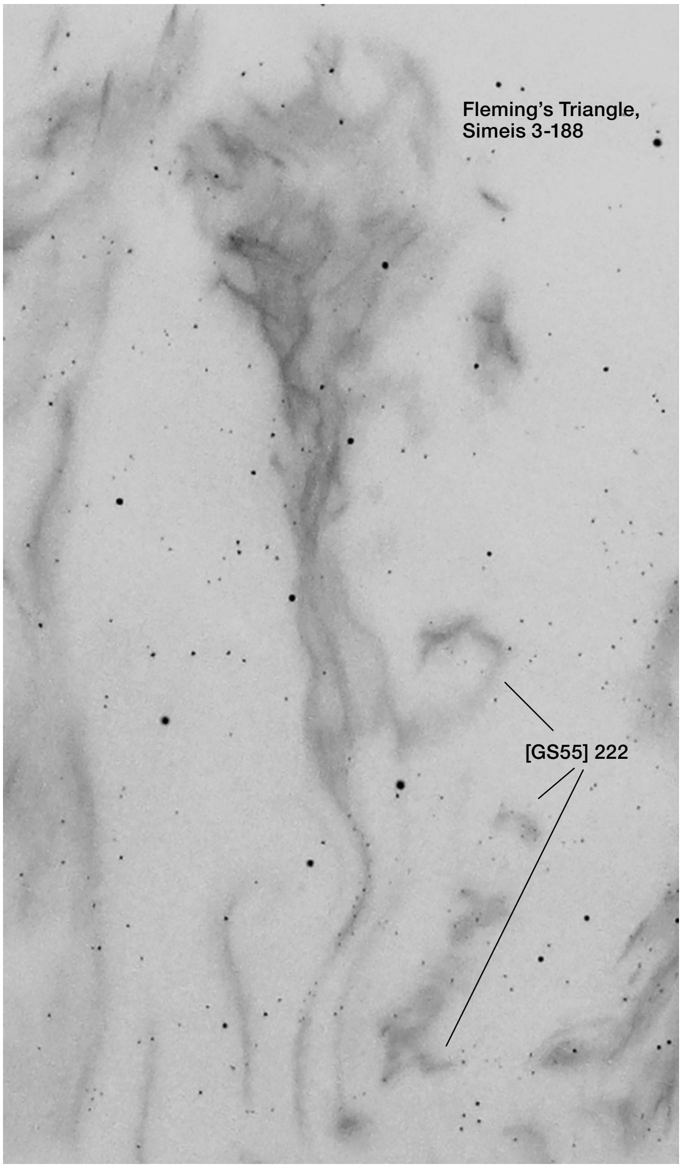
This section of the Cygnus Loop, **Simeis 3-188**, is moving away from us, which puts it on the far side of the Loop's expanding bubble. Generally known as Pickering's Triangle (after E. C. Pickering, director of the Harvard College Observatory from 1877 to 1919), it was actually discovered by Williamina Fleming in 1904 on a glass photographic plate. At the urging of his wife, Pickering hired Fleming in 1879 to do part-time administrative work at the Observatory, and two years later she engaged in astronomical research. It was common practice at the time for the head honcho to get the credit for the work of his subordinates, but Fleming is the undisputed discoverer, so here I'll refer to it as **Fleming's Triangle**.

This area is generally fainter and less spectacular than the First Veil, but it's still the third-brightest section of the Cygnus Loop. The wispy, northern triangular area gradually tapers to the south and a long, curvy, and rather delicate tail extends even farther south. To me it looks like a kite flying in moonlight.

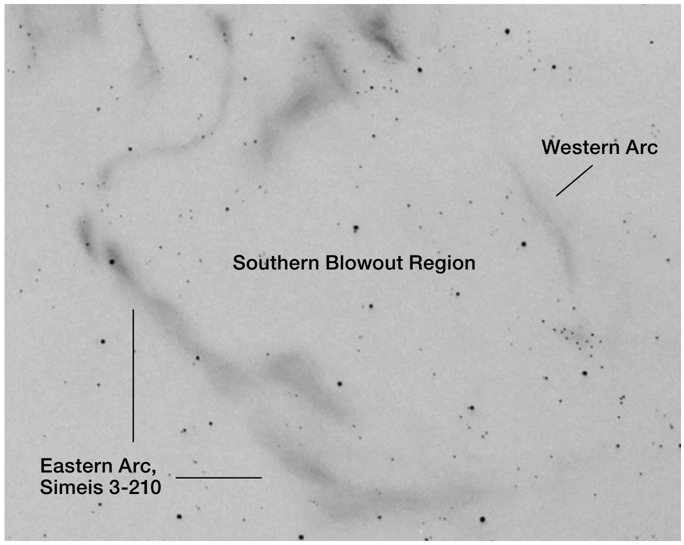
The eastern side of the northern triangular area is the brightest and includes some wonderfully intertwined streamers. Farther south, I enjoy spending time on a strongly curved streamer in the tail that's seemingly peppered with more than a dozen faint stars. It's tempting to think the stars give the impression of nebulosity, but that's not the case here. And don't overlook several patches of nebulosity floating between Fleming's Triangle and the First Veil designated **[GS55] 222**. They're easy to pass by unless you deliberately seek them out.

▶ **SHOCK WAVES** This composite image of X-ray (blue), ultraviolet (grayish white), and infrared (dark blue and red) data highlights how the expanding supernova shock wave is sculpting the Cygnus Loop as it encounters pre-existing clouds. It shows how the Loop is expanding more readily north and south toward relatively dust-free areas. Superposed in white is the visual emission. The bright dot left and slightly below of center is the Southeastern Knot that I note in my description of the Fifth Veil (see the sketch on page 32).

SKETCH: HOWARD BANICH; X-RAY: NASA / R. FESEN / MONTHLY NOTICES OF THE ROYAL ASTRONOMICAL SOCIETY 2018



▲ **VEIL #2** The tail of Fleming's Triangle closes in on the First Veil the farther south one looks. Keeping track of what's what in these far southern reaches requires concentration.



▲ **VEIL #3** The Southern Blowout Region presents a challenge for observers, but if you manage to see these delicate features, especially the Western Arc, you'll be richly rewarded.

The Third Veil — Southern Blowout Region

As you reach the southern limit of the tail of Fleming's Triangle, you come to the **Southern Blowout Region** (SBR). This area is faintly involved with Fleming's Triangle and the Fourth Veil at their wispy southern ends. The brightest part is the **Eastern Arc** of the SBR, also designated **Simeis 3-210**. To me, this is the most unexpected Veil, and I'm flabbergasted I never thought to look for it until I started this project — it's far from being the faintest area of the Loop.

Research first suggested the SBR might be the wisps of a separate supernova explosion overlapping the Cygnus Loop. But we now know it to be an area of low interstellar dust density where the supernova shock wave has simply traveled farther due to less resistance. The brighter Eastern Arc is a fascinating series of streamers blended together that extend a degree southwest from the main bubble of the Loop and — another surprise — is mostly over the border in neighboring Vulpecula. Fairly straight at its northern end, it divides into two segments — a bright knot in each branch makes this clear. The main branch curves almost due west at its southern end, gradually disappearing before it could merge with the Western Arc.

By far the most visually challenging part of the entire Cygnus Loop, the **Western Arc** of the SBR flows mostly north-south. I could barely see a couple of wisps with determined averted vision, so to confirm my observation I slowly scanned back and forth and noted where the sky background looked a little brighter. Although quite subtle, those wisps may not be the only parts of the Western Arc of the SBR that are visible.

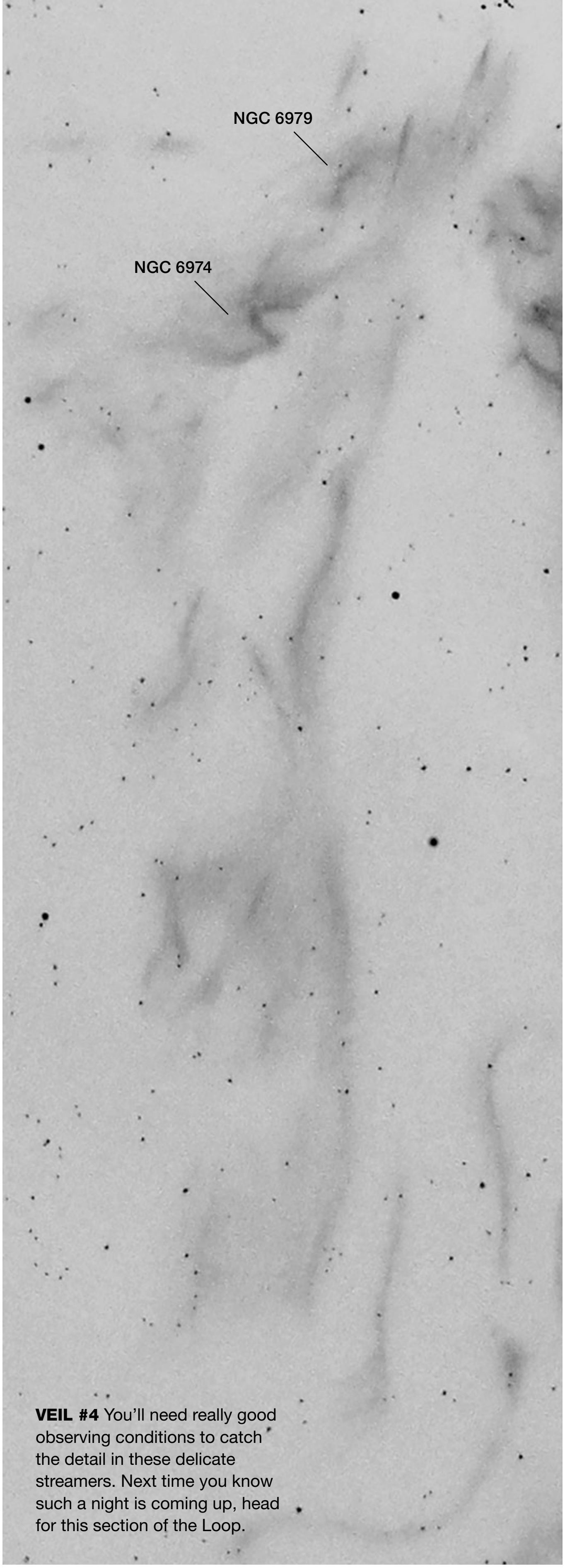
At the southern end of the First Veil are two relatively bright streaks of nebulosity that point directly at the Western Arc. I don't know if that means they're all part of the same arc, but it sure looks like they could be. If so, they would be the easiest bits of the entire Third Veil to see.

The Fourth Veil — NGC 6974, NGC 6979, and Assorted Filaments

It didn't strike me until I began sketching **NGC 6974** and **NGC 6979** that they're just the brightest areas of nebulosity that parallel Fleming's Triangle to their west. The more I sketched, the more I saw, until I realized this extensive feature is its own Veil. The softly glowing wisps of the Fourth Veil have enough streamers and patches to connect them into a visually coherent, separate section of the Loop. It meanders southward until it nearly connects with the SBR. This Veil is expanding toward us on the near side of the supernova shock wave bubble.

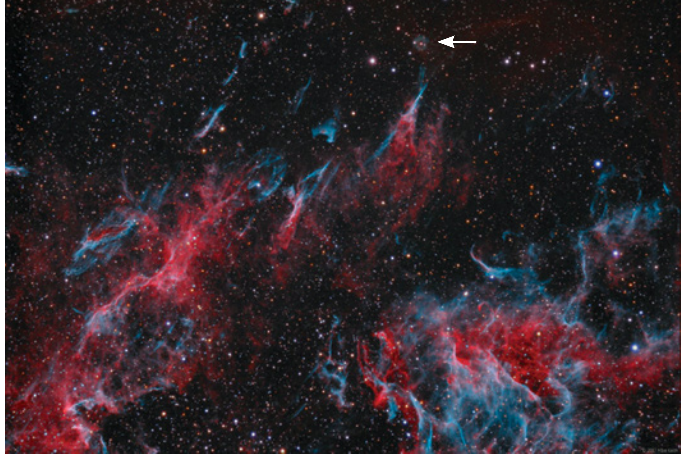
Make no mistake: Most of the Fourth Veil is challenging to see and is only accessible to those observing under a truly dark and transparent sky. Its overall character is of soft, smoothly curving, and difficult-to-see nebulous streamers. If we could

HOWARD BANICH (2)



VEIL #4 You'll need really good observing conditions to catch the detail in these delicate streamers. Next time you know such a night is coming up, head for this section of the Loop.

SKETCH: HOWARD BANICH; PLANETARY NEBULA: MIKE KEITH



▲ **ELUSIVE BUBBLE** Following a possible detection, I and my observing buddies proved unable to bag the elusive planetary nebula (arrowed). Let me know if you manage to spot it (or have already seen it)!

observe them edge-on, they would appear much brighter. At the Veil's southern end, positioned somewhat between Fleming's Triangle and the Fourth Veil as a whole, is a thin, faint wisp that makes a graceful right-angle curve eastward, leading to the Eastern Arc of the SBR. This is a challenging but delightful wisp to see well.

The NGC designations of the brightest knots at the northern end of this Veil indicate that many amateur-size scopes can see them under a halfway decent sky. To my eye they're almost as accessible as the bright section of Fleming's Triangle.

A fascinating area to seek out are three short streaks that crown NGC 6979, which remind me of *light pillars*, an optical phenomenon in which a beam of light appears to extend up into the atmosphere. That's not the case here, though. The easternmost of the three streaks is the faintest and is neatly bracketed by a trio of stars. The westernmost is actually a double streak and points almost directly at Patchick 27, a suspected planetary nebula a few arcminutes away.

American amateur Dana Patchick discovered the planetary nebula candidate, which is probably not associated with the Loop, in 2014. In 2018 I had a "maybe" detection with my 28-inch scope. A year later, along with Jimi Lowrey and *Sky & Telecope* Contributing Editor Steve Gottlieb, we were skunked twice using Jimi's 48-inch scope. Other highly experienced observers have reported positive observations, but for now I'm not convinced Patchick 27 is a visual object. Perhaps its detection depends on which filter is used as much as the sky conditions and telescope.

The Fifth Veil — NGC 6992, NGC 6995, IC 1340, and the Southeastern Knot

This is my favorite section of the Cygnus Loop: It actually looks like the result of an explosion. It's also the brightest and most richly detailed portion, and every observer seems to have their own nickname for it. To me it looks like a garden claw tool.

At summer star parties the Fifth Veil is certain to create a line at my 28-inch scope, and people almost always come away shaking their heads in amazement. Under the best conditions it looks three-dimensional. As is true for the entire Cygnus Loop, the Fifth Veil is being sculpted by the supernova shock wave interacting with pre-existing interstellar dust clouds.

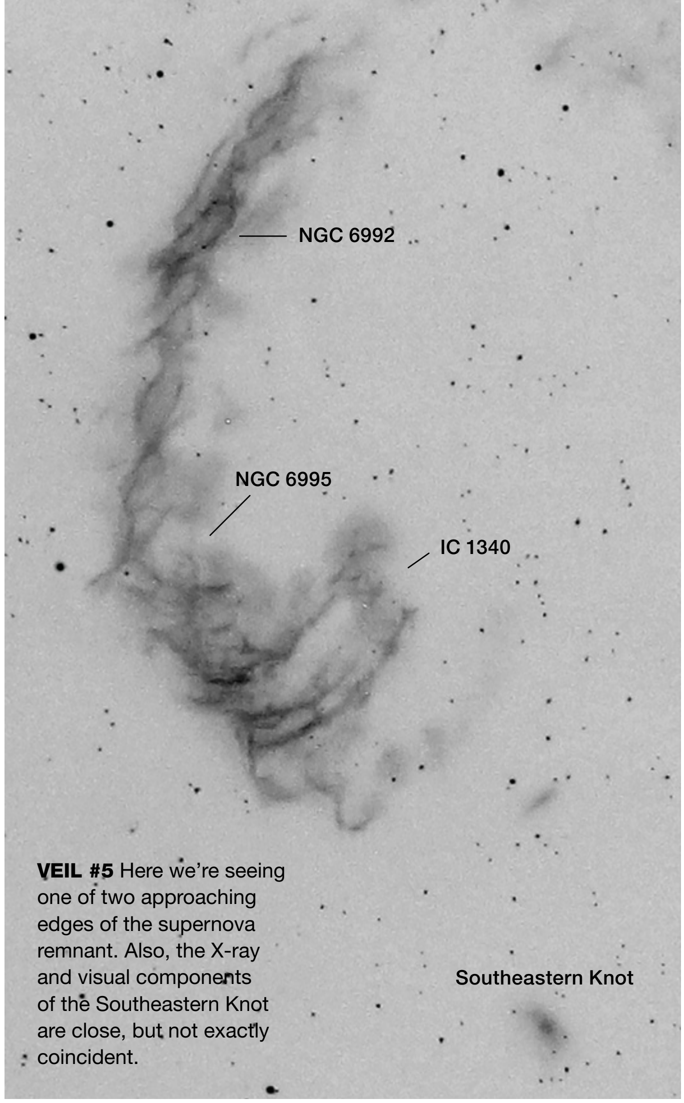
Studies have shown the Fifth Veil to be slightly closer to us than the First Veil, and, combined with Fleming's Triangle on the far side and the Fourth Veil on the near side, we now have a feel for the 3D arrangement of most of the Cygnus Loop.

The northern half of the Fifth Veil, **NGC 6992**, looks much like a curved, twisted rope of nebulous fibers, which become more distinct as they extend into the area of **NGC 6995**. A smidgen farther south, a series of three east-west curvilinear, ragged wisps look like shattered cirrus clouds. These are a combination of NGC 6995 and **IC 1340** and constitute my single favorite field of view of the entire Cygnus Loop.

Paralleling the northern edge of NGC 6992 is a series of small, faint nebulae that arc westward toward the Fourth Veil, nearly connecting with it near NGC 6979. Faint extensions along the inner perimeter of NGC 6992 not only make this region look wider but also slightly more three-dimensional.

South of IC 1340 hangs a faint, puffy extension that's difficult to see but mimics the general shape and direction of IC 1340's curvilinear outline. At the base of this area a wonderful nebulous squiggle projects southward like a signature flourish.

And now, another surprise. About half a degree south of that squiggle is an isolated but fairly bright little knot of nebulosity dubbed the **Southeastern Knot**. Arguably the most fascinating bit of the Cygnus Loop, it's remarkable for being the early stages of the supernova shock wave encountering a cloud of gas and dust. Associated with a notable source of X-rays, it's also fairly bright visually. Quite likely this knot will become considerably larger and brighter in the next few hundred years or so. Maybe it's just me, but *WOW*!



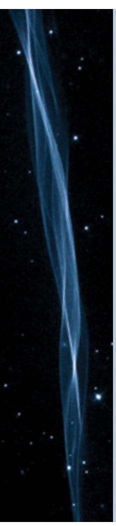
VEIL #5 Here we're seeing one of two approaching edges of the supernova remnant. Also, the X-ray and visual components of the Southeastern Knot are close, but not exactly coincident.

VEIL TEXTURE: NASA / ESA / HUBBLE HERITAGE TEAM; SKETCH AND ARTIST: HOWARD BANICH (2)

All Together Now

Although the various sections of the Loop are amazing to explore bit by bit with a large telescope, it's rather like examining an elephant with a magnifying glass. A short-focus telescope — such as the homemade 8-inch f/3.3 scope I rebuilt a few years ago (*S&T:* Sept. 2020, p. 58) — allows one to see the entire Loop at once. It produces a 3.5° true field of view with a 25-mm 100° eyepiece. Equipped with an O III filter, it delivered a spectacular view under the dark skies of central Oregon.

The 3° diameter of the main bubble of the Cygnus Loop fits beautifully in the 3.5° field of view. This highly rewarding sight highlights the Loop's just-cracked-egg look due to the southern area's more spread-out appearance, which is somewhat misleading, though, because the actual shock



Notes on Sketching

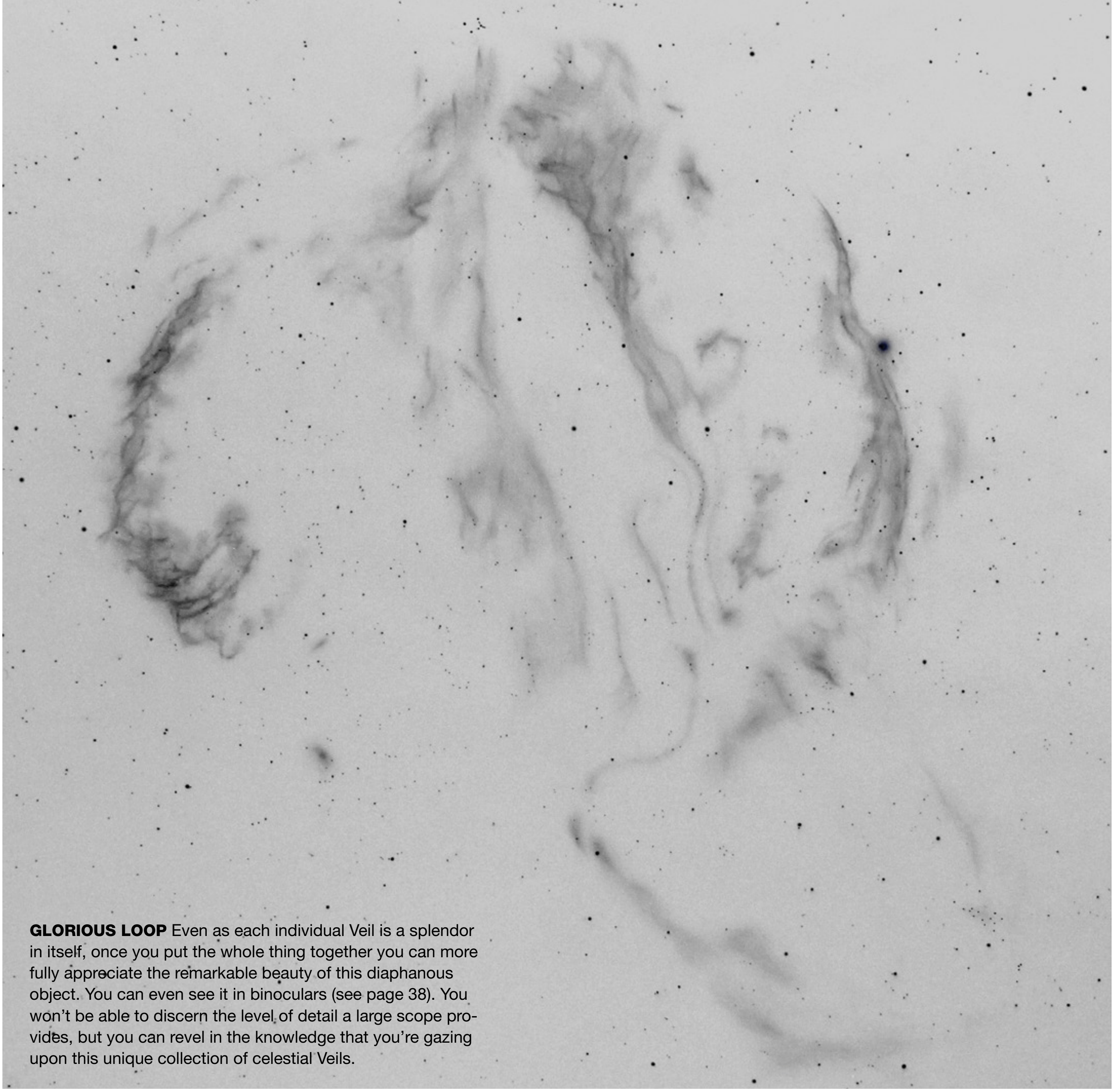
My original goal was to only make renderings of the three brightest sections of the Veil Nebula as seen with my 28-inch scope from the dark skies of central Oregon's high desert. I'd observed the brighter parts of the Loop for 30 years but never sketched them.

At the start of the project, I set up three 15 × 16-inch sketching clipboards to use at the eyepiece. Then I lightly traced the outline of the three brightest sections of the Cygnus Loop from photographs so I could depict details in their correct places and proportions. A useful rule of thumb is to draw at a size that allows the smallest detail to be clearly shown, hence the large sketching clipboards.

Combining the individual eyepiece sketches of all five Veils into one drawing of the Loop required a 32-inch-square piece of paper. This allowed me to transfer all the detail I'd recorded in my eyepiece sketches to the finished pencil drawing without any loss.

I didn't count, but there are *many* overlapping fields of view represented in the finished drawing. It shows what the entire Cygnus Loop would look like through my 28-inch scope if it had a wide enough field of view — or if the 8-inch f/3.3 scope could produce an image as bright and detailed as the 28-inch.

The two telescopes gave such different views that I consider them both essential to the success of the project. Even though I did all my eyepiece sketching with the 28-inch, without the 8-inch scope I wouldn't fully appreciate the impact of the Cygnus Loop as a single object. It was the view through the 8-inch that changed how I think about this beautiful supernova remnant.



GLORIOUS LOOP Even as each individual Veil is a splendor in itself, once you put the whole thing together you can more fully appreciate the remarkable beauty of this diaphanous object. You can even see it in binoculars (see page 38). You won't be able to discern the level of detail a large scope provides, but you can revel in the knowledge that you're gazing upon this unique collection of celestial Veils.

HOWARD BANICH

wave (as revealed by soft X-ray studies) is mostly spherical. It's the clumpy dust and gas clouds arrayed around the perimeter of the shock wave that give the Loop its asymmetrical look in visual wavelengths.

The First and Fifth Veils stand out the most in the 8-inch scope, but it's surprisingly easy to trace out the full north-to-south extent of Fleming's Triangle. Details are too small to see at the low magnification of 27×, but it's all there. Amazingly, so is the entire Fourth Veil. It's fainter than Fleming's Triangle, so I can barely discern its full length. I could even spot the brightest bit of the Eastern Arc of the SBR, which is a little easier to see than the southern parts of Fleming's Triangle and the Fourth Veil. Although informed by my observations with the 28-inch scope, the view the 8-inch produced under a top-notch sky was an extraordinary sight all on its own.

Seeing the actual wisps of the Cygnus Loop in one incredible field of view — and understanding their relative positions along the perimeter of the supernova shock wave bubble — boosted my appreciation of the ferocity of their formation. The long-ago supernova is enriching the interstellar medium with ingredients for the next generation of stars and all that comes with them. And at the same time it's providing both a spectacular show and is an inspiring object of research. No wonder we all love this object.

We're beginning to understand how the Loop became one of the most impressive objects in the summer and autumn sky, and we have hints of how it may continue to evolve. I can't help but wonder what it will look like in a few hundred years.

■ Contributing Editor **HOWARD BANICH** nevertheless is grateful that our corner of the Milky Way has such a fabulous view right now. He can be reached at **hbanich@gmail.com**.

Touring Cygnus with Binoculars

The celestial Swan is rich with Milky Way treasures for observers with binos and small scopes.

On summer evenings, Cygnus, the Swan, soars high overhead, winging its way along the hazy band of the Milky Way toward the galactic center. The constellation is full of bright star fields, hazy nebulae, and numerous clusters that help reveal something of the structure of our home galaxy.

This is the fifth binocular tour in our series. Previously we explored the Milky Way from Canis Major to Hydra (*S&T:* Dec. 2015, p. 32); Monoceros to Gemini (*S&T:* Mar. 2017, p. 30); Perseus to Auriga (*S&T:* Jan. 2018, p. 60); and, most recently, Cepheus to Cassiopeia (*S&T:* Oct. 2019, p. 28). Now it's time to delve into the Cygnus Milky Way.

I made my observations with 15×70 binoculars, which have a true field of view of 4.4°. But I expect most targets included here will be visible in smaller binoculars with magnifications in the 7× to 10× range. A rich-field telescope, such as a small reflector or short-tube refractor, would also work well for these Cygnus targets. Indeed, I often find a small scope is helpful for confirming my binocular sightings, or for follow-up observing sessions. So, grab your favorite starcatcher and let's take wing.

Getting Oriented

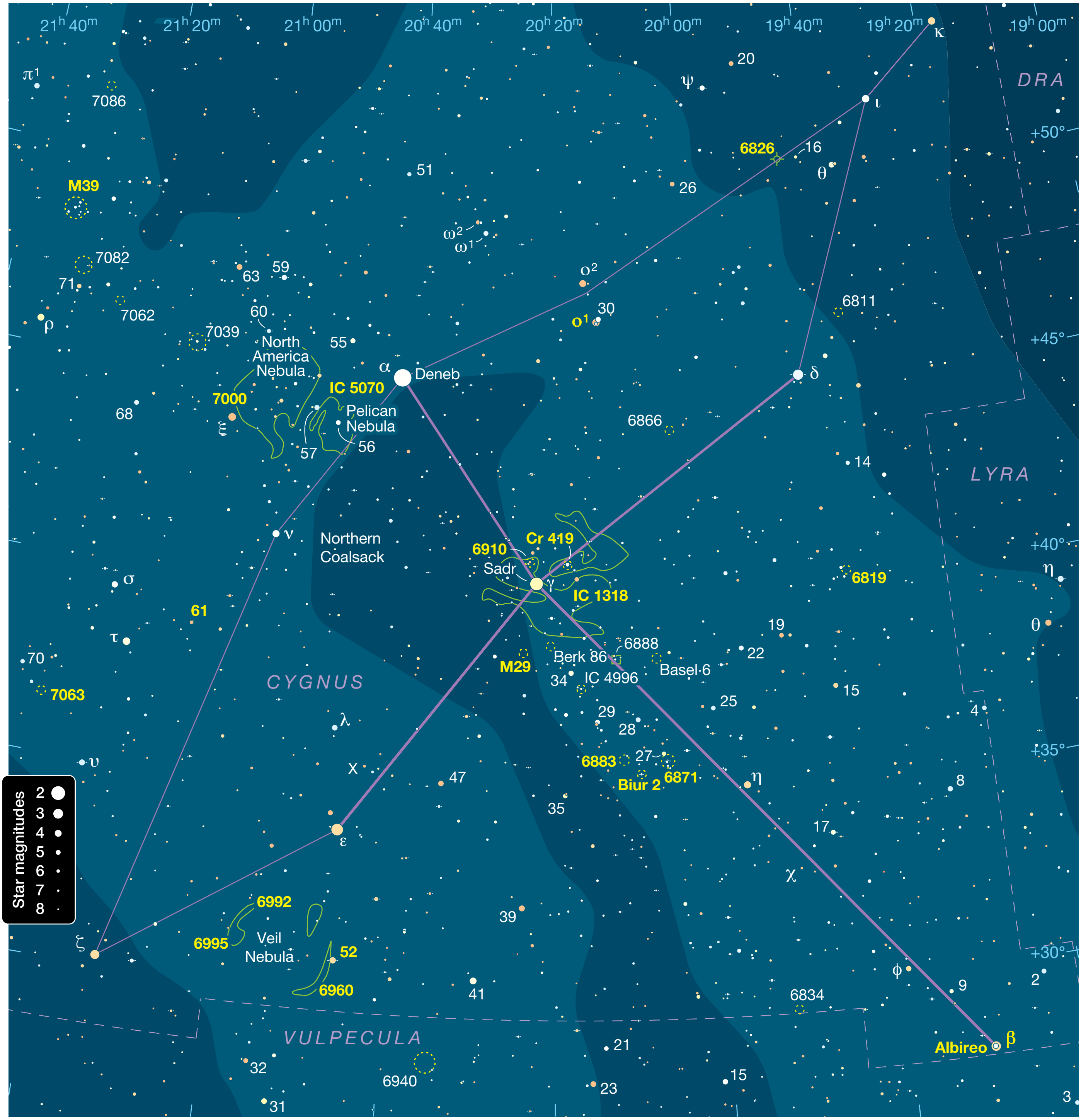
Before taking up optics, spend a moment to admire Cygnus with your unaided eyes. The first thing that jumps out is the distinctive Northern Cross asterism with its long axis formed by Alpha (α) Cygni (Deneb), Gamma (γ) Cygni (Sadr), and Beta (β) Cygni (Albireo), and the cross piece marked by Delta (δ) and Epsilon (ε) Cygni. Now imagine the cross is a south-flying swan and note the pleasing symmetry of its wings, with Iota (ι) and Zeta (ζ) Cygni as the northwestern and southeastern wingtips, respectively.

Finally, check out the wide, naked-eye doubles in the trailing edges of the wings: Omicron^1 (o^1) and Omicron^2 (o^2) Cygni in the northwestern wing, and Sigma (σ) and Tau (τ) Cygni in the southeastern wing. The stars in both pairs are nearly equally bright, and when they're oriented horizontally in the sky, they seem to stare back like pairs of spooky eyes!

Let's start our binocular exploration at the head of the Swan, with the alluring double star **Albireo**. Some of you will already have noticed that I've singled out this star for special treatment as September's Binocular Highlight on page 43. I'm using Albireo as the jumping-off point for our tour, so when you're ready to move on, consult the star chart on page 36 and scan northeast along the axis of the constellation to Eta (η) Cygni. About 3° east-northeast of Eta you'll find 28 Cygni and a pair of curious star chains that arc southwards to a set of open clusters. The western arc leads to **NGC 6871**, while the eastern arc terminates with **NGC 6883** and **Biurakan 2**. None of these objects stands out distinctly from

◀ **STREAM OF STARLIGHT** Given its large size and prime location in the heart of the summer Milky Way, Cygnus is, perhaps surprisingly, home to only two Messier objects: M29 and M39. However, for the careful binocular observer there are many additional delights, including faint nebulae, double stars, and a host of lesser-known open clusters.

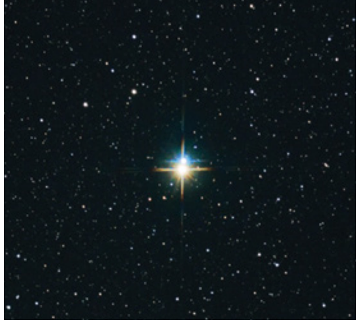
ALAN DYER



the background star field, but collectively they help define their respective arcs. I don't know if the arcs have ever been named, but they make me think of a sloppily stacked hamburger bun with a patty of dark sky between them.

For an even richer view, turn to Sadr at the very center of the constellation. *Sadr* is derived from the Arabic word for "chest," and by coincidence the star at the heart of the Swan is surrounded by a heart-shaped asterism about 2° across. The heart is formed by a ring of 6th-magnitude stars, which bends inward at its northwest margin. The binocular field is enriched by a trio of open clusters. **NGC 6910** and **Collinder 419** lie on the border of the heart asterism, to the north and northwest of Sadr, respectively.

Just south of the heart you'll find 6.6-magnitude **M29** — the easiest of the three clusters to recognize as a distinct object. By contrast, you'll need patience and determination to pick out NGC 6910 and Collinder 419 from the brighter, foreground stars. Finally, if you're observing under exceptionally dark skies, you may detect **IC 1318** as a vast field of faint nebulosity enclosing Sadr like the petals of a flower.



◀ **BEAUTIFUL BETA** Our binocular tour begins with the lovely double star Albireo, Beta (β) Cygni, located at the foot of the Northern Cross asterism. The stellar duo are a difficult split in binoculars but easy in small telescopes.

Winging It

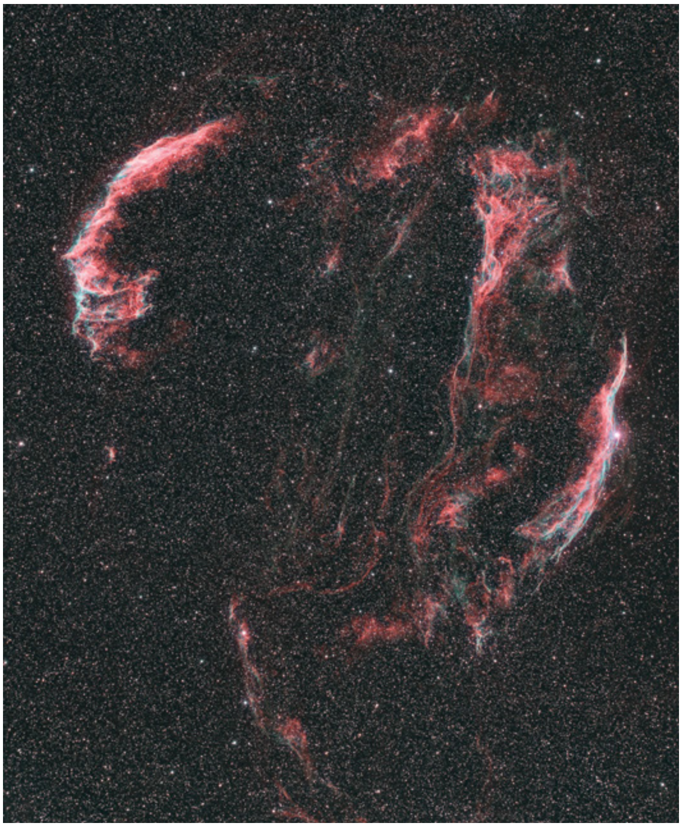
We'll find more nebulae and clusters in the wings of the Swan. But first, scan 8° due west of Sadr, and look for a little, sideways Y-shaped asterism comprising three 7th-magnitude stars and one of 6th magnitude. Spilling out of the western end of the Y like fruit from a cornucopia is the open cluster **NGC 6819**. It doesn't show much detail at binocular magnifications, but that's mainly because it's 7,700 light-years away. That's quite distant for such a bright cluster and means that everything else in the surrounding binocular field is much closer. Cygnus is full of rich, deep views like this, with multiple objects lying at different distances along the same line of sight. Each vista offers tantalizing insights into the local structure of our galaxy.

The binoculars-and-telescope advice I offered earlier goes double for the next object on our tour, **NGC 6826**. Better known as the Blinking Planetary, look for the tiny nebula ½° due east of 6th-magnitude 16 Cygni, on the trailing edge of the western wing. The object is so named because in telescopes the delicate oval of light blinks out when you look at it directly, leaving only its 10.6-magnitude central star in view. It's a curious effect that nicely demonstrates the difference between *direct* and *averted* vision. At binocular magnifications, however, the trick is recognizing the tiny nebula at all. As much as I prefer freehanding my binoculars, putting them on a mount or resting them on a convenient fence post really helps me pick out NGC 6826 as a slightly fuzzy, 8.8-magnitude "star."

Now, let's glide 6° southeast to the naked-eye double formed by Omicron^1 and Omicron^2 Cygni. **Omicron^1 Cygni** (the more southern of the pair) holds a nice surprise for binocular observers — along with 30 Cygni and HD 192579, it forms an optical triple star. The component suns aren't gravitationally bound to one another, they simply appear close in the sky as seen from our earthly perspective. Omicron^1 is a 3.8-magnitude orange giant, 30 Cygni is a 4.8-magnitude white giant, and HD 192579 is a 7th-magnitude blue-white

▲ **RICH FIELD** The Cygnus Milky Way is replete with subtle splendor, including open cluster M29, positioned left of center in this image. The star at lower right is the variable P Cygni, while the top of the frame glows pinkish-red with the faint haze of IC 1318.

ALBIREO: GARY SERONIK; M29 FIELD: ALAN DYER



main-sequence star. Together they are sometimes referred to as the Patriotic Triple, because of their red, white, and blue hues. I find the colors most intense at lower magnifications, but the perception of star colors varies immensely among observers, so check for yourself.

Loop back down to Sadr and trace the Swan's eastern wing out to Epsilon, then proceed south to 4.2-magnitude 52 Cygni. This is where you'll find the **Veil Nebula** — the finest supernova remnant in the night sky. More than 20,000 years ago, a massive star blew itself apart here, and millennia later we're left with faint wisps of light, scattered across a full 3°. At the remnant's distance of 2,400 light-years, that corresponds to a width of some 120 light-years. Catalogs list the eastern arc of the Veil Nebula as NGC 6992 (the northern part) and NGC 6995 (southern part), and the western arc (near 52 Cygni) as NGC 6960. Whatever you call them, each wisp requires good skies and fanatical attention to dark adap-

◀ **GONE BUT NOT FORGOTTEN** The Veil Nebula is all that remains today of a massive star that exploded some 20,000 years ago. As with other nebulae in Cygnus, careful hunting and pristine dark skies are musts for detecting the Veil in binoculars.

▼ **NORTHERN NEBULA** Located in northern Cygnus, just east of Deneb, is one of the constellation's best-known deep-sky objects, the North America Nebula. Spanning nearly 2° from "coast to coast," the nebula shows up surprisingly well in binoculars if sky conditions are sufficiently dark. To its right is the Pelican Nebula — a much more difficult find.

VEIL NEBULA: RON BRECHER; NORTH AMERICA NEBULA: MASIL IMAGING TEAM tation to see them. Many observers report good results with narrowband nebula filters, but that's something I haven't tried yet with this object. From my favorite observing spots in the Mojave Desert, the various parts of the Veil swim into binocular visibility like seashells in the surf — delicate and tenuous, but undeniably real. Turn to page 28 for more on this fascinating target.

Northeast of the Veil Nebula, a wide triangle formed by Epsilon, Zeta, and Upsilon (υ) Cygni points toward the 7th-magnitude open cluster **NGC 7063**. Looking back at my old observing notes I see that my original description of it reads "compact, round, and evenly lit — a very nice open cluster." Nothing in the intervening years has changed my assessment. If your eyes are very sharp, you may also detect what appears to be a dark, starless band cutting northwest to southeast between the cluster's brightest stars. Do you see it?

Northwest from NGC 7063 is the naked-eye optical double formed by Sigma and Tau Cygni. Making a triangle

▶ **IMPRESSIVE EXPANSE** The summer Milky Way is aglow with faint starlight, but equally prominent are the numerous dark nebulae that bisect our home galaxy. The most conspicuous of these is the Great Rift, which extends southward from Cygnus, through Aquila, and down into Sagittarius.

▼ **ALMOST LOST IN SPACE** The rich backdrop of the Cygnus Milky Way makes identifying some open clusters a little tricky. However, M39 stands out better in binoculars than this photo suggests.

ALAN DYER (2)

with them is **61 Cygni**, or Piazzi's Flying Star. It's named after the Italian astronomer who first noticed the star's unusual habit of not sitting still in the sky. Arguably one of the most interesting stars in the heavens, 61 Cygni is both a true double *and* a high-proper-motion star, meaning that it's moving quickly across the sky. "Quickly" in this case means 5″ per year, or roughly 1° every 720 years. To put it another way, it takes about eight years for Piazzi's star to move one Jupiter diameter. Its rapid apparent motion is partly due to its proximity — only 11.4 light-years away. Most double stars are too distant to split with handheld binoculars, but 61 Cygni is near enough that it's worth a shot. With a current separation of 31.8″, this pair is a bit tighter than Albireo, whose colorful components are 34.6″ apart. I find I need at least 15× to crack 61 Cygni's 5.2- and 6.0-magnitude stars.

Faintly Familiar

As you shift your gaze from the Swan's eastern wing back to Deneb, you may encounter a vast field of nebulosity with a familiar shape. This is the North America Nebula, **NGC 7000** — an immense emission nebula that looks remarkably like its namesake. At my favorite camping area near the Salton Sea in California, the nebula is visible to the naked eye and shows considerable detail in binoculars. In particular, look for the embayment on the southwestern side (in the sky!) that corresponds to the Gulf of Mexico. If skies are exceptionally clear and dark, you may also detect a glowing patch floating where the Atlantic Ocean should be. That's the Pelican Nebula, **IC 5070**. It's a much tougher catch thanks to its lower surface brightness and the presence of a couple of bright foreground stars competing for attention.

About 9° northeast of Deneb is **M39**, the best binocular open cluster of the tour. Whereas many of the other clusters I've mentioned are too small or faint to offer much resolution, even 7× binos will show M39 to be a roughly triangular arrangement of 6th- to 8th-magnitude stars. A scattering of lesser lights adds to the cluster's glow and helps pull it out from the surrounding star field. Photographs show the blue-white stars of M39 set against a background of predominantly yellow field stars. I've yet to detect these colors in binoculars, but M39 is pretty and complex enough that I return to it often.

The final stop of our tour is worth exploring with binoculars, but it may be best appreciated without optics. Look for a dark patch of sky between the North America Nebula and Sadr. This is the **Northern Coalsack**, a particularly dense knot of interstellar dust in the plane of the Milky Way. Broaden your view to encompass the whole galactic band, and you'll see the Coalsack as the start of a dark slash that cuts through the bright star fields of the Cygnus Milky Way, paralleling the spine of the Swan. That dark river is part of the famous **Great Rift**, which runs southward toward the galactic center in Sagittarius. The Great Rift isn't a hole in the Milky Way but rather one of the dust lanes that clot the spiral arms of our galaxy.

Cygnus is so rich that just when I think I've seen it all, I'll stumble across a previously overlooked cluster, asterism, or beautiful double star. For this tour I've only described a handful of the constellation's best and brightest objects. Cygnus will reward a more patient exploration — its open clusters alone could keep a determined observer busy for a whole season. But do yourself a favor and set the binoculars down occasionally to appreciate how much of the grand structure of our home galaxy can be seen with your eyes alone. We're part of that picture — soaring through the Milky Way along with Cygnus. And we have so much to explore.

Selected Binocular Targets in Cygnus

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Albireo	Double star	3.2, 4.7	34.6″	$19^h\ 30.7^m$	+27° 58′
NGC 6871	Open cluster	5.2	30′	$20^h\ 06.5^m$	+35° 47′
NGC 6883	Open cluster	8.0	35′	$20^h\ 11.3^m$	+35° 51′
Biur 2	Open cluster	6.3	12′	$20^h\ 09.2^m$	+35° 29′
NGC 6910	Open cluster	7.4	10′	$20^h\ 23.2^m$	+40° 47′
Cr 419	Open cluster	7.6	5′	$20^h\ 18.1^m$	+40° 44′
M29	Open cluster	6.6	10′	$20^h\ 24.1^m$	+38° 30′
IC 1318	Emission nebula	—	50′ × 30′	$20^h\ 22.2^m$	+40° 15′
NGC 6819	Open cluster	7.3	5′	$19^h\ 41.3^m$	+40° 11′
NGC 6826	Planetary nebula	8.8	36′	$19^h\ 44.8^m$	+50° 32′
Veil Nebula	Supernova remnant	—	2.9°	$20^h\ 51^m$	+30° 48′
NGC 7063	Open cluster	7.0	9′	$21^h\ 24.2^m$	+36° 29′
61 Cyg	Double star	5.2, 6.0	31.8″	$21^h\ 06.9^m$	+38° 45′
NGC 7000	Emission nebula	5.0	120′ × 100′	$20^h\ 59.3^m$	+44° 31′
IC 5070	Emission nebula	8.0	60′ × 50′	$20^h\ 51.0^m$	+44° 24′
M39	Open cluster	4.6	31′	$21^h\ 31.9^m$	+48° 26′

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

■ Contributing Editor **MATHEW WEDEL** has been writing this magazine's Binocular Highlight column since June 2016.

3 DAWN: Kick the month off by looking east to see the waning crescent Moon, Pollux, and Castor equidistant from one another in a tidy line.

4 DAWN: The thinnest sliver of a Moon is about 4° from the Beehive Cluster (M44) in Cancer.

4 DUSK: Low in the west-southwest, Venus, the Evening Star, is less than 2° from Virgo's lucida, Spica (see page 46 for further details on this and other events listed here).

5 DAWN: At northern latitudes, the soft glow of the zodiacal light should be visible in the east beginning some two hours before morning twilight. Find a dark viewing spot and look for a faint, hazy pyramid of light tilted toward the right, stretching up through Cancer and Gemini into Taurus. You should be able to enjoy this sight for the next two weeks.

9 DUSK: The Moon, three days past new, joins Venus in Virgo, while Spica flickers lower right of the pair. Around 3½° separates the lunar crescent from the planet.

9 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:55 p.m. PDT.

12 DUSK: The waxing crescent Moon and the Scorpion's heart, Antares, sink in tandem toward the southwestern horizon, some 3° apart.

12 EVENING: Algol shines at minimum brightness for roughly two hours centered at 11:44 p.m. EDT.

15 EVENING: Look toward the south-southeast to see the Moon, Saturn, and Jupiter form a graceful line.

16 EVENING: The Moon approaches Saturn and sits a bit more than 4° lower right of the Ringed Planet.

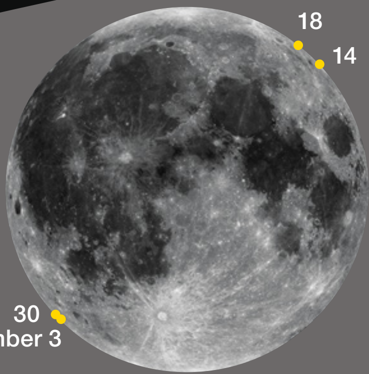
17 EVENING: Tonight it's Jupiter's turn for a lunar visit — a fatter gibbous Moon hangs 5½° lower right of the gas giant.

26 DAWN: Get out of bed early and look high above the southwestern horizon to spot the attractive sight of the Moon about halfway between Aldebaran and the Pleiades.

30 DAWN: The month concludes as it began with the waning crescent Moon back in Gemini, around 2½° separating it from Pollux.
— DIANA HANNIKAINEN

▲ Cygnus, the Swan, soars high on September evenings. Turn to page 34 for a delightful binocular tour, and to page 28 for a deep dive into one of the constellation's most alluring targets.
ALAN DYER

SEPTEMBER 2021 OBSERVING
Lunar Almanac
Northern Hemisphere Sky Chart



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

MOON PHASES

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

NEW MOON
September 7
00:52 UT

FIRST QUARTER
September 13
20:39 UT

FULL MOON
September 20
23:55 UT

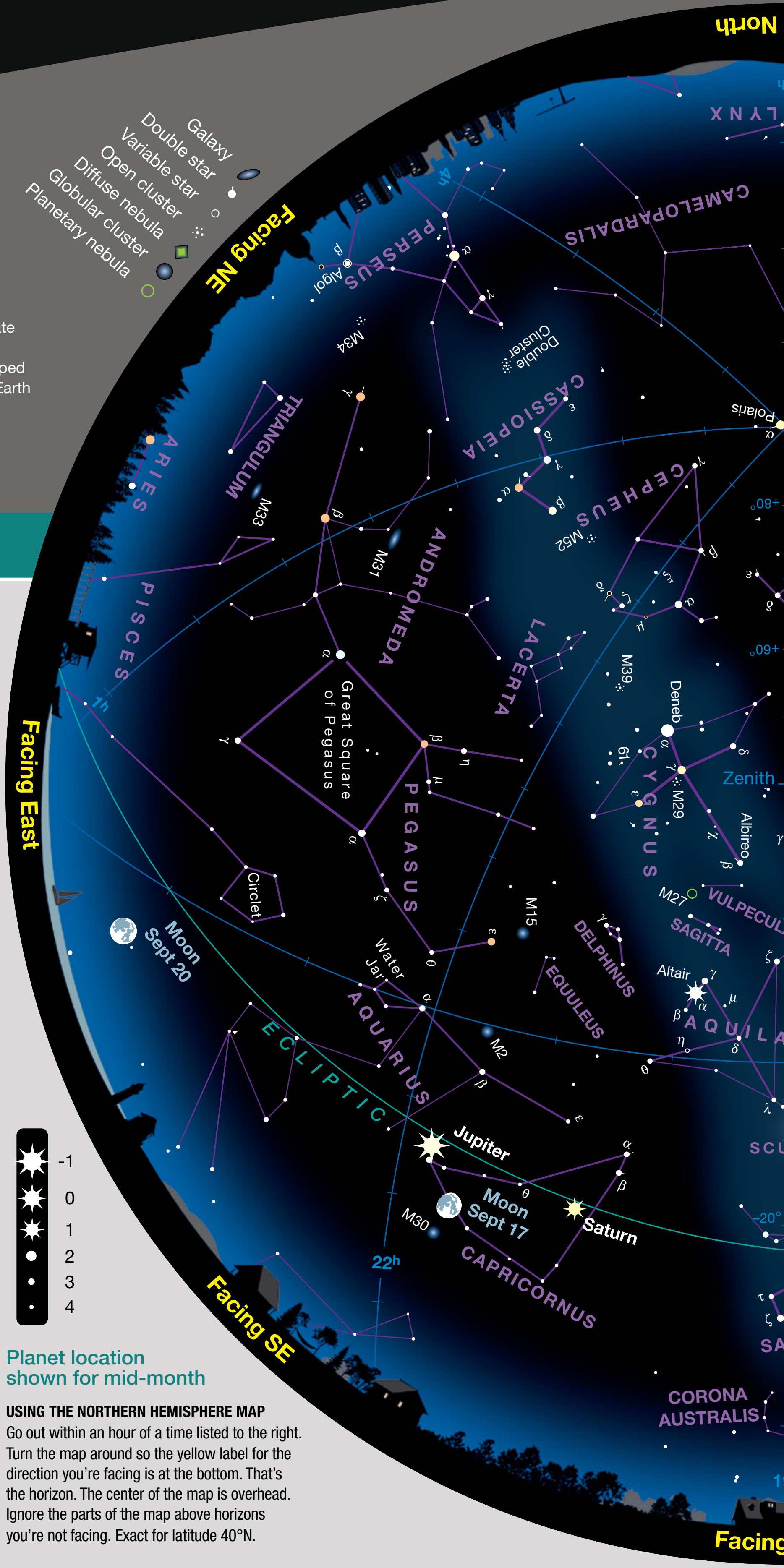
LAST QUARTER
September 29
01:57 UT

DISTANCES

Perigee	September 11, 10ʰ UT
368,462 km	Diameter 32′ 26″
Apogee	September 26, 22ʰ UT
404,640 km	Diameter 29′ 32″

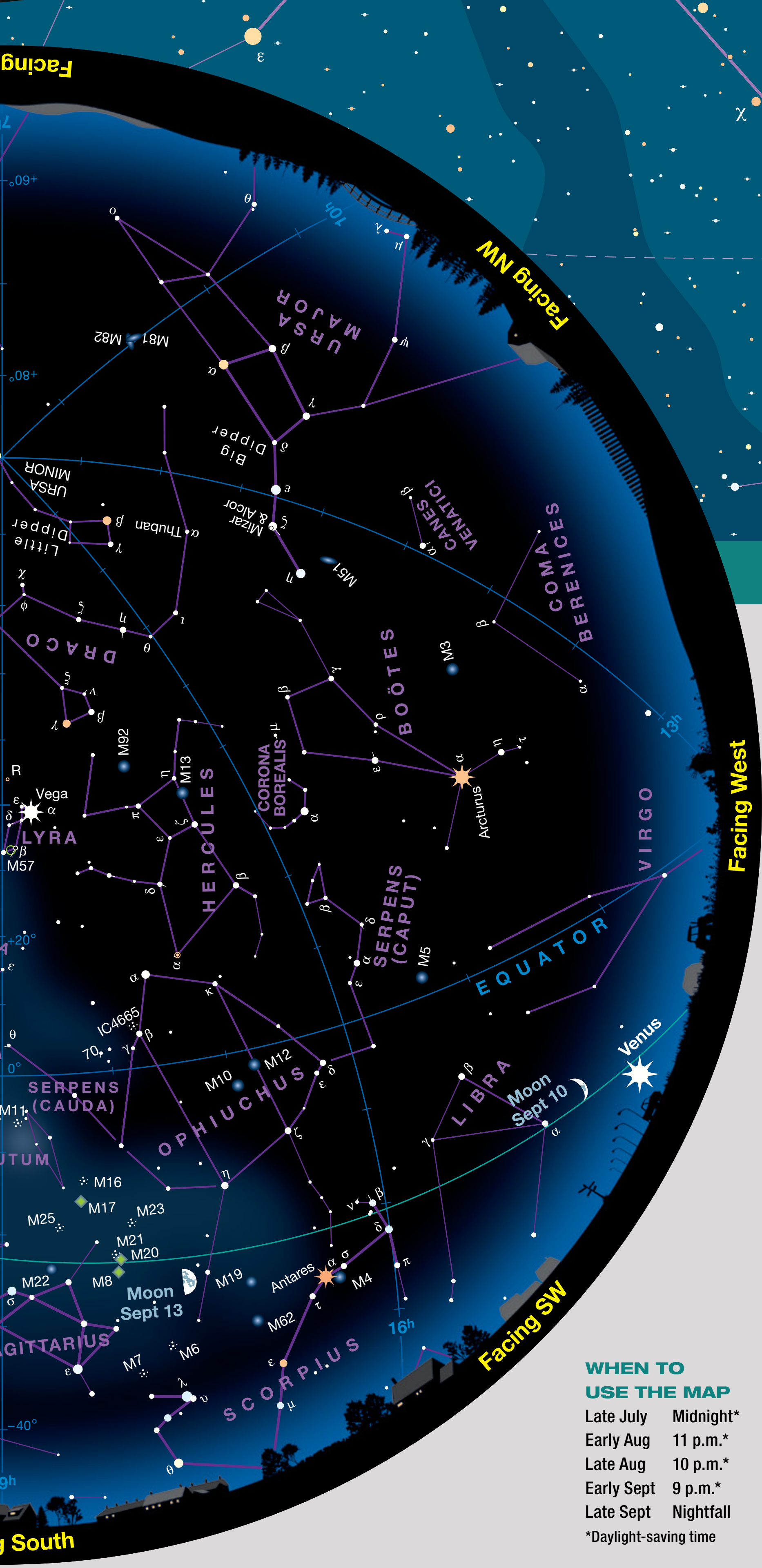
FAVORABLE LIBRATIONS

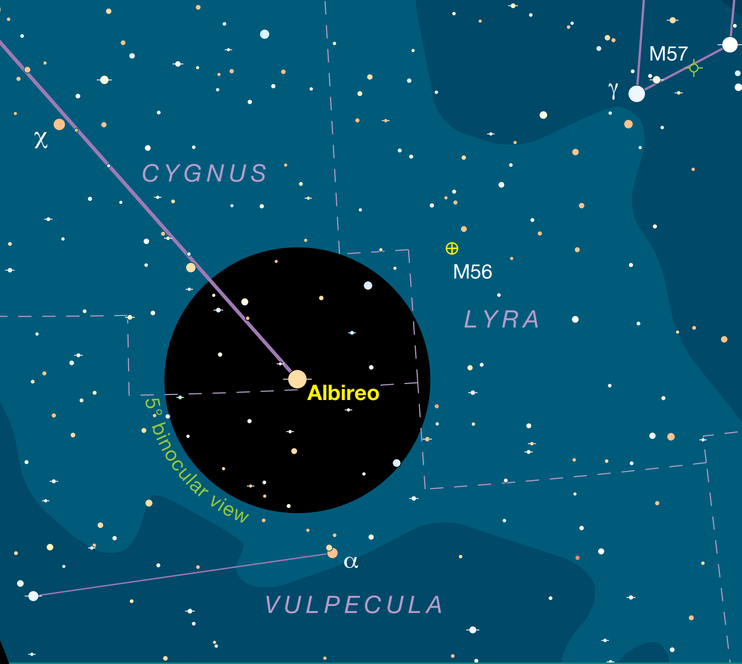
- Schickard Crater — September 3
- Lacus Spei — September 14
- Mare Humboldtianum — September 18
- Graff Crater — September 30



Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

A Delightful Double

I don't know if **Albireo** is the most popular double star of all, but it has to be in the running. Also known as Beta (β) Cygni, Albireo marks the head of Cygnus, the Swan. Thanks to its prominent position, the double is an easy find even for those just learning their way around the sky. Less easy is glimpsing its two component stars in binoculars. With a separation of just 35″, the twosome can theoretically be split with 10× binos, but I've never been able to get a clean separation with less than 15×.

Regardless of magnification, the trick is to make sure you hold your binoculars as steady as possible — the slightest amount of jiggling will blur the two stars into one. If you use a reclining lawn chair (advisable, given Albireo's neck-straining altitude at this time of year), try resting your elbows on the arms of the chair. Even better is a binocular mount or a pair of image-stabilized binoculars.

Albireo A is a *K*2-type orange giant, and Albireo B is a hot, massive *B*8-type bluish star. (As a University of California alum, I tend to see the pair dressed in Cal blue and gold.) But is Albireo a true double star, in which the two suns are gravitationally bound to each other, or are its stars simply coincidentally aligned? For the time being, the answer remains (if you'll forgive the pun) "unresolved." Even with astrometric data from orbiting observatories it's tough to tell. Data from the Gaia satellite suggest the stars are 30 to 60 light-years apart and moving in different directions, which would mean they're unrelated. On the other hand, the margin of error is great enough that maybe, just *maybe*, the disparate stars really do belong together. For some reason that conclusion makes the binocular view more satisfying.

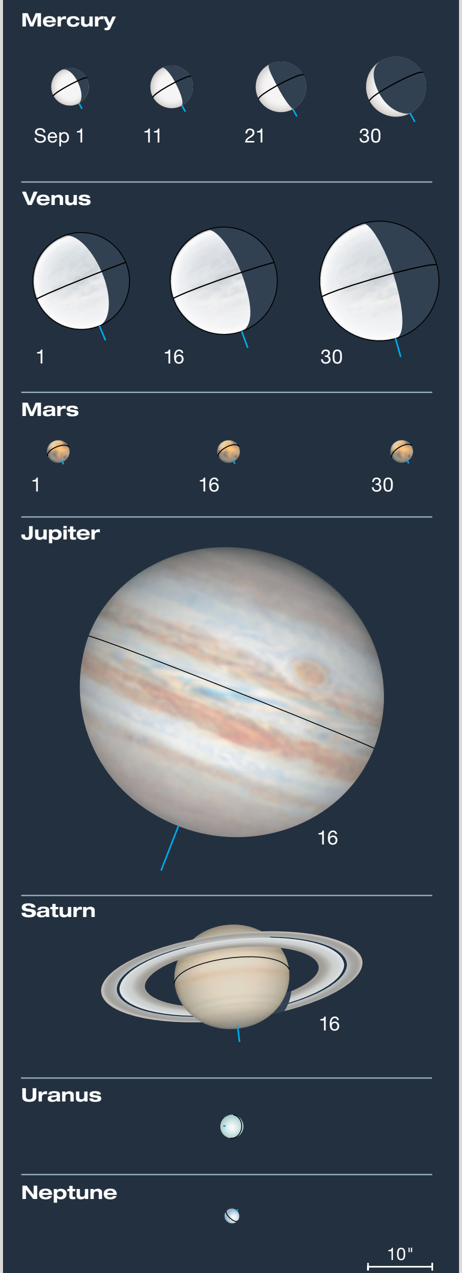
■ Close double stars make **MATT WEDEL** wish he had steadier hands.

WHEN TO USE THE MAP

Late July	Midnight*
Early Aug	11 p.m.*
Late Aug	10 p.m.*
Early Sept	9 p.m.*
Late Sept	Nightfall

*Daylight-saving time

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** is lost in the Sun's glare all month • **Venus** shines brightly in the west-southwest at dusk • **Mars** is too close to the Sun to be viewed all month • **Jupiter** and **Saturn** rise before dusk and transit in the late evening.



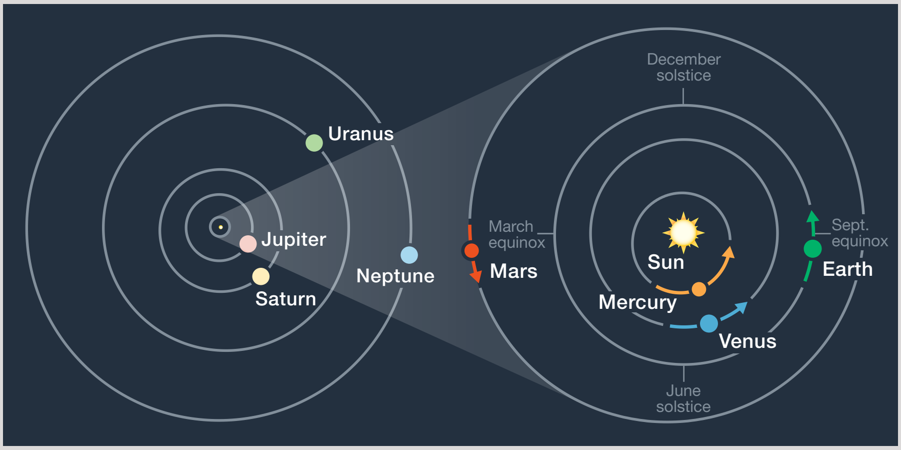
September Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	10^h 40.5^m	+8° 23′	—	–26.8	31′ 42″	—	1.009
	30	12^h 24.8^m	–2° 41′	—	–26.8	31′ 56″	—	1.002
Mercury	1	12^h 06.9^m	–1° 34′	24° Ev	–0.1	5.9″	74%	1.147
	11	12^h 50.6^m	–7° 47′	27° Ev	+0.1	6.7″	62%	1.010
	21	13^h 21.0^m	–12° 12′	26° Ev	+0.2	7.9″	44%	0.854
	30	13^h 26.0^m	–13° 02′	18° Ev	+1.3	9.4″	20%	0.717
Venus	1	13^h 07.2^m	–7° 19′	40° Ev	–4.0	15.1″	73%	1.108
	11	13^h 49.9^m	–12° 12′	42° Ev	–4.1	16.1″	70%	1.036
	21	14^h 33.5^m	–16° 40′	43° Ev	–4.2	17.3″	66%	0.962
	30	15^h 13.7^m	–20° 10′	45° Ev	–4.2	18.6″	63%	0.895
Mars	1	11^h 27.2^m	+4° 31′	12° Ev	+1.8	3.6″	100%	2.626
	16	12^h 02.6^m	+0° 36′	7° Ev	+1.7	3.5″	100%	2.637
	30	12^h 35.8^m	–3° 05′	3° Ev	+1.7	3.6″	100%	2.635
Jupiter	1	21^h 52.3^m	–14° 11′	167° Ev	–2.9	48.9″	100%	4.034
	30	21^h 41.3^m	–15° 06′	136° Ev	–2.7	46.4″	100%	4.247
Saturn	1	20^h 41.9^m	–19° 05′	149° Ev	+0.3	18.3″	100%	9.063
	30	20^h 37.2^m	–19° 24′	120° Ev	+0.5	17.7″	100%	9.401
Uranus	16	2^h 47.5^m	+15° 42′	129° Mo	+5.7	3.7″	100%	19.091
Neptune	16	23^h 30.4^m	–4° 28′	178° Ev	+7.8	2.4″	100%	28.917

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

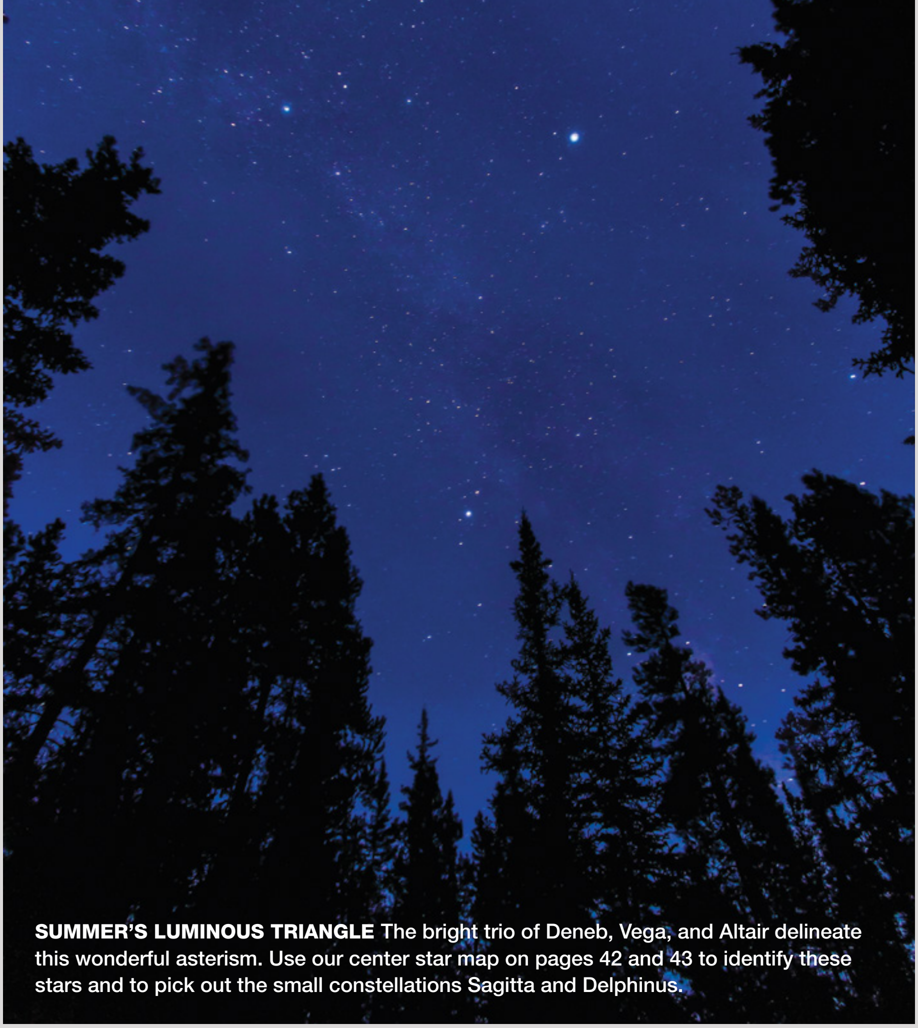
▲ **PLANET DISKS** have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

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



Little Gems in the Summer Triangle

Good things come in small packages.



SUMMER'S LUMINOUS TRIANGLE The bright trio of Deneb, Vega, and Altair delineate this wonderful asterism. Use our center star map on pages 42 and 43 to identify these stars and to pick out the small constellations Sagitta and Delphinus.

ALAN DYER

During September evenings, the Summer Triangle is more or less overhead for observers at mid-northern latitudes. This famous star pattern stretches across several constellations and comprises Lyra's zero-magnitude Vega, Aquila's 1st-magnitude Altair, and Cygnus's 1st-magnitude Deneb. The Summer Triangle is large enough for the Big Dipper to easily fit inside. But size isn't everything. In and around the Triangle there are a number of tiny but fascinating asterisms and naked-eye double stars for you to enjoy.

Let's begin our tour of little gems with the main pattern of Lyra, the Lyre — a tiny triangle connected to a small parallelogram. That equilateral triangle is only about 1½° to a side and includes blazing Vega — also known as Alpha (α) Lyrae — along with Epsilon (ε) and Zeta (ζ) Lyrae. Under good conditions, keen-eyed observers can split Epsilon into a pair of 5th-magnitude white stars 3½′ apart without optics. Most of us, with average vision, tend to see Epsilon as only an elongated point of light. But Epsilon is most famously known as the Double Double because each of the two stars is in turn a close pair. A fairly small telescope at about 150× can split Epsilon^1 and Epsilon^2 into two sets of similarly bright suns.

Zeta Lyrae performs double duty as a star in the little Lyra triangle *and* one of the four stars of the Lyra parallelogram. The other marker on the northern end of the parallelogram is Delta (δ) Lyrae, which is a double whose components are a bit more than three times farther apart than Epsilon^1 and Epsilon^2. The Delta pair are separated by 10½′, which is almost exactly the same as Mizar and Alcor at the bend in the handle of the Big Dipper. Delta^1 is a 5.6-magnitude blue-white star while Delta^2 is a 4.3-magnitude orange star. A small telescope or binoculars also show a widely scattered star cluster (cataloged as Stephenson 1) surrounding the delightful Delta duo.

The south end of the Lyra parallelogram features stars only about 2° apart, Beta (β) and Gamma (γ) Lyrae, also known as Sheliak and Sulafat, respectively. Gamma shines at magnitude 3.2 while Beta is a marvelous eclipsing binary whose brightness varies from magnitude 3.2 down to 4.4. Beta and Gamma are perhaps best known as signposts to the Ring Nebula, M57. This popular deep-sky treasure is located about two-thirds of the way along a line extending from Gamma to Beta. The Ring, however, is tiny and requires a telescope to glimpse.

Other outstanding little groupings in this region are the minute constellations Delphinus, the Dolphin, and Sagitta, the Arrow. Delphinus is shaped like a little diamond with a tail. Sagitta is an even tinier, very short arrow of stars. In terms of area, Sagitta ranks 86th among the 88 official constellations. By comparison, Delphinus has a bit more celestial real estate assigned to it and comes in at #69.

Altair is your key to locating these two diminutive figures. Look for Delphinus about 10° northeast of Altair and just outside the Summer Triangle. Sagitta is about the same distance from Altair, but due north and fully within the confines of the Summer Triangle. Delphinus is the markedly brighter of the two — Sagitta requires a rather dark sky to see plainly.

■ **FRED SCHAAF** enjoys collecting stellar gems on clear September nights.

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

Low-lying Planets Greet the Moon

Both Mercury and Venus are visible at dusk — one is easy, one is not.

SATURDAY, SEPTEMBER 4

Broadly speaking, **Mercury** apparitions come in two flavors: short and high, and long and low. Mercury's current showing is of the latter variety — it's simultaneously the longest of the year and presents the planet's poorest visibility. And because the planet remains mired in horizon muck during its longest apparitions, Mercury has a reputation for being difficult to see.

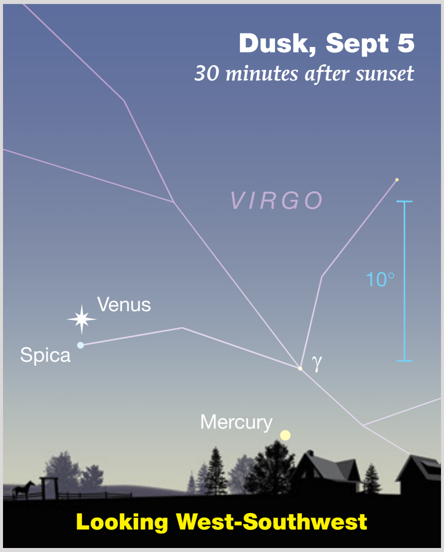
The innermost planet doesn't reach its greatest elongation from the Sun until the 14th. However, thanks to the shallow angle the ecliptic makes to the western horizon at dusk at this time of year, Mercury attains its greatest altitude for observers at mid-northern latitudes 10 days early. Even using the phrase "greatest altitude" here misrepresents the situation. At the end of civil twilight, the planet stands just a hair more than 4° above the western horizon (as it does from the 2nd to the 6th, inclusive). Even though Mercury shines at magnitude +0.0, its low altitude makes it a tough find. I expect you'll require binoculars to have any hope of sighting the speedy planet this time around, and a telescope equipped with a Go To mount would be an even better choice. Or you could simply wait. It'll be much easier to see Mercury at dawn next month when it has one of those "short and high" apparitions I mentioned earlier.

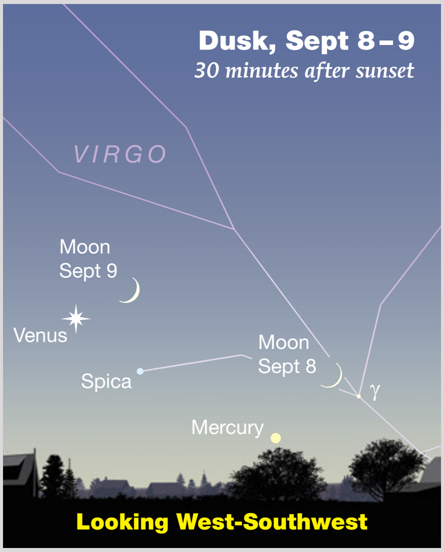
SUNDAY, SEPTEMBER 5

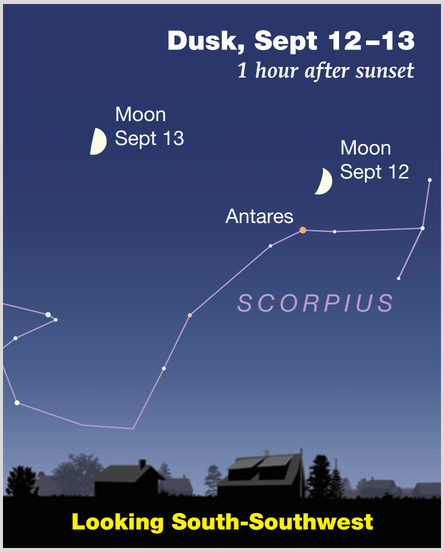
Like Mercury, **Venus** is also in the midst of a lengthy dusk apparition. The brilliant world has reigned as the Evening Star since it emerged from its conjunction with the Sun back in March, and it will continue to adorn the evening sky well into January 2022. Venus currently shines at a magnificent magnitude –4.1 and is both much brighter and much higher than Mercury. In fact, Venus is hard to miss. What you *might* overlook with a casual glance, however, is Spica shining nearby. Venus has been closing in on Spica for some time, and this evening it's at its very closest, with just 1½° separating it from the 1st-magnitude star. If you want to catch the pairing when it's at its highest, seek out Venus soon after sunset. Once you've located the planet, use your binoculars to find Spica below and left. As twilight fades, it'll be easier to spot Spica, and eventually you'll be able to dispense with the optical aid.

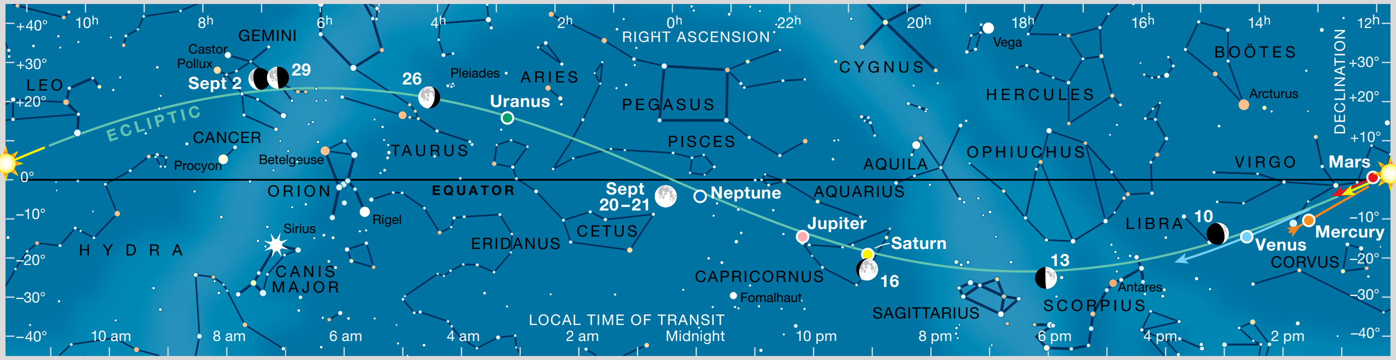
Mercury has its own encounter with Spica on the 21st, but that particular event will be very difficult to observe since both objects will be extremely low

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







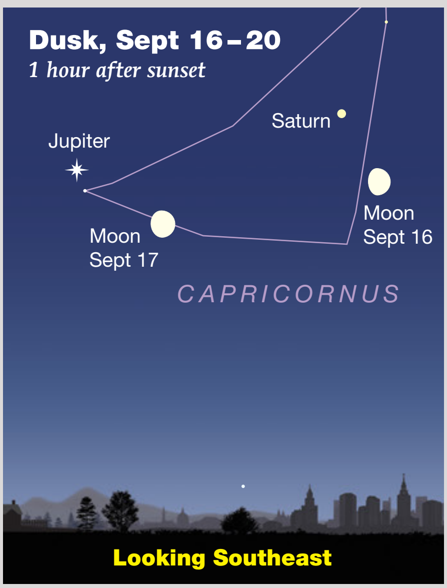


▲ The Sun and planets are positioned for mid-September; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of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

in the west-southwest and awash in bright twilight.

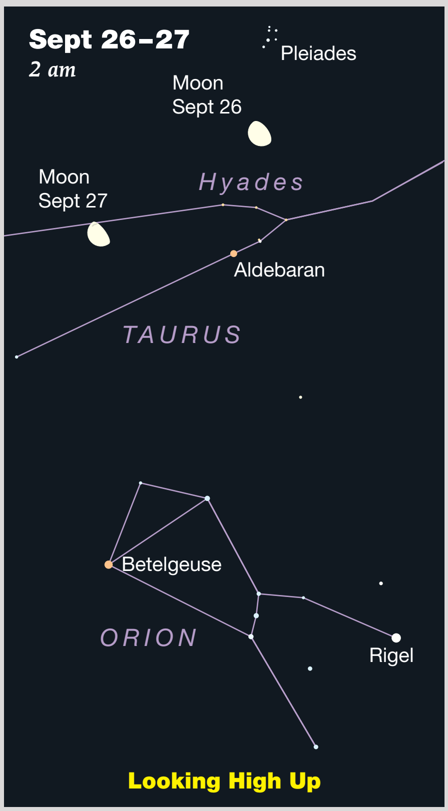
THURSDAY, SEPTEMBER 9

September's one and only **Moon**-and-**Venus** encounter occurs this evening. As these things go, this one is pretty good. The Moon is an appealingly thin crescent enhanced by earthshine and positioned less than 4° upper right of Venus. Because both objects are quite low, they present a great opportunity for you to include an appealing bit of terrestrial foreground in a photo. A twilight shot of Venus and the Moon over a lake or the ocean is a reliably pretty composition. And if you choose your time and location carefully, you might also be able to include Mercury (still hanging around) and Spica in the frame. Those two set less than one hour after the Sun, while Venus and the Moon linger an additional half hour.



SUNDAY, SEPTEMBER 12

Having slipped by Mercury and Venus, the **Moon** traverses the relatively barren expanse of eastern Virgo and Libra to arrive in Scorpius and visit the Scorpion's leading light, 1st-magnitude **Antares**. This evening the waning lunar crescent sits roughly 3° from the star in the south-southwest. Antares is a red supergiant, and its warm hue is easy to detect. However, if you catch Antares at dusk — when there's still plenty of blue left in the sky — its tint appears even more distinct. Having the Moon nearby is handy for an early sighting. Get out your trusty binoculars and locate the Moon 30 to 45 minutes after sundown. You should be able to spot Antares in the same field of view, below and left of the Moon, set against a deep blue sky. The later you look, the easier it'll be to see Antares, but the less dramatic its color will appear.



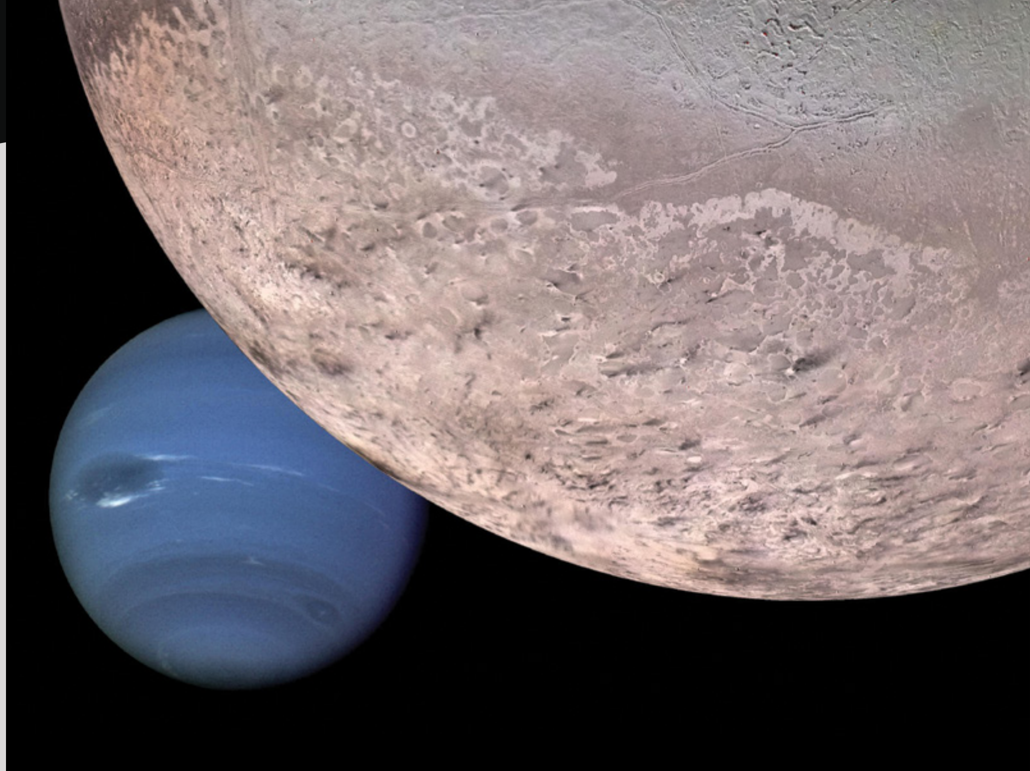
SUNDAY, SEPTEMBER 26

If you're looking for an excuse to stay up late (or get up early), here's a pretty conjunction that includes a preview of winter. During the predawn hours, you'll find the waning gibbous **Moon** is neatly positioned between two bright Taurus clusters: the **Pleiades** and the **Hyades**. I tend to regard Taurus as leading the parade of winter constellations. However, if you're taking in this conjunction as morning astronomical twilight begins, you may also be getting your first look at Orion and brilliant Sirius since last spring. Nothing makes the end of summer feel more definite than an early-morning sighting of winter's most iconic constellation and the night sky's brightest star. Time to bundle up!

■ Consulting Editor **GARY SERONIK** doesn't mind searching the horizon muck for low-lying planets.

Neptune and Pallas Pal Up at Opposition

The big blue planet and a big asteroid put on a show.

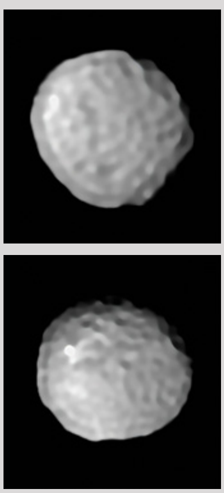


In this computer-generated montage made from Voyager 2 images, Triton (foreground) and Neptune appear as they might through the window of an approaching spacecraft. The dark streaks across Triton's south polar cap are thought to be due to recent, geyser-like eruptions that spewed dust and ice across the moon's surface.

Neptune reaches opposition on September 14th in the star-sparse wilds of eastern Aquarius, near the Circlet of Pisces. Despite being more than 4.3 billion kilometers (2.7 billion miles) away, the solar system's most remote major planet shines at magnitude 7.8, which means you can claim it with 10×50 binoculars from any reasonably dark location.

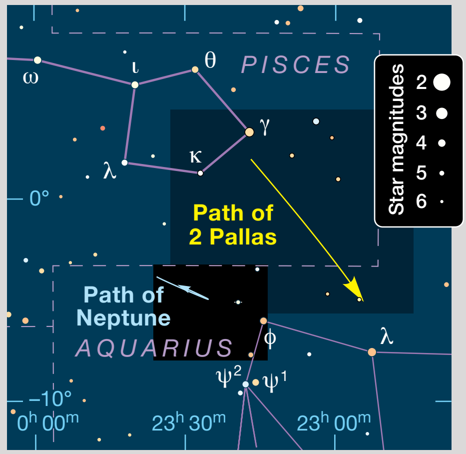
As if to avoid the astronomical paparazzi, the distant blue world stays clear of any bright stars that could easily give away its location as it slowly treks westward in retrograde motion. As the chart opposite shows, only a couple of 6th-magnitude stars mark its path during the current apparition. I recommend trying to catch Neptune on the night of September 23–24 when it glides just 1.6′ south of 6.3-magnitude HD 221148.

One of my favorite Neptunian observing activities is tracking down its largest moon, Triton. It's the only large satellite that orbits backwards (in retrograde) around its host planet. That oddity and a composition similar to Pluto's suggest that Triton may be a captured dwarf planet from the Kuiper Belt. When it's at its greatest elongation from Neptune, the 13.5-magnitude moon is readily seen in 10-inch or larger telescopes used at magnifications around 200×. Triton's distance from Neptune varies this season from about 9.5″ to 17.0″. To locate it, use the online Triton Tracker, found in the Tools section at **skyandtelescope.org**.



▶ These high-resolution images of the north (top) and south (bottom) hemispheres of Pallas were made with the SPHERE imager on the Very Large Telescope in 2020. Numerous craters in both hemispheres give the asteroid a dimpled appearance, making it resemble a giant golf ball.

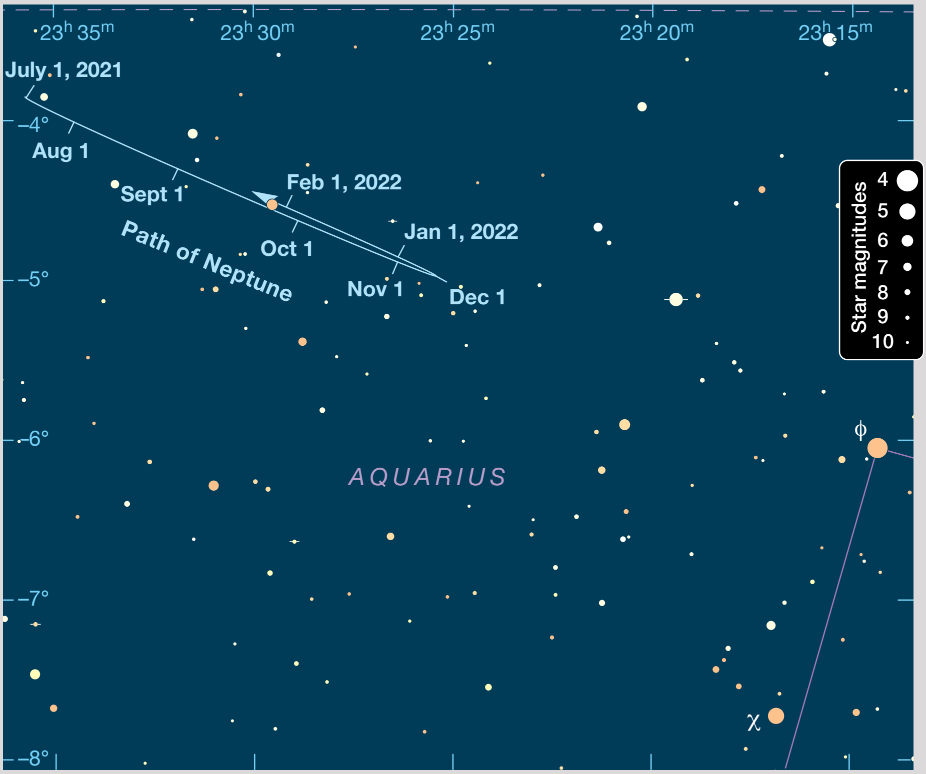
From Neptune it's a short hop northwest to 2 Pallas. As its designation would suggest, Pallas was the second asteroid discovered, and it's the third largest, with a mean diameter of roughly 513 kilometers. Pallas comes to opposition on the night of September 10–11, when it shines at magnitude 8.5 — within range of 10×50 binoculars under a dark sky. Pallas begins September 1.6° south-southwest of 3.7-magnitude Gamma (γ) Piscium and ends the month 2.9° north-northeast of 3.7-magnitude Lambda (λ) Aquarii.

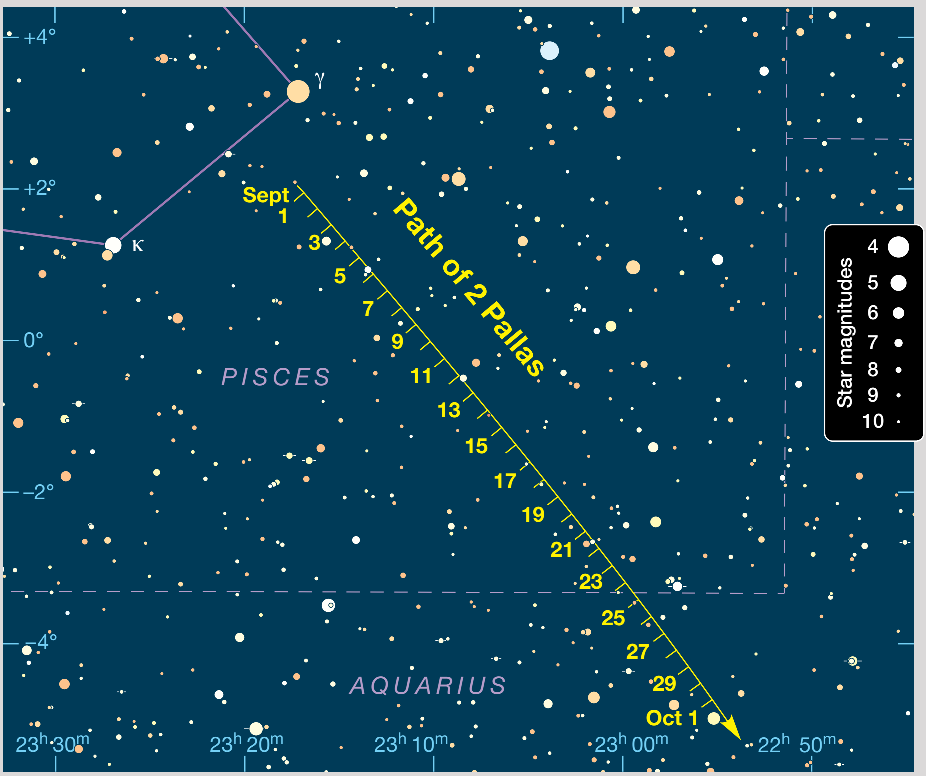


At this year's opposition, Pallas beckons from a relatively remote 320.5 million kilometers away. During closer oppositions it can reach magnitude 6.6, which means that under exceptional skies it's bright enough to see without optical aid. We'll next get that chance in March 2028.

If Pallas has whetted your asteroid appetite, you have an excellent shot at

NEPTUNE / TRITON MONTAGE: NASA / JPL / USGS; PALLAS PAIR: ESO / VERNAZZA ET AL





snaring another one. The first asteroid discovered (and the largest) is 1 Ceres, which reaches opposition in November. However, this month Ceres passes just 4′ south of 5.1-magnitude Sigma[1] (σ^1) Tauri on the morning of the 17th. Sigma[1] and Sigma[2] form a close optical double 1° southeast of Aldebaran. The asteroid will shine at magnitude 8.5 on the night of the conjunction.

Seeking Very Old Lunar Crescents

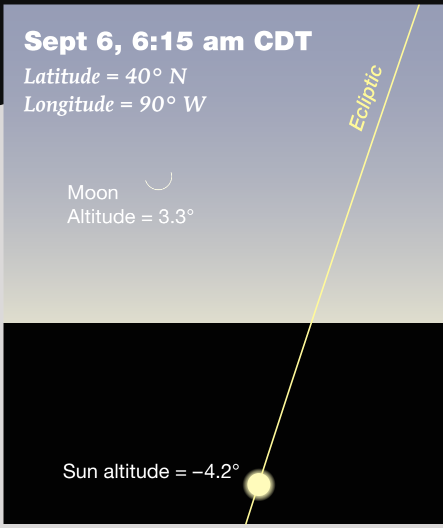
AMATEUR ASTRONOMY is all about challenges. Challenges make us better observers while deepening our knowledge of the night sky. And if you're up for a particularly interesting (and daunting) observing test, how about trying to view this month's *very* old lunar crescent.

In the same way that early spring offers the best opportunities for Northern Hemisphere skywatchers to spy a young, waxing Moon at dusk, early fall is prime time for catching an old, waning crescent at dawn.

Because its orbit is tipped relative to the plane of Earth's orbit, the Moon can sit up to 5.5° north or south of the ecliptic. If a spring or autumn crescent coincides with the northern extreme of this range, the Moon's angle to the horizon becomes steeper yet. The closer the azimuth of the Moon and the soon-to-rise Sun agree, the greater their apparent separation and the better your chance of spotting a breathtakingly thin lunar crescent.

The Moon's distance from the Earth also plays a role. At *perigee*, when it's closest, the Moon moves faster than at *apogee*, its most distant point. An old or young crescent that coincides with perigee is not only larger and marginally thicker, but its apparent distance from the Sun is also slightly greater. It's when all these factors add up that you have your best shot at catching an ultra-thin crescent.

Talented observer Stephen James O'Meara holds the naked-eye record for the youngest Moon: In May 1990, he caught a sliver that was a mere 15 hours 32 minutes young. Mohsen G. Mirsaeed of Tehran broke the record for youngest Moon visible with optical aid when he swept up a crescent that was only 11 hours 42 minutes



◀ Observing the very old crescent Moon before sunrise on September 6th will be challenging. Use binoculars or a Go To telescope to pinpoint the thin crescent's location.

old in his giant 40×150 binoculars on September 7, 2002. At the time, the Moon was just 7.5° from the Sun.

On September 6th, meticulous observers have a chance to spot an exceedingly old crescent at dawn. From Des Moines, Iowa (41.6° N, 93.6° W), the Moon reaches an altitude of 3° at 6:25 a.m. Central Daylight Time, when it's 13 hours 27 minutes before new. The crescent will be just 0.5% illuminated and 7.8° from the Sun, but on the plus side it will also be 4.7° north of the ecliptic and five days shy of perigee. Even so, sighting such a razor-thin lunar crescent is a challenge requiring tripod-mounted binoculars or a telescope.

For locations farther west the crescent is unlikely to be seen at all, but prospects improve slightly in the Eastern Time Zone. From New York City, the old lunar crescent stands 3° high at 6:05 a.m., 20 minutes before sunrise. The Moon will be 14 hours 47 minutes before new and have an illuminated extent of 0.5%.

Regardless of location, conditions have to be just right with haze-free skies, an unobstructed view, and, most importantly, knowing exactly where to look. Most charting and planetarium software packages (including the popular freeware program *Stellarium*) will allow you to figure out the circumstances for your specific location.

Bear in mind that only 75° of the crescent's 180° arc will be illuminated. Your best bet is to use a Go To telescope to lock onto the Moon's position and then carefully examine the view with a wide-field eyepiece. Make sure you've carefully focused the scope on a bright star beforehand since the smallest amount of mis-focus will cause the crescent to completely blend into the sky. Once you've spotted the Moon in your scope, try binoculars.

Minima of Algol

Aug.	UT	Sept.	UT
1	3:35	1	16:29
4	0:24	4	13:18
6	21:12	7	10:07
9	18:01	10	6:55
12	14:49	13	3:44
15	11:38	16	0:32
18	8:27	18	21:21
21	5:15	21	18:10
24	2:04	24	14:58
26	22:52	27	11:47
29	19:41	30	8:36

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**.

▲ With the end of summer in the Northern Hemisphere, Perseus climbs in the northeastern sky in the evening. Every 2.7 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate its brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

JUPITER REACHED OPPOSITION on the night of August 19th and as a result is in prime viewing position from dusk through the wee hours of the predawn. You'll have plenty of chances to view the comings and goings of its four brightest moons and observe its famous Great Red Spot. At mid-month Jupiter gleams at magnitude –2.8 and presents a disk that spans a generous 48″.

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

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

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

September 1: 1:17, 11:13, 21:09; **2**: 7:04, 16:59; **3**: 2:55, 12:51, 22:47; **4**: 8:42, 18:38; **5**: 4:33, 14:29; **6**: 0:25, 10:20, 20:16; **7**: 6:11, 16:07; **8**: 2:03, 11:58, 21:54; **9**: 7:50, 17:45; **10**: 3:41, 13:37, 23:32; **11**: 9:28, 19:23; **12**: 5:19, 15:15; **13**: 1:10, 11:06, 21:02; **14**: 6:57, 16:53; **15**: 2:48, 12:44, 22:40; **16**: 8:35,

GREGG DINDERMAN / S&T

18:31; **17**: 4:27, 14:22; **18**: 0:18, 10:14, 20:09; **19**: 6:05, 16:01; **20**: 1:56, 11:52, 21:48; **21**: 7:43, 17:39; **22**: 3:34, 13:30, 23:26; **23**: 9:21, 19:17; **24**: 5:13, 15:08; **25**: 1:04, 10:59, 20:55; **26**: 6:51, 16:47; **27**: 2:42, 12:38, 22:34; **28**: 8:29, 18:25; **29**: 4:21, 14:17; **30**: 0:12, 10:08, 20:04

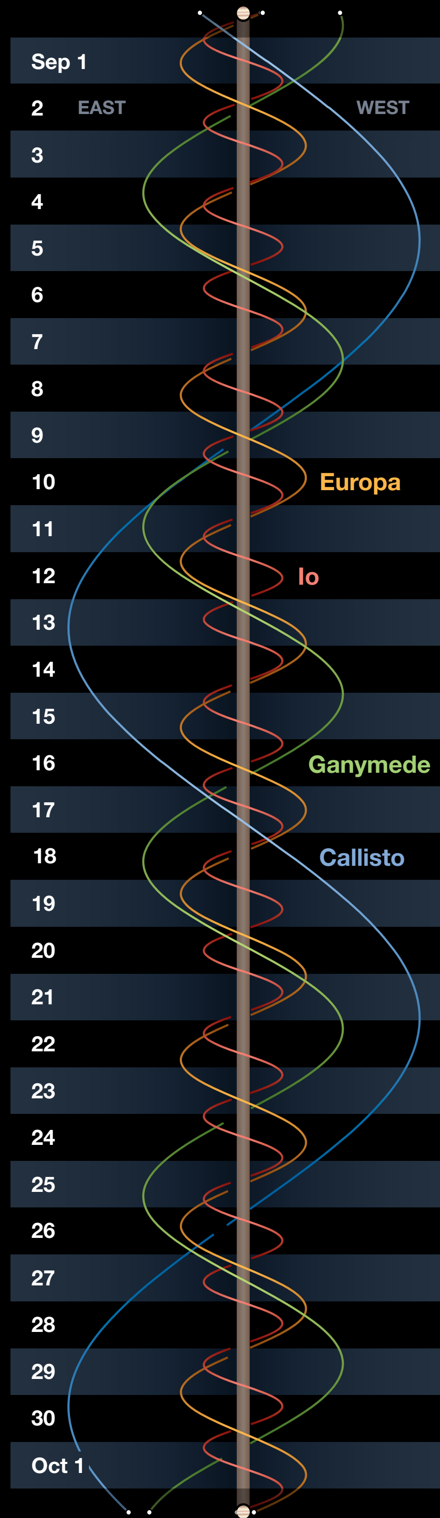
These times assume that the spot will be centered at System II longitude 5° on September 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 5° and 1²/₃ minutes later for each degree more than 5°.

Phenomena of Jupiter's Moons, September 2021

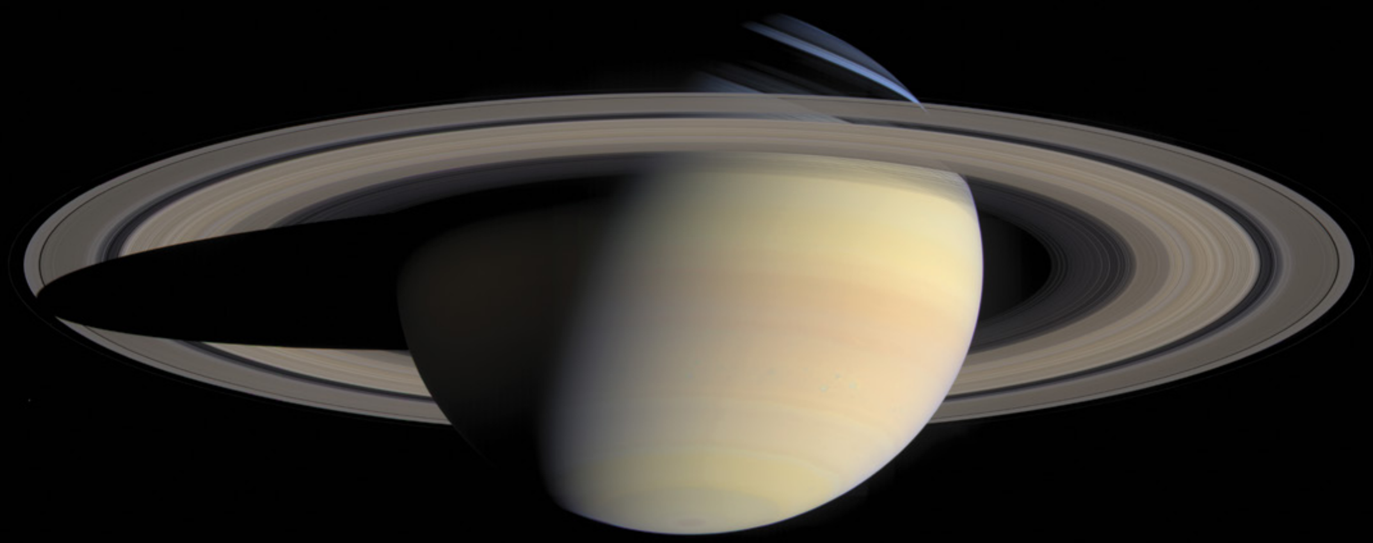
Sept. 1	1:31	IV.Tr.I
	4:25	IV.Sh.I
	5:56	IV.Tr.E
	9:02	IV.Sh.E
	10:52	I.Tr.I
	11:12	I.Sh.I
	13:10	I.Tr.E
	13:30	I.Sh.E
Sept. 2	8:05	I.Oc.D
	9:04	II.Tr.I
	9:44	II.Sh.I
	10:42	I.Ec.R
	11:22	III.Oc.D
	11:53	II.Tr.E
	12:34	II.Sh.E
	16:22	III.Ec.R
Sept. 3	5:19	I.Tr.I
	5:40	I.Sh.I
	7:37	I.Tr.E
	7:59	I.Sh.E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



Saturn Gets the Blues

Look for this striking seasonal color change on the ringed planet.

▲ In 2004, NASA's Cassini spacecraft arrived at Saturn to find a vivid blue haze over the planet's northern hemisphere.

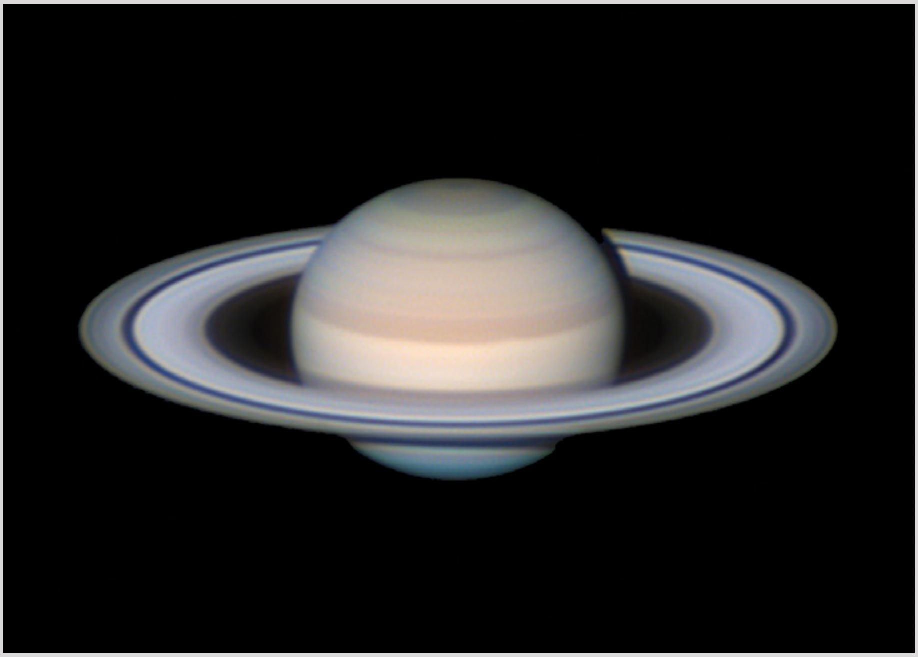
NASA / JPL / SPACE SCIENCE INSTITUTE

Saturn's rotational axis tilts by almost 27 degrees to the plane of its orbit, giving the ringed planet a full array of Earth-like seasons. While seasons on Earth last only three months, Saturn ponderously circles the Sun once every 29 years, so each season lasts for more than seven years.

Saturn's dusky belts and bright zones resemble those of Jupiter but are comparatively muted in contrast and bland in appearance. At the lower temperatures that prevail at the ringed planet's greater distance from the Sun, clouds form deeper in its colder atmosphere. The planet's weaker gravity greatly reinforces this thermal effect. Although Saturn is just 15% smaller in diameter than Jupiter, it's only 30% as massive. Jupiter's atmosphere is pulled much more powerfully toward the center of the planet, so the pressure gradient in the Jovian atmosphere is almost three times steeper.

Nevertheless, the ringed planet's deeper atmosphere is similar in both structure and composition to Jupiter's, with a deck of water clouds at the bottom, ammonium hydrosulfide clouds in the middle, and a visible deck of frozen ammonia clouds at the top, discolored by traces of sulfur and phosphorous compounds. The upper troposphere and stratosphere that lie above the ammonia cloud layer comprise hydrogen, helium, a trace of methane, and a murky haze of photochemical smog that plays a surprisingly vital role in determining both the planet's color and the visibility of features within its belts and zones.

Viewing Saturn's cloud deck through the hazes of its distended upper troposphere washes out details and subdues



▲The ringed planet's southern hemisphere displays a distinct blue tint in this image captured on May 15th by David Hamilton with a Celestron C14 and ZWO ASI224MC camera.

color saturation. Its belts appear pale greyish brown rather than the reddish sepia characteristic of Jupiter's belts, while the ringed planet's tropical and temperate zones usually feature a warm palette of straw yellow, butterscotch, and saffron hues.

Saturn's polar regions typically display cooler colors ranging from olive green to teal, aquamarine, and azure blue. These hues aren't limited to high latitudes; even an entire hemisphere of the planet can display them. In a 1984 review of Saturn observations submitted to the British Astronomical Association between 1943 and 1981, Richard McKim and Keith Blaxall reported that a hemisphere begins to lose its warm tint as it turns away from the Sun, taking on a cool cast after a prolonged reduction in exposure to sunlight.

In 2017, Saturn's northern hemisphere experienced summer solstice when the planet's north pole and the northern face of its rings were tilted toward the Sun (and earthbound observers) to their maximum extent. During last year's apparition the slow closing of the rings became apparent and the planet's southern hemisphere came into view. After being shrouded beneath the shadow of the rings for five terrestrial years, this portion of the globe was once again exposed to sunlight and displayed a striking blue color.

The noted planetary observer and astronomy historian William Sheehan reported a similar appearance almost three decades (or one Saturnian year) ago. In 1992 Sheehan — who today is also a fellow *S&T* contributing editor — observed Saturn under superb conditions through the 42-inch Cassegrain reflector of the Pic du Midi Observatory in the French Pyrenees. "I was astonished by the rich colors of the planet," he reported, "which are washed out in small apertures and mediocre seeing conditions . . . The most remarkable aspect of the planet was the strongly bluish tint of the entire southern hemisphere, which I had not suspected in smaller instruments." In 1993 Sheehan again found that the color of that hemisphere through both the 40-inch Yerkes refractor and a 15-inch reflector bore "an uncanny resemblance" to the colors of frigid ice giants Uranus and Neptune. The stark difference in the colors of the northern and southern hemispheres was still apparent to my eye as late as 1997 through my 10-inch reflector.

In Saturn's deep troposphere, photochemical reactions between solar ultraviolet radiation and trace gases like methane, ethane, and acetylene produce hazes composed of minute droplets of liquid hydrocarbons like benzene.

▲With the aid of color filters, observers using instruments of modest aperture can still discern the bluish tint of the planet's southern hemisphere.

FILTERS: TOM DOBBINS

As the intensity of sunlight diminishes during autumn and winter, the production of these aerosols dwindles, causing the planet's upper troposphere to become more transparent. With sunlight able to penetrate the troposphere to a greater depth, Rayleigh scattering by gas molecules imparts a blue color just as it does in Earth's atmosphere. Methane's selective absorption of light from the far red end of the spectrum amplifies this effect.

The intensity of sunlight is about 90 times weaker on Saturn than here on Earth. The distant planet's low apparent surface brightness makes it difficult to discern subtle color differences using small telescopes. But the bluish cast of the southern hemisphere should be obvious to a keen-eyed observer through an 8- to 10-inch instrument. Those with smaller apertures should try a yellow (Wratten 12), orange (Wratten 21), or light red (Wratten 23A) filter to selectively darken the southern hemisphere and accentuate its contrast with its northern counterpart.

■ Contributing Editor **TOM DOBBINS** uses historical observations to inform his modern ones.

RON BRECHER

▲ **MESSIER'S 72ND NON-COMET** French comet hunter Charles Messier observed this small, dim globular cluster — later named M72 — in early October 1780, a month after his colleague Pierre Méchain discovered the object. M72 is about 55,000 light-years away, making it one of the most distant globulars in the Messier catalog.

Submerged in Aquarius

At the confluence of two watery constellations are targets both decent and difficult.

Early September, nightfall. I'm in my yard inspecting a 12° by 5° stretch of the zodiac, running from northwestern Capricornus eastward into Aquarius. The field includes a naked-eye double star to test my aging eyesight, a dim globular cluster to challenge my best telescope, a mystery Messier to satisfy my curiosity, and a lustrous planetary nebula to stoke my wonder. Altogether, a tidy collection for prime-time viewing.

But I don't like it.

My complaint (thanks for asking!) is urban light pollution. I live on the north side of a small Canadian burgh (pop. 91,000) that, in terms of outdoor lighting, thinks it's Chicago or New York. Gazing southward, I behold not the astral forms of Capricornus and Aquarius but a sky-wide photon bomb. The Sea Goat (Capricornus) and the Water Bearer (Aquarius) are drowning in an ocean of artificial light. But the situation isn't as hopeless as it might first seem. Time to set up some scopes and give it a try.

Sea Goat Doubles

Capricornus is one unusual critter. Part fish and part goat, this ad hoc hybrid certainly adds variety to the 12-member zodiac. Alas, the fishtailed ruminant has no allure in my bleak sky. The constellation offers only a weak, vaguely wedgelike star pattern. I can't fully trace it out even with the help of Jupiter and Saturn, which currently serve as navigational beacons to the area. But at the western end of the wedge, two medium-bright stars, slanted a couple of degrees apart, shine heroically through the murk. My tour begins there.

The lower of the two twinklers is 3.2-magnitude **Beta (β) Capricorni**. My 4-inch (102-mm) f/6.5 achromatic refractor working at 20× shows that yellowy Beta is accompanied by a 6.1-magnitude star almost 4′ to the west, an 8.6-magnitude star roughly 12′ northwest, and an 8.8-magnitude star nearly 4′ southeast. These three unassuming attendants make a 15′-long string, with Beta beaming slightly to one side.

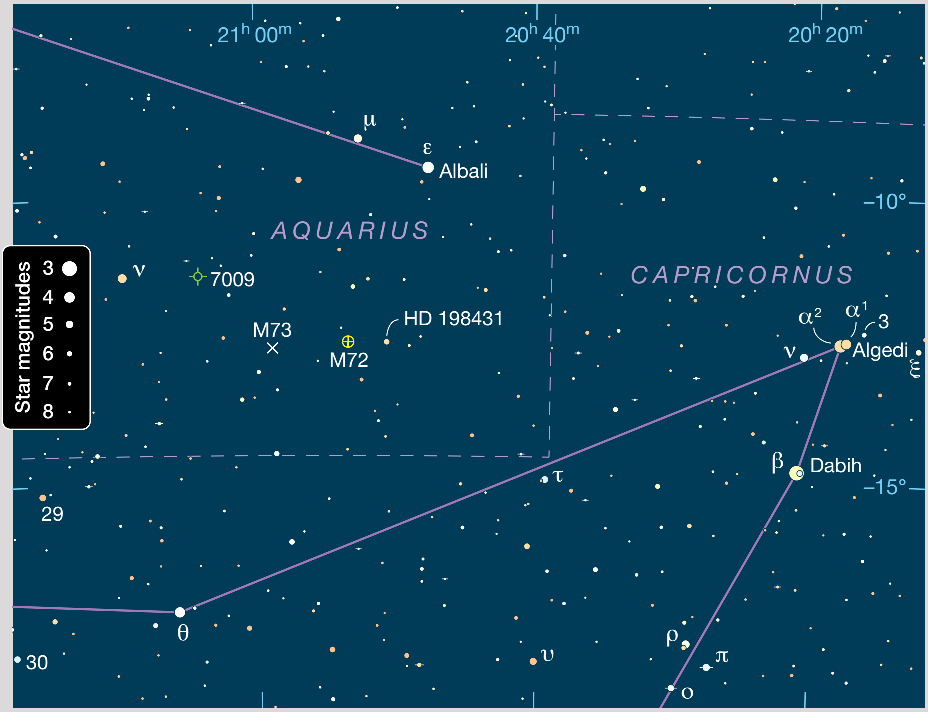
Northwestward, **Alpha (α) Capricorni** comprises two golden-yellow suns separated by 6.3′. Observers blessed with eagle eyesight need no optical aid to resolve the gorgeous tandem. Their duality, though, is an illusion: 3.7-magnitude α^2 is 109 light-years away, while 4.2-magnitude α^1 is six times more distant. The Alpha suns being close to each other on the sky fool us into thinking they're related.

Each Alpha has company. My refractor, still at 20×, nets a 9.6-magnitude star 47″ southwest of α^1 and another of 10.5-magnitude 2.5′ south-southeast of α^2. The low-power view includes 6.3-magnitude 3 Capricorni a third of a degree northwest of α^1, plus 4.8-magnitude Nu (ν) Capricorni 40′ east-southeast of α^2. It's not an exceptional congregation, but pleasing enough in my 4-inch scope.

Blob in a Dob

Venturing eastward from the Alpha-Beta group takes us into neighboring Aquarius. I'm confining our exploration of this vast constellation to its southwest corner. Here, submerged in the Aquarian weeds, are two challenging entries in the 110-object Messier catalog. We're gonna need a bigger scope.

The 9.2-magnitude globular cluster **M72**, a wan glow barely 6.6′ in diameter, is located 8.6° due east of Alpha Capricorni. If I use an equatorial mount and center Alpha, I can simply slew the scope eastward to capture M72, taking care not to overshoot the teeny target. Frankly, I prefer to star-hop with my 10-inch f/6 Dob. I aim my finderscope 8° east-northeast of Alpha Capricorni to 3.8-magnitude Epsilon (ε) Aquarii, then drop south-southeast 3° to the 5.8-magnitude star HD 198431. From there I shift eastward past a lonely 9.0-magnitude star called HD 198613, then continue onward to 9.4-magnitude HD 198885. The latter guards our shy performer a few arc-minutes to the northwest.



▲ **DIM STARFIELD** Large swaths of Capricornus and Aquarius aren't easily visible to suburban stargazers. However, the area of sky shown in this chart features an intriguing collection of deep-sky targets viewable in modest backyard scopes.

▼ **NO KIDDING** Attractive double stars Alpha (upper right) and Beta Capricorni dominate this 7°-wide image. Alpha's popular name is Algedi (or Giedi), which means simply "the Kid," suggesting that Capricornus is a young goat.

AKIRA FUJII

When Charles Messier scrutinized this "non-comet" in 1780, he considered it a faint nebula. No wonder. M72 is a class IX (very loose) globular whose brightest members are 14th magnitude. In my 10-inch at 64×, M72 is a pale blob next to the above-noted guardian star, HD 198885. However, 169× reveals a larger patch that's teasingly granular. At 218×, my averted vision picks up several peripheral pinpoints of light. Not bad!

The Y in the Sky

A mere 78′ east of M72 is the somewhat mysterious and hugely underwhelming **M73**. Often designated an open cluster, M73 is actually just a Y-shaped quartet of unrelated stars. The four feeble components have magnitudes of 10.4, 11.3, 11.7, and 11.9. The Y spans 1′ and at low magnification resembles an out-of-focus, 9th-magnitude star. M73 is arguably the least inspiring entry in the Messier canon.

To capture the wee Y, I start at M72 — not the greatest signpost, but still useful. I throttle down the magnification to 64×, nudge the scope over to the guardian star, HD 198885, then head directly eastward 1° to 9.3-magnitude HD 199524. I stop there, rev up to 169×, and creep cautiously an additional ¼° to the paltry prize.

▲ **FUZZY SATURN** English astronomer William Herschel discovered the remarkable Saturn Nebula, NGC 7009, in 1782. NGC 7009's threadlike ansae earned the nebula its popular name. The object is roughly 3,000 light-years from Earth.

BRAD EHRHORN / ADAM BLOCK / NOAO / AURA / NSF

Messier described his 73rd object as a cluster containing nebulosity. My backyard 10-inch at 169× guarantees a fuzz-free Y, but M73 is a tougher catch in smaller optics. My little refractor collects precisely one of the four stars. My 7.1-inch (180-mm) f/15 Maksutov-Cassegrain operating at 113× coughs up two stars. Doubling to 226× delivers the full letter. I recommend high power in city conditions to darken the sky background and improve the resolution of this intricate "cluster."

Deep-sky dud? Meager celestial curiosity? Obscure multiple star? Whatever — ya gotta get M73 to conquer the Messier catalog!

The Nebula Called Saturn

Less than 2° northeast of the Messier set is the aptly named Saturn Nebula, **NGC 7009**. This superb 8.0-magnitude planetary nebula features threadlike protrusions, or *ansae*, extending east-west from its 35″-wide disc. The dim and delicate ansae were discovered in 1850 by Irish astronomer William Parsons, who awarded NGC 7009 its evocative moniker.

I approach NGC 7009 from 4.5-magnitude Nu (ν) Aquarii, just above the Capricornus wedge. The nebula is situated 1⅓° west of Nu. Using my Mak-Cass at 90×, I sweep westward from Nu until I spot a tiny bluish disk. At 113×, the Saturn Nebula becomes oval like its namesake planet, though to me the aqua object invokes Neptune more than Saturn. The Neptune impression is even stronger in my 10-inch Dob at 128×. The luminous disk fades noticeably at higher power, yet I still can't perceive the 12th-magnitude central star lurking inside.

What about the ansae? Detecting them requires steady seeing, high magnification, averted vision, and likely a narrowband nebula filter. Employing the 10-inch at 218×, I can occasionally glimpse the ansae — particularly the slightly thicker thread west of the disk — with the aid of an Ultra-High Contrast (UHC) filter. A doubly ionized oxygen (O III) filter produces greater contrast but no extra detail.

In truth, filters aren't needed to appreciate NGC 7009. Indeed, an O III nullifies the nebula's lovely aqua color and extinguishes the surrounding field stars. Adding (or changing) a filter might also alter the focus. A good way to achieve a sharp filtered image at high power is to retreat to Nu Aquarii and focus on that bright beacon. One more reason to know your Nu.

My smallish, low-in-the-south tour region is forever submerged in a "milky way" of urban light pollution. Those of you south of the 49th parallel will do better, provided your city sky isn't milkier than mine. So, knock off the Sea Goat doubles and snap up those minuscule Messiers.

■ When he was a teenager, budding deep-sky observer **KEN HEWITT-WHITE** finished second in a Messier contest. The objects he missed? M72 and M73.

Watery Treats

Object	Type	Mag(v)	Size/Sep	RA	Dec.
β Cap	Double star	3.2, 6.1	205″	$20^h\ 21.0^m$	–14° 47′
α^{1+2} Cap	Double star	3.7, 4.2	381″	$20^h\ 18.0^m$	–12° 32′
α^1 Cap	Double star	4.2, 9.6	47″	$20^h\ 17.6^m$	–12° 30′
α^2 Cap	Double star	3.7, 10.5	153″	$20^h\ 18.0^m$	–12° 32′
M72	Globular cluster	9.2	6.6′	$20^h\ 53.5^m$	–12° 32′
M73	Asterism	8.9	1.4′	$20^h\ 58.9^m$	–12° 38′
NGC 7009	Planetary nebula	8.0	35″	$21^h\ 04.2^m$	–11° 22′

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

Pro-Am Conjunction
by Diana Hannikainen

Chase a Centaur

With the right equipment, you can help unravel the nature of an intriguing class of solar system objects.

▲ **COMET IN OUTBURST** In this composite photo, Comet 29P brightens during an outburst in 2013, starting on June 16th (lower left) and finishing on July 28th. The comet may very well represent a linchpin of our continued understanding of solar system formation and evolution.

DAMIAN PEACH

Who doesn't love a comet? Many of you likely enjoyed spectacular Comet NEOWISE last summer (*S&T:* Nov. 2020, p. 14). Such otherworldly visitors episodically swing by the Sun, only to be slingshotted back into icy outer space. How exactly do they find their way to us from the solar system's outer reaches?

The answer may lie with this tongue twister: Comet 29P/Schwassmann-Wachmann 1.

Gateway objects. Astronomers have identified a region just beyond Jupiter that channels most of the faraway Kuiper Belt objects into the inner solar system, where they then scurry busily about flouncing fancy tails. Objects entering this "comet gateway" region are called *Centaurs*, and the most sought-after of these is 29P. At about 900 million km (560 million mi) from the Sun, 29P is one of the most distant objects to show heightened comet activity. Normally around magnitude 16–17, the iceball always exhibits a dust coma, and it undergoes dramatic outbursts seven or more times a year. And by dramatic, we're talking brightening by 3 to 5 magnitudes, bringing the object within easy reach of 8- to 10-inch telescopes. During its brightest outbursts, it might even flare to magnitude 9 — grab your 6-inch!

Campaign for a Centaur. Several years ago, then-graduate student Kacper Wierzchos (now University of Arizona) was monitoring 29P with a millimeter-wave telescope in Arizona to measure amounts of carbon monoxide, the most abundant gas in 29P's outbursts. Comet 29P also frequently exhibits a dusty, jetlike feature, and comparing the gas and dust emissions helps astronomers unveil the nucleus's composition. Since visual magnitudes mostly track dust, Wierzchos scoured the literature for magnitude estimates from observations coincident with his own. And then the light bulb lit up for his advisor, Maria Womack (University of Central Florida and the National Science Foundation).

Womack and her colleague Gal Sarid (SETI Institute) devised a campaign dedicated to understanding 29P, with the aim of kicking observations into high gear. "It's time to go beyond just documenting the overall brightness of the object as it changes over time," Womack says. "This Centaur is already a much-loved target of the amateur community, but the campaign provides the framework for a more coordinated effort."

And they're looking for *you* — observers with CCD cameras and maybe even spectroscopes. The bigger your telescope, the better, but a 6- to 8-inch when the source is in a major outburst should do the trick. Brownie points for those who can record a time series: If you can take images every 30 seconds, "that would be amazing," she adds. "Capturing an outburst evolution over time would be really helpful."

If this tickles your fancy, then go to **https://is.gd/observing29p**, where you can list your recent past and upcoming observations. (Signing up doesn't commit you, should you change your mind.) Professional astronomers with observing programs at wavelengths other than visual, such as radio or infrared, can then consult the webpage, see who else is out there pointing their scopes at 29P, and invite them to collaborate.

And yes, the campaign is calling on professionals to sign up as well! If you're scheduled to observe 29P, go ahead and list yourself — let's make this a true *pro-am endeavor.*

All together. The larger goal of this global project is to provide a place for observers to meet up and find one another. New collaborations might develop independent of Womack or her colleagues — and that's fine by them. This campaign is still in its infancy, and Womack is eager to see how it develops.

The next outburst observing window runs from September 2021 through March 2022, but the campaign is projected to last at least a decade (see the website). So get out there, take your equipment with you, and let's help crack the nut that is Comet 29P/Schwassmann-Wachmann 1. Ultimately, your data might contribute to our understanding of the nascent solar system.

■ Observing Editor DIANA HANNIKAINEN loves picturing iceballs zipping around the solar system.

Interacting WITH TOTALITY

Here's how you can add a personal element to your solar eclipse photography.

▲ **PIERCED DIAMOND RING** Photographing a total solar eclipse can be challenging. Integrating figures within the field during the event can add a new level of connection between the viewer and the event often lacking in typical eclipse photography. Author Eugen Kamenew describes his intricate plans culminating in this unique view of the November 3, 2013, hybrid solar eclipse recorded in a single exposure.

Total solar eclipses are without a doubt one of the most spectacular astronomical events that celestial mechanics has to offer. To stand within the shadow of the Moon is a life-changing moment for almost anyone who experiences it. From my very first total solar eclipse on August 11, 1999, I longed to capture that fleeting moment forever.

But typical eclipse photography left me with the feeling that something was missing. Then it struck me — what was lacking in typical eclipse pictures was the human presence. So I set out to combine the beauty of a solar eclipse with the joy of the experience.

Eclipse with a Twist

What I had in my mind wasn't the usual wide-angle photo of the backs of people gathered in the foreground and the eclipsed Sun above. Nor did I plan a "selfie" with myself or another close to the camera and the eclipse being a minor component of the composition.

Instead, I envisioned placing a person at a similar scale to the Sun and Moon, ideally integrating the two subjects. This required the model to be far from the camera, captured through a long telephoto lens. However, I didn't want the subject to simply be near the event. My vision was very clear: to capture a person during totality interacting with the eclipse itself in a single exposure. Such a picture would establish an intimate connection between the event, the witnesses, and the location where they are experiencing the eclipse.

▶ **FIGURE WITH PURPOSE** The author's wife Korlan Ablaissova poses in traditional native American attire as a way to pay tribute to the many tribes located around the area of the Painted Hills, Oregon during the eclipse of August 21, 2017. He recorded the image using a Fujifilm GFX 50S medium-format mirrorless camera.

It's All About Location

In order to achieve my vision, the position of the eclipsed Sun had to be relatively low to the horizon. This meant I had to find a location along the path of totality where mid-eclipse occurs not long after sunrise or before sunset. The requirement greatly increases the chance of being clouded out, since I'd be looking through much more of Earth's atmosphere than when witnessing the event high in the sky — the low perspective meant clouds hundreds of kilometers away could scuttle my plans. Usually, eclipse chasers prefer a geographical location midway along the path of totality where the event occurs high in the sky, which also produces the longest duration of totality.

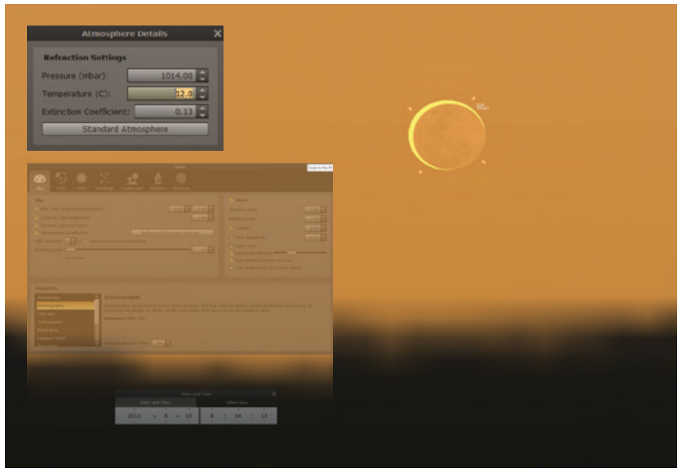
Identifying the ideal location to execute my plan proved challenging. Roughly 70% of Earth is covered by water, so most eclipse tracks begin or end above oceans. I instead searched for an eclipse where the shadow path either began or ended on or near land. The eclipse of May 10, 2013, afforded my first opportunity, with totality occurring during sunrise. Unfortunately, this eclipse was annular rather than total. Nonetheless, I saw it as a good opportunity to test my vision. The Moon's antumbral shadow would land in Western Australia, with a relatively wide path of about 221 km (137 miles). Normally when chasing an eclipse, I'd try to get as close as possible to the central line. Since the Moon's shadow was racing from west to east over the Australian desert, it was easily accessible via the Great Northern Highway 95 that runs north to south. Along this route someone on the eclipse central line would experience exactly 4 minutes and 4 seconds of annular phase. Unfortunately, I wasn't able to find any suitable hills to position my model within the proper line-of-sight at this location.

Through further location scouting, I found an excellent spot at Radio Hill Lookout in Newman, Australia. This was near the northern limit of the path of annularity, about 121 km from the central line, which meant that annularity lasted just 1 minute and 51 seconds. That meant that I'd be sacrificing 133 seconds of annularity, and the lunar silhouette wouldn't produce a perfect solar ring. No matter — this was still acceptable for my goal.

I planned to position a couple within the lunar silhouette so that they would appear to be embracing the ring of fire. Since the Sun's apparent diameter is about ½°, I had to position my models approximately 200 meters away so that perspective would make them appear small enough to be framed within the ring of annularity.

Displaced Sun

Shooting an event so low in the sky turned out to be a challenging experience. The eclipse began with the Sun 13.4°



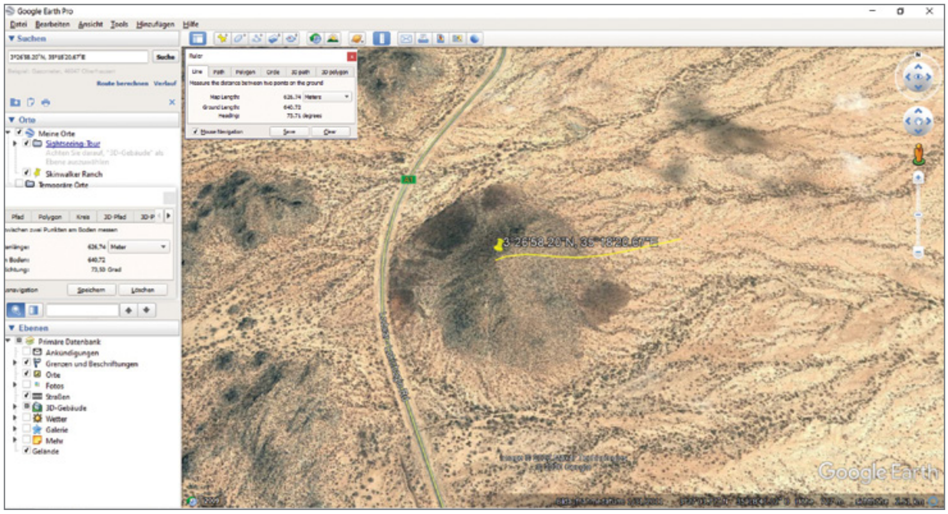
▲ **CALCULATING REFRACTION** Shooting astronomical targets close to the horizon requires taking atmospheric refraction into account. Some nightscape planning apps, as well as the free desktop software *Stellarium* (shown above), allow you to input the barometric pressure and temperature to accurately compensate for the Sun's displacement close to the horizon.

below the horizon. Just 3 minutes after sunrise, 2nd contact occurred with the Sun only +0.6° above the horizon. One minute later the Moon was at its maximum point within the solar disk, and the Sun's altitude was only +0.8°.

An additional problem I needed to consider when calculating the shot's precise time and location was *atmospheric refraction*. At such a low elevation, the atmosphere that sunlight was passing through bent the light, displacing the Sun's apparent altitude. The exact amount of this displacement varies with barometric pressure and air temperature. Just above the horizon, atmospheric refraction typically causes the Sun to appear higher by slightly more than its own diameter. But at a point only 1° above the horizon, this "lift" is reduced to slightly *less* than the Sun's apparent diameter. So taking refraction into account was very important for my project. I used the planetarium software *Stellarium* (**stellarium.org**),

▲ **WITH AND WITHOUT** While the image of an annular eclipse at left is impressive, positioning embracing figures within the annular ring inserts a relatable element to the scene. Through meticulous planning, the author captured Sarah Ponceblan and Gregory Sabatier on a hilltop in Newman, Australia, as the eclipsed Sun rose over the hilltop on May 10, 2013.

ALL PHOTOS COURTESY OF THE AUTHOR



▶ **PLANNING WITH GOOGLE** Finding the perfect location for the November 3, 2013, hybrid solar eclipse required the use of Google Earth Pro, which includes topographical information. Using the program's Ruler tool, the author plotted his exact distance and angle from his model to place him within the eclipsed Sun at the right moment.

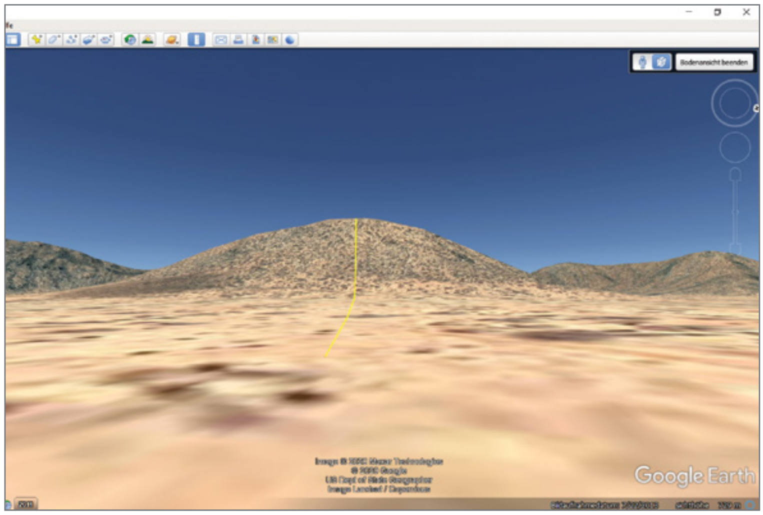
input the barometric pressure, temperature, and extinction coefficient in the Atmosphere Details menu to simulate refraction, and determined *exactly* where and when I needed to be to get the shot.

With my models Sarah Ponceblan and Gregory Sabatier patiently waiting for the unusual sunrise, some clouds near the horizon appeared that threatened to ruin the project. Just in time, they dispersed enough to reveal the ring of fire.

At the time, I was shooting with a Canon EOS 5D II full-frame DSLR paired with a Sigma 50-500-mm f/4.0-6.3 APO lens unfiltered at maximum zoom. This permitted a lot of free space around the Sun to include some of the surrounding landscape. I stopped down the lens to f/9 to increase its depth of field, as I was focused on my models rather than on the distant eclipsed Sun. As a result, an appealing *bokeh effect* bloated the Sun and edge-illuminated clouds. I also set the camera to ISO 1000 with a fast shutter speed of 1/5,000 to greatly reduce the potential for blurring due to wind or my models' movements during our brief opportunity.

While shooting this eclipse, I decided not to employ a solar filter on the telephoto lens. This could have been potentially dangerous had I looked at the Sun through the camera's viewfinder. I avoided this problem by using Live View to frame the shot, only looking at the Sun on the camera's rear screen. While this still risks damage to my camera's sensor, it was a risk I was willing to take — cameras can be replaced, while my eyesight cannot. Using a solar filter would also require much longer exposure times, potentially blurring my subjects. Additionally, solar filters impart a color cast to the scene. These days, using a mirrorless camera such as those offered by Canon, Fujifilm, Nikon, and others would be an even safer option, as the camera always provides a video readout of the detector on its LCD screen. Keep in mind there still is a high risk of permanent damage to the sensor.

ADDITIONAL PRIZE
Shortly after third contact, Peter Ekai Nakua is seen framed between the "horns" of the partially eclipsed Sun.



▲ **SIMULATION VS. REALITY** *Left:* The author's camera pack is placed at the exact position he chose using the simulation seen in the image at right. *Right:* Though not perfect, the 3D rendering of topography in Google Earth Pro is good enough for planning photo shoots.

Take II: A Hybrid Solar Eclipse

My test proved that framing figures within an annular solar eclipse was possible in a single exposure, giving me high hopes that the same principle would work for a total solar eclipse. An excellent opportunity to try it out arose later that year.

On November 3, 2013, a rare hybrid solar eclipse was to end while setting over Eastern Africa. This event began over the Atlantic Ocean at sunrise as an annular eclipse but transitioned to a total eclipse as the narrow path crossed and set over the continent.

In this case, being near the centerline of totality was important for the sake of time. Because the Moon only appeared slightly larger than the solar disk, it cast a path of totality just 14.3 kilometers wide near the end of the event. The farther from the centerline, the shorter the duration of totality I would see, and I needed as much time as possible.

I hunted for my location using the NASA eclipse website (**eclipse.gsfc.nasa.gov**). Here I could virtually "fly" over a map of the path of totality. Clicking on a location along the eclipse path presented the information I needed to triangulate my exact position. During the maximum phase of totality for the location I chose in Kenya, the Sun would have an altitude of +12.9°.

Planning with *Google Earth Pro*

Still, the NASA website doesn't give any topographical information, so I had to switch to *Google Earth Pro* (**google.com/earth/versions**) to obtain detailed information on places that I've never physically visited before. Using the geographical coordinates of my chosen site taken from the NASA website, I searched for a tall hill that would put my model at an altitude of 12.9°. I succeeded in locating one just 500 meters (1,600 feet) south of the central line and approximately 140 meters higher than the surrounding terrain. That meant that a straight-line distance from photographer to the photo model would be approximately 627 m.

At the time of maximum eclipse, the Sun would be at an azimuth of 253.5°, so I needed to be at a 73° azimuth angle to the hill. Using the Ruler tool in *Google Earth Pro*, I plotted the precise position between myself and my model. Note that this work can be done more easily using several smartphone apps, including *PhotoPills*, *Planit Pro*, *SkyView*, or *Sun-Surveyor*, or using the website The Photographer's Ephemeris (**photoephemeris.com/en**).

Another Success

On November 3, 2013, my model Peter Ekai Nakua was standing on that hill, patiently awaiting our 16-second opportunity. The moment was so surreal that had I not photographed it, I wouldn't have believed it was possible. I was firing the shutter of my Canon 5D MarkII as many times as I could. This time, I chose an aperture of f/16 so that the depth of field ensured both my model and the eclipsed Sun were in focus. I also used a lower, 400 ISO and a shutter speed of 1/800 second with the same Sigma 50-500-mm zoom.

My resulting image (see page 58) displays a whole spectrum of phenomena in a single frame. On the top of the frame, several pinkish prominences ring two-thirds of the lunar silhouette, while Baily's Beads are seen at the 3 o'clock position. Peter bisects the diamond ring effect. The ghostly inner corona crowns the image, and a detached prominence is just visible at the 1:30 position.

From this moment, I knew how I'd approach eclipse photography ever after. I would find creative ways to establish an intimate connection of the event using the place and individuals unique to each landfall of the lunar shadow. I encourage others to forge their own path in depicting the fleeting moments of totality.

■ **EUGEN KAMENEW** is an official Fujifilm X-Photographer residing in Germany. Visit his website at **www.kamenew.net** to see more of his work.

▲ The DayStar SolaREDi SR-127 QT set up for visual use. Users will need to provide a star diagonal, eyepieces, solar finder, and mount.

DayStar Filter's SolaREDi SR-127 QT

We look at a premium 5-inch hydrogen-alpha solar telescope.

SolaREDi SR-127 QT

U.S. Price: $5,995 (Prominence model); $7,995 (Chromosphere model)

What We Like

All-in-one simplicity

Lightweight

Precise bandpass adjustments

What We Don't Like

Doesn't include solar finder

Quantum control software for Windows only

AFTER A LONG, QUIET MINIMUM, solar cycle 25 has finally begun, and with its increased activity comes a renewed interest in observing our Sun. While there are many options to safely inspect the solar "surface," the premium option is to use a dedicated telescope that provides views at the narrow wavelength of hydrogen-alpha (Hα). This wavelength reveals the Sun's chromosphere, where dynamic activity such as plages, spicules, filaments, and prominences are visible.

DayStar Filters, a well-established maker of temperature-regulated solar filters, recently expanded its line of specialized telescopes with integrated filters (*S&T:* Mar. 2019, p. 58). The company's newest offering in the line is the SolaREDi SR-127 QT, a doublet

◀ The telescope's 127-mm (5-inch) doublet objective is coated to reduce reflections. Internal optics increase the effective focal length to 2,667 mm (f/21).

ALL PHOTOS PROVIDED BY AUTHOR

refractor optimized for Hα wavelengths. I own a DayStar Quantum solar filter myself, so I was anxious to see how this new instrument and built-in filter performs. DayStar loaned us one along with several additional accessories for this review.

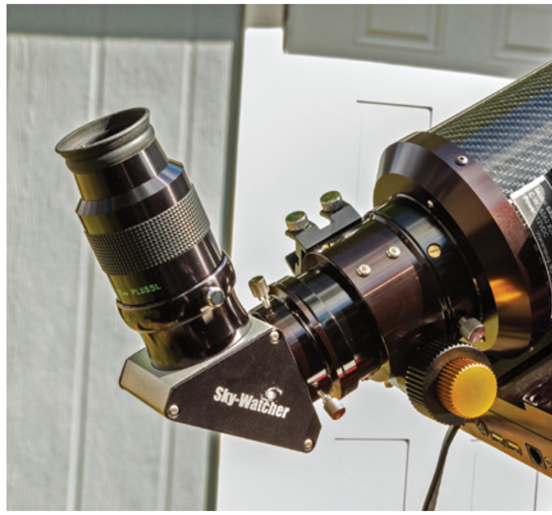
What's In the Box

The SR-127 QT comes in two flavors: a prominence version and a higher-priced chromosphere model. The prominence telescope utilizes a wide passband (around 1 Å) that displays gigantic prominences and tiny spicules on the limb of the Sun, but not much more. The chromosphere model has a narrower, sub-angstrom passband that improves contrast across the solar disk to reveal plages, filaments, and sunspots. We borrowed the chromosphere version, and while prominences display notably fainter than with the other model, they're still readily visible, and the system provided many satisfying views of them.

The scope ships in a foam-lined Pelican Storm case with wheels at one end that make for easy transport and storage. The SR-127 comes equipped with tube rings and a Vixen-style dovetail bar. The scope includes a 2-inch, dual-speed, rack-and-pinion focuser that's as smooth and solid as any of the premium focusers I've used in the past. It has a focus lock that is helpful when supporting heavy eyepieces and diagonals or cameras. Both the focuser and its included 1¼-inch adapter use compression rings to prevent damage to the barrels of your gear. The tube is made of black carbon-fiber, and the entire assembly is surprisingly lightweight — just 13 pounds (6 kg). All you need to add to this kit for visual use is a solar finder, a star diagonal, an eyepiece, and electricity.

I was surprised the telescope didn't include a solar finder. It can be extremely difficult to place the Sun in the eyepiece field without one, particularly because you can't safely sight your one-and-only target along the side of the tube. Using the tube's shadow as a guide gets you close, but purchasers should plan on adding a solar finder to their must-have accessory list.

Counterintuitively, the included



▲ The scope includes a dual-speed, 2-inch, rack-and-pinion focuser, and a saddle to accept standard finderscope bases.

manual states that you should keep the scope pointed directly at the Sun as much as possible without the lens cap in place. If you're pointed just a little off target, sunlight will land on the six internal baffles or inner wall of the telescope, which will then heat up and create turbulence within the tube, significantly degrading the view.

▶ The author's typical setup while reviewing the SolaREDi SR-127 QT.

▼ In addition to a Pelican armored case, the telescope includes mounting rings and a Vixen-style dovetail mounting bar.

◀ An LCD digital readout displays the exact bandwidth of the internal Quantum solar filter. An LED status indicator at right appears yellow as the filter is stabilizing and changes to green when it has reached its target temperature. The red button increases the filter passband, and the blue button decreases it in order to display wing-shifted features in the chromosphere.

The SR-127 incorporates additional optics to achieve its long 2,667-mm (f/21) focal length in such a comparatively short 74-cm (29-inch) optical tube and ensure the light rays are as parallel as possible before entering its etalon filter. An inline blocking filter reflects nearly all of the unneeded incoming sunlight out the front of the refractor, letting only a small portion of that concentrated energy reach the main etalon.

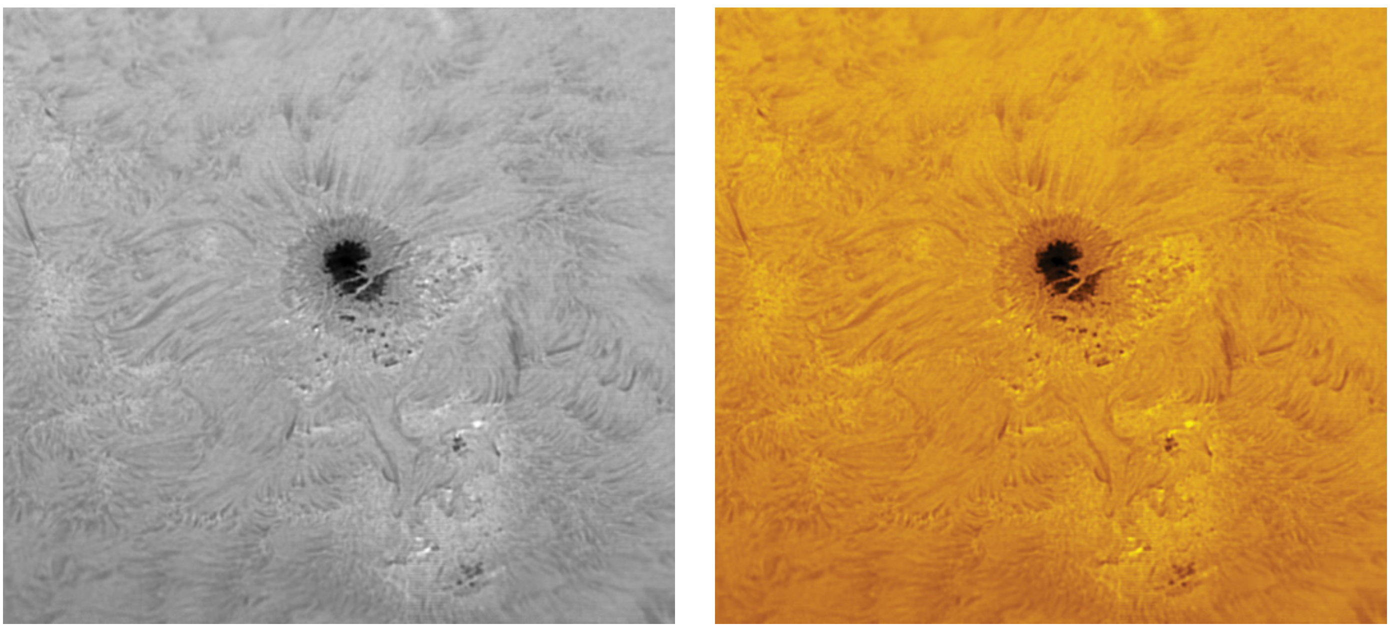
Basic Operation

The scope's temperature-regulated etalon filter requires electrically generated heat to precisely control the width of the passband. DayStar includes an AC adapter, though you can also use a 12-volt supply provided it produces at least 1.2 amps. An LCD screen on the side of the tube near the focuser displays the current passband. A status LED appears yellow while heating or cooling to the proper temperature, then turns green when it's ready for use. The filter heats to between 100° and 150°F (38° to 66°C) and takes about 10 to 15 minutes to reach temperature after initial power-up. Adjustments to the passband may take as much as 5 to 10 minutes for the filter's temperature to settle, though in my hot Florida climate it often took only a minute or two. The red and blue buttons to the right of the display adjust the passband in increments of 0.1 Å from the central value of 6562.8 Å.

The reason there's a range of adjustments, rather than a single "set-and-forget" setting is to compensate for what's known as *wing shift*. Features in the chromosphere, particularly prominences, can evolve over short time spans, sometimes changing within a few minutes. This is due to plasma travelling along magnetic fields at speeds fast enough that they can actually be blueshifted when approaching the viewer, and redshifted as they race in the opposite direction. The effects are noticable along the limb of the Sun. You can use the red and blue buttons to slightly adjust the passband by as much as +/- .5 angstroms to bring out these wing-shifted features. However, it may take some practice to be able to see the difference. When studying features along the solar limb, you can see these changes in brightness and contrast more easily at high magnifications. Some features required a change of .3 to .4 angstroms to see an improvement in contrast and clarity.

The Sun is a relatively large target, so at the scope's focal length of 2,667 mm, you should use an eyepiece with as

▼ Under good seeing, the SR-127 produces high-resolution images of sunspots, filaments, plages, and even prominences. This excellent photo of AR 2786 was recorded in late October 2020 using a ZWO ASI120MM monochrome video camera. The image at right is the same picture colorized for aesthetic purposes. The Sun appears bright reddish pink through this and any hydrogen-alpha solar filter.



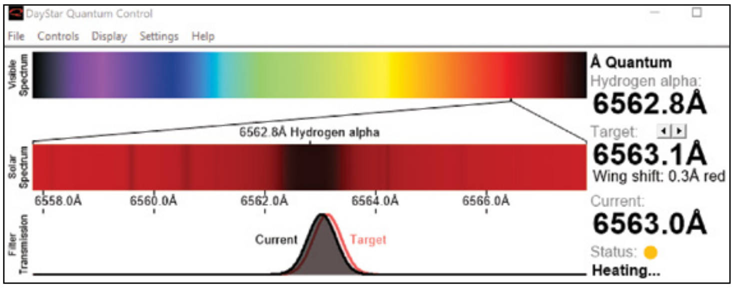
long a focal length as possible in order to provide low magnifications. DayStar recommends Tele Vue Plössl eyepieces in the 15-mm to 55-mm range. I have both the 55-mm and the 32-mm models and used them often with the scope. The 55-mm produces an excellent view of the entire solar disk at 48×. Prominences stand out well, and anytime I looked at the Sun there were at least some small ones visible along the limb. On the Sun's churning disk, spicules are easily seen, and when sunspots are present closer to the limb, they really stand out from the active regions, producing a three-dimensional appearance.

The field surrounding the Sun isn't quite black, but rather an unobtrusive, faint, pinkish glow. Prominences appeared just as bright and visible no matter if they were in the center of the field or placed near the edge.

The best way to describe the view through a dedicated Hα solar telescope is "electric." Solar Hα light is a bright reddish pink — like a neon sign on steroids. Photographs really don't capture the vibrant appearance accurately. Slightly out of focus the Sun is a pinkish blur, but as I turn the focuser, the details simply pop into focus, and I feel a mental jolt at the intricate scene.

A 32-mm eyepiece produces 83× and brings out even more surface detail.

▲ Daystar offers an optional FlatCap diffuser that permits imagers to use the Sun as a light source for making flat-field calibration images to correct for uneven illumination and dust motes.



▶ The *Quantum Control* software graphically displays the status of the telescope's internal filter and allows users to adjust the filter's bandpass.

One particularly active region surrounding a small cluster of sunspots was a real treat to observe. Prominences are also more pronounced, as the higher magnification also increases contrast. I also tried some eyepieces in the scope with focal lengths in the range of 20 mm or less, but the daytime atmospheric seeing just would not cooperate. DayStar also warns that anything shorter than 12 mm produces magnifications beyond the diffraction limit of the instrument.

In practice, warm, turbulent daytime air limits how much you can push magnification anyway. On a morning of good seeing, a 24-mm Takahashi LE eyepiece provided great views, but I could not go beyond that. The Moon is nearly the same apparent size as the Sun, and at night you can often get great high-resolution views of it that approach the resolution limits of your telescope. Daytime skies, however, are far less forgiving.

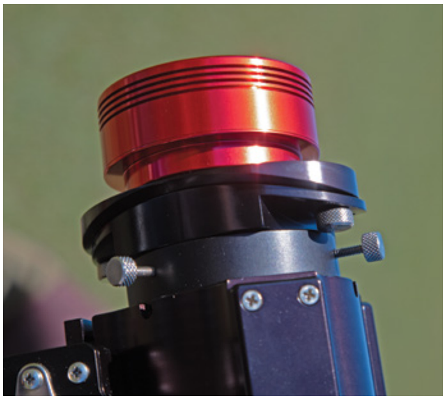
Imaging Performance

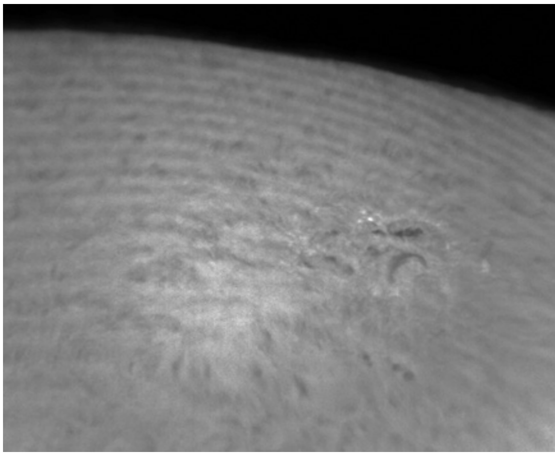
Naturally, with the addition of a few adapters, you can also use the SR-127 for solar imaging. As Hα light is a narrow wavelength found in the red end of the spectrum, a color camera is unnecessary. Those amazing color images of the Sun you often see were shot with monochrome cameras and colorized after the fact.

The telescope includes sufficient back focus to accommodate a 90°-star diagonal and a wide range of eyepieces. However, you'll need an additional extension tube to get to focus when imaging straight through without a diagonal. I find it much easier to have a motorized focuser when imaging so I can do everything from the computer. I added a small Optec focuser on the back of the existing focuser, and even with this added weight the focuser never slipped. The added focuser took up enough back focus that additional spacers weren't necessary.

Once focus is achieved, imaging is a snap — I just had to remember to keep my videos to about 30 seconds in length

▼ Another helpful accessory for Hα solar imaging is DayStar's optional Interference Eliminator. This device allows users to slightly tip their camera in order to remove interference patterns known as Newton's rings (bottom image). These rings arise from reflections between the cover slip of a digital detector and the rear element of the etalon filter.





because features in the chromosphere change so quickly.

The SR-127 QT has a 9-pin serial port that allows for software monitoring and control of the telescope's filter bandpass — a convenient option for imagers like me. Users can download DayStar's *Quantum Control* software for Windows from the DayStar website, which works seamlessly with the telescope. Connecting the scope's filter to a laptop requires an optional USB-to-serial adapter. A nice feature of the software is that it searches for the Quantum filter on all the available ports on your computer, so you don't have to figure out what COM port your adapter is connected to. A graphical display shows the settings and if the filter is currently heating, cooling, or at the desired temperature.

There are two additional accessories DayStar recommends for imaging. The first is their Interference Eliminator ($175). Because the light rays exiting the etalon are parallel, they can often cause a reflection between the camera sensor's cover glass and the final surface of the SR-127's filter that interferes with the incoming light and produces a moiré pattern on solar images. The solution is to tilt the camera very slightly. DayStar offers the Interference Eliminator with either C- or T-threads to connect to most cameras.

▲ Users will need to add a solar finder.

The other helpful accessory is DayStar's FlatCap Imaging Diffuser. This device makes flat-field calibration frames in order to remove dust motes from images and correct any uneven illumination. The diffuser is placed over the front aperture of the telescope, diffusing the light entering the scope. You simply point at or near the center of the Sun and record the image to use as flat-field calibration frames.

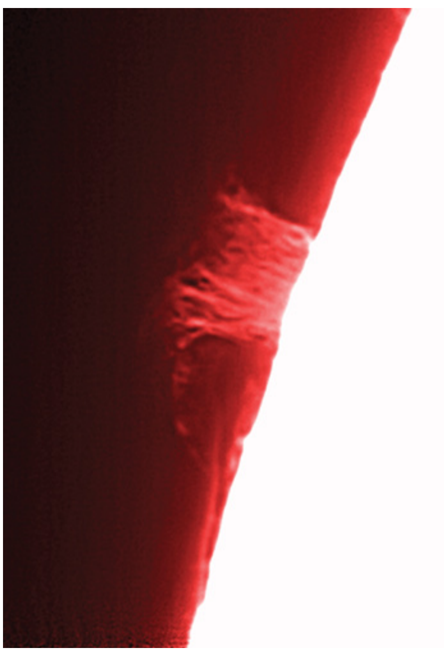
I also took a few images using a full-frame mirrorless camera just to see if it could capture the entire solar disk. It almost fits, but not quite, as seen below. To capture the entire Sun, you'll need to add DayStar's Imaging Focal Reducer (available on the DayStar website for $285). In all other ways, using the SR-127 QT was just like imaging with a Quantum solar filter on one of my other refractors.

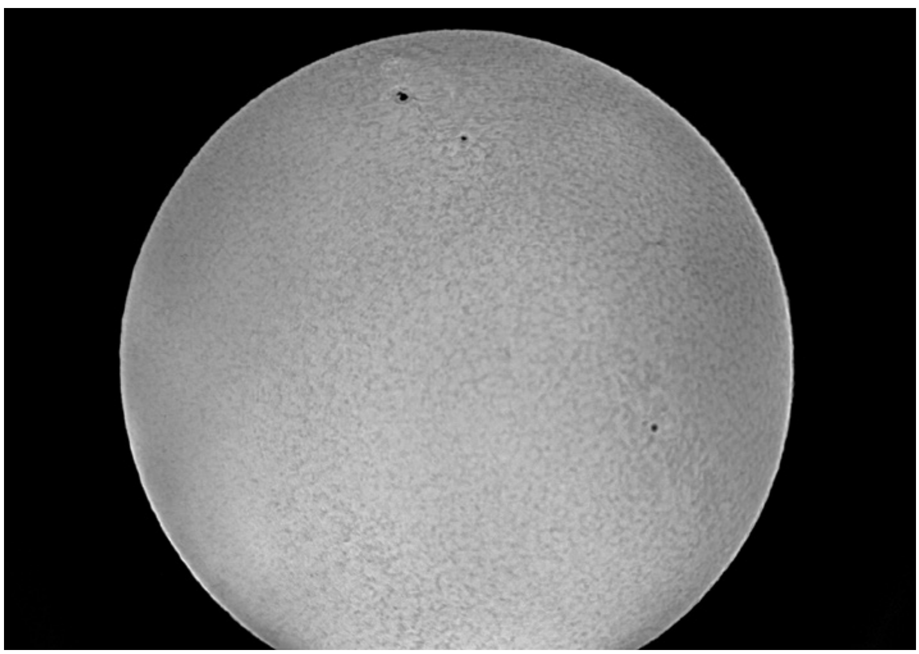
For Solar Aficionados

The SolaREDi SR-127 QT represents a serious investment for the dedicated solar observer or imager. Its long focal length means that imagers should also consider the additional cost of the focal reducer and other accessories. But this solidly constructed telescope is surprisingly lightweight and can easily switch back and forth between visual and photographic use. I feel the chromosphere model offers a good balance between views of the solar disk and of prominences that justify the extra cost.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** enjoys observing stars, including the closest one.

▼ *Left:* Prominences are still clearly visible through the chromosphere version of the SR-127. *Right:* This image recorded with a Canon EOS Ra shows the SR-127 QT doesn't quite fit the entire Sun on a 24×36-mm detector, requiring the addition of DayStar's optional Imaging Focal Reducer.





▲ FAST APOCHROMAT

Stellarvue adds a new model to its extensive line of apochromatic refractors. The SVX140T ($6,995) is a 140-mm (5.5-inch) f/6.7 air-spaced triplet apochromat that incorporates an Ohara S-FPL-53 super-low-dispersion center element and a lanthanum rear element to produce color-free views. The scope's aluminum tube is fully baffled, weighs 10 kilograms (22 lbs), and measures 79 cm (31 in) long with its dew shield retracted (38 inches with dew shield extended). The SVX140T comes with a robust 3½-inch-format Feather Touch focuser, and users have the option of upgrading to a 3½-inch computerized, rotating Moonlight focuser. Both focusers are designed to accommodate the largest imaging detectors on the market today. Each unit includes CNC-machined mounting rings and a padded, heavy-duty C130L case.

Stellarvue
11802 Kemper Rd., Auburn, CA 95603
530-823-7796; stellarvue.com

▲ STANDALONE GUIDER

StarAid announces its latest autoguider for deep-sky astrophotography. The StarAid Revolution – Revision B (890€, or about $1,078) promises hassle-free astrophotography with AI-powered guiding. This 39-mm × 63-mm (1½-inch-by-2½-inch) guider is designed around a Sony IMX290LL CMOS detector with a 1,920 × 1,080 array of 2.9-micron pixels. The guider is controlled using a Windows PC or your smartphone connected through integrated Wi-Fi and is powered through its USB-C port (power supply not included). Its nosepiece fits standard focusers and is threaded to accept 1¼-inch filters. The Revolution automatically identifies the location it is pointed at, and it aids with polar alignment as well as executes fully autonomous, multi-star tracking. A 1-meter USB-A to USB-C cable, ½-meter RJ-12 guide cable, 2-meter RJ-45, CAT 6 cable, and port splitter are included.

StarAid
bSentient B.V., Leeuwenbrug 89A, Deventer, NL 7411TH
staraid.ai

▶ POLAR SCOPE AID

Orion Telescopes & Binoculars aims to take the hassle out of using a polar-alignment scope. The Orion Right-Angle 1× – 2× Viewer for Polar Scopes ($109.99) uses three thumbscrews to attach to the eyepiece end of 25-to-30-mm polar scopes and projects the view at a 90° angle. No more sore necks or dirty knees! The unit contains an Amici prism to provide the same image orientation as your mount's polar scope and for convenience is rotatable to any angle. The Right-Angle Viewer also includes both 1× and 2× magnification options and has a helical focusing eyepiece with a soft rubber eyecup.

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

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A Convertible Moon Buggy

Haul the whole kit and caboodle in one fell swoop.

LIKE MANY PROJECTS, Jack Roach's "Moon Buggy" was born out of necessity. Jack's observing site is at the end of 90 meters (300 feet) of driveway, and by the time he and his granddaughter, Chloe, hauled the telescope, base, eyepieces, chairs, table, chart, etc. out to the site, they logged close to half a mile. That led to the obvious question: What if they could put everything on a rolling platform and take it all in one easy trip? Something like a little red wagon, only bigger, would do nicely.

Well, Jack had a little red wagon nobody was using anymore. That was way too small, but it served as a starting point. He also had a surplus jogging stroller. The stroller's center of gravity was way too high, and its three-wheel design was way too unstable, but it had two nice, big rear wheels. If he took the steering truck from the front of the wagon and the rear wheels from the stroller, then spanned the gap with some leftover plywood, he could make the cart any size he wanted.

Jack has two telescopes: an 8-inch f/9 Dobsonian and a 6-inch f/5 home-built equatorial. He measured the footprint of each scope and built a cardboard scale model to make sure the platform would accommodate either scope. He wanted the cart to be as low as possible for stability, so he designed the platform to hang from the baby stroller's axle supports (its former legs), which meant the front needed a gooseneck in order for the deck to remain level when connected to the wagon wheels. That worked in his favor in that the gooseneck allows room for the wheels when the cart makes a tight turn.

◀ Jack's granddaughter, Chloe, easily pulls the fully loaded Moon Buggy out to their driveway observing site.

The deck also needed to be wider than the baby stroller wheel separation. Jack could have gone to considerable trouble to lengthen the axle, but he felt the wheels were spaced wide enough as they were, so he simply cut notches in the platform for the wheels to fit into. The wagon steering mechanism proved too loose, which made the buggy wobbly in front, but removing the cotter pin and tightening the bolt snugged it up enough to eliminate that problem.

▲ The buggy is basically a platform with steerable wagon wheels in front and baby stroller wheels in back. Jack built a gooseneck for the front wheels to keep the platform both low and level.

The platform itself had some front-to-back flex to it, so Jack screwed a 2-by-4 edge-on to the underside down the middle. That worked great until the first trip over the threshold of his storage building, when the buggy high-centered on the 2-by-4. So Jack ripped it down to a 2-by-2, which gained enough room to clear the threshold while still retaining enough stiffness to keep the deck rigid.

The gooseneck provided a good spot to store an eyepiece case, but it needed something to hold the case in place. So Jack screwed two semicircles of plywood — rough first-quarter Moons — to the sides. He considered painting craters on them, but then he remembered that he had a fairly good photo of the Moon he'd taken through his 8-inch scope. He printed that out and sandwiched the hemispheres between acrylic sheets, and

JACK ROACH (2)

JACK ROACH

▲ With the addition of screw-on legs, the buggy becomes a chart table.

thus the buggy became the Moon Buggy.

The buggy evolved after Jack used it a few times. It was okay for transporting gear, but once in the field it was too low to serve for holding charts and such. At first Jack considered how he could carry a table along with all his other gear, but then the light bulb went on: Why lug another piece of equipment when he had a perfectly good flat platform right there? He just needed to raise it high enough to use comfortably. Some 2-by-2s salvaged from the scrap bin at a local big box store made perfect legs, with ⅜-inch studs on the ends that reach through holes in the corners of the platform and are tightened with hefty knobs.

The legs serve a dual purpose: When the buggy is loaded for transport they can be attached to the topside of the deck, and a couple more knobs screwed into their sides become brackets from which to hang the observing ladder.

No project is ever completely finished. Jack plans to add a battery in the gooseneck to power a red light that will illuminate the tabletop. And he hopes to take the Moon Buggy to Stellafane this summer if possible, where many of us can see and admire it in person.

For more information contact Jack Roach at **Jack.roach82@gmail.com**.

■ Contributing Editor **JERRY OLTION** has wheeled a 20″ mirror box on a skateboard but thinks Jack's idea is probably more practical.

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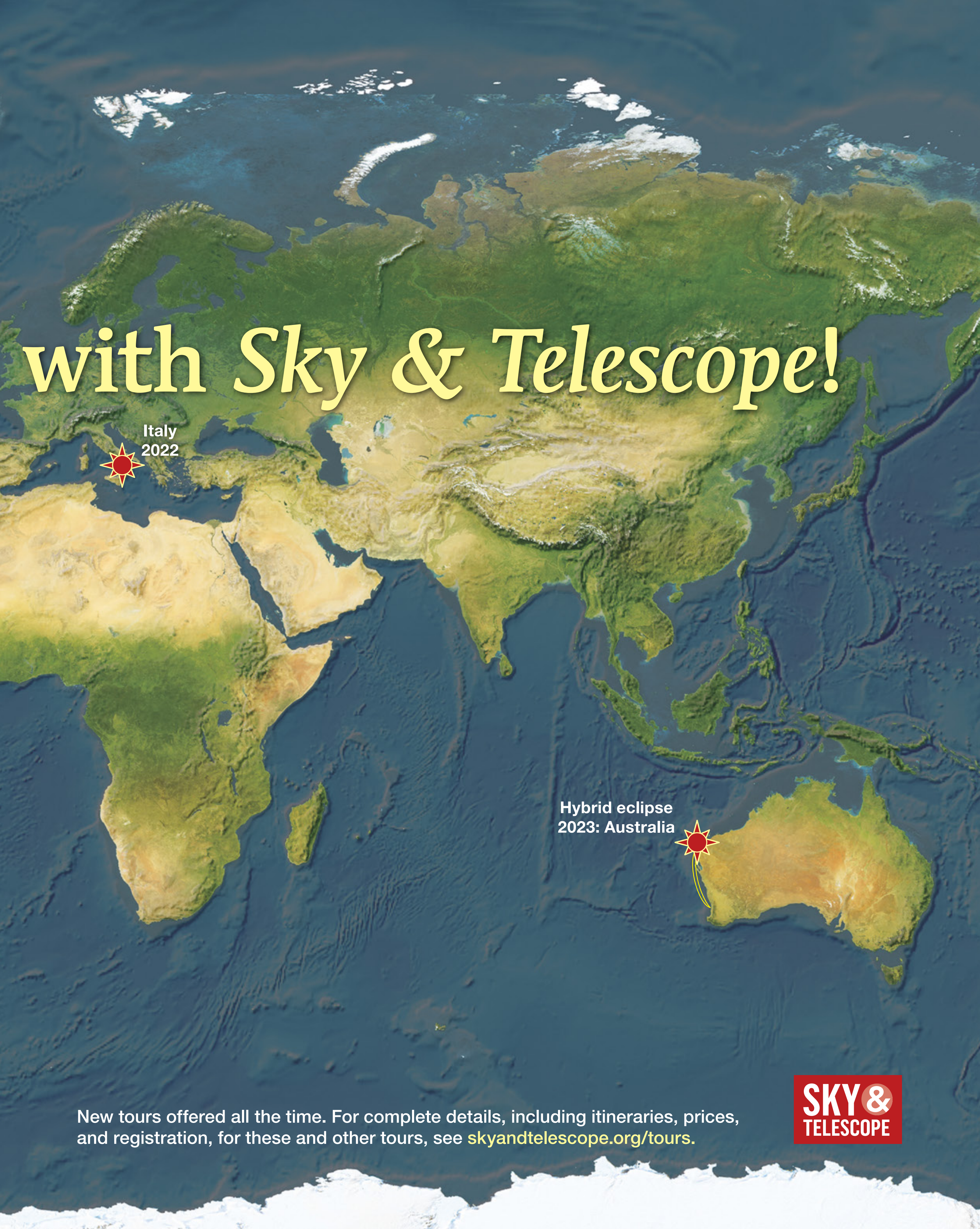
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◁ NIBBLING ON OUR STAR

Arne Danielsen

The Moon appears to take a bite out of the Sun in this hydrogen-alpha image of the annular eclipse of June 10, 2021. A large but faint prominence is seen on the solar limb at bottom right.

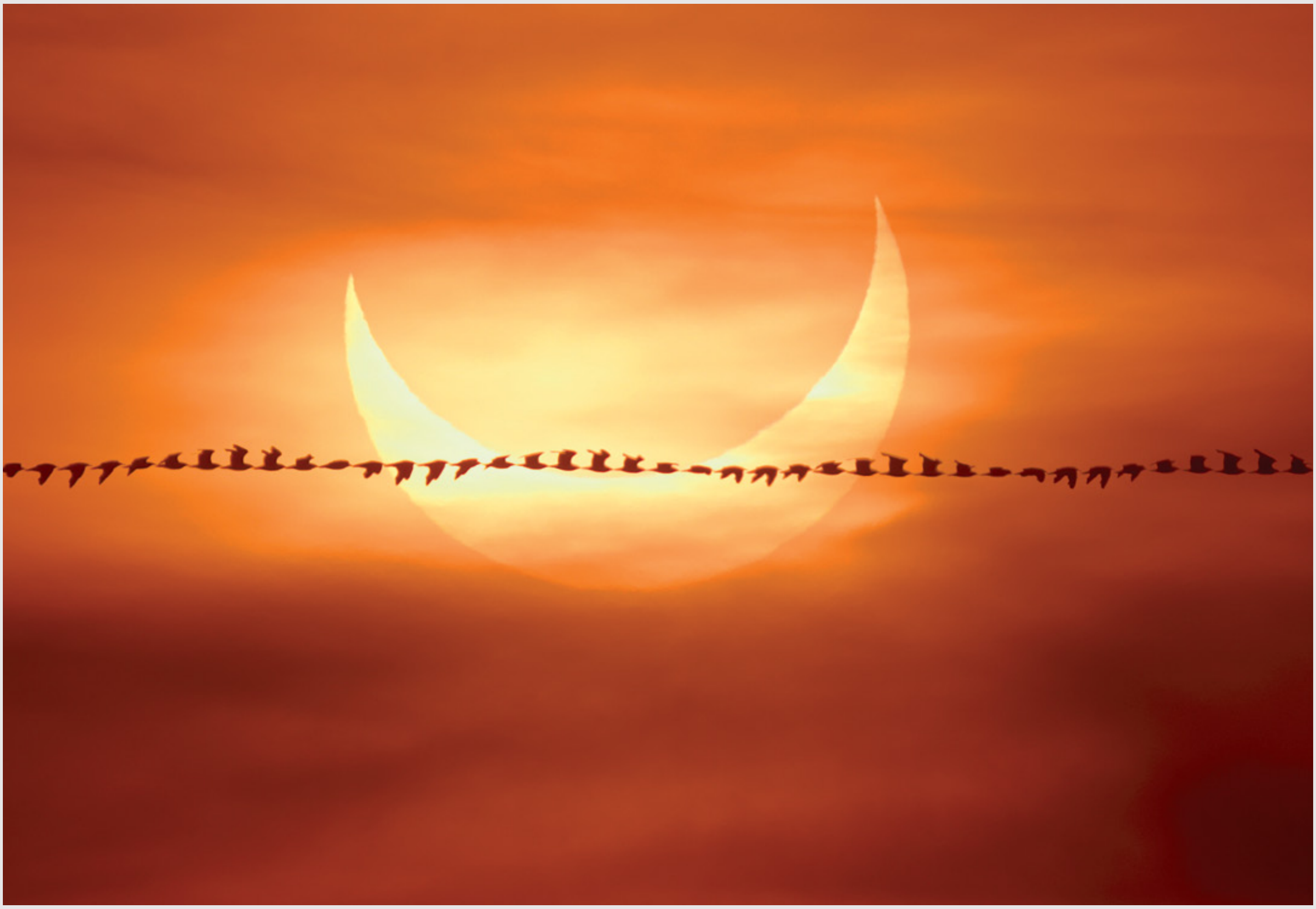
DETAILS: *Takahashi Sky-90II APO refractor with ASI1600MM Pro camera. Stack of 400 images through Coronado SolarMax 90 II Hα filter.*

▽ SERENDIPITY

Zev Hoover, Christian Lockwood, and Zoe Chakoian

In this composite image, a gull passes in front of the Sun near the moment of maximum eclipse over Boston Harbor. The dark silhouette of the bird contrasts well with the orange light reflecting off the clouds.

DETAILS: *Tele Vue-76 APO refractor with Sony Alpha 7S III Mirrorless camera. Stack of 42 exposures.*



▷ CRESCENT SUN

Richard Germain

This sliver of sunlight smiled down on Vaudreuil-Dorion, Québec, as the new Moon eclipsed the Sun just a few days after reaching apogee, the farthest point from Earth in its orbit.

DETAILS: *Orion ED80T CF refractor with Canon EOS 6D Mark II camera. Total exposure: 1⁄200 second at ISO 500 through an Orion solar filter.*

▽ FISHING FOR AN ECLIPSE

Jeffrey Myers

A distant fishing boat crosses in front of the distorted horns of the partially eclipsed Sun rising over the Atlantic Ocean. Sunlight passing through the thick atmosphere near the horizon creates a lovely reddish glow.

DETAILS: *William Optics Zenithstar 66-mm SD refractor with Nikon D90 camera. Total exposure: 1⁄125 second at f/5.9, ISO 400.*

▷ JUROMENHA FORTRESS

Sérgio Conceição

Stars appear to circle above the Church of the Misericórdia, located inside a medieval fortress in Juromenha, Portugal.

DETAILS: *Canon EOS 5D Mark III DSLR camera with 14-mm lens. Stack of 270 exposures each totaling 30 seconds at f/3.5, ISO 1600.*

▽ PROPELLER NEBULA

Emil Andronic

Simeis 57, commonly known as the Propeller Nebula, is a bright area in a much larger cloud of ionized gas in northern Cygnus.

DETAILS: *TS Optics 65-mm APO refractor with ZWO ASI294MC Pro and QHY5L-II cameras. Stack of 160 exposures totaling 11½ hours through Antlia Hα and IDAS LPS-D2 filters.*

FIERY ECLIPSE
Bray Falls
Sunlight refracted through Earth's atmosphere casts a blazing red hue across the Moon's surface during the lunar eclipse of March 26.
DETAILS: *Celestron EdgeHD 9.25-inch Schmidt-Cassegrain telescope with Sony Alpha 7S III camera. Total exposure: 40 seconds.*

EARTH'S UMBRA

Joe Cali

Combining 15 images of the Moon recorded at different points throughout the May 26th total lunar eclipse over New South Wales, Australia, reveals the shape of Earth's shadow.
DETAILS: *Vixen VC 200L reflector with Pentax K-1 DSLR camera. Total exposure: 1/125 second during partial phases, 8 seconds during totality.*

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

~~August 3–7~~ **CANCELED**
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

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

August 4–9
SASKATCHEWAN SUMMER STAR PARTY
Maple Creek, SK
https://sssp.saskatoon.rasc.ca

~~August 5–8~~ **CANCELED**
STARFEST
Ayton, ON
http://www.nyaa.ca/starfest.html

August 5–8
STELLAFANE CONVENTION
Springfield, VT
stellafane.org/convention

August 6–8
NORTHWOODS STARFEST
Fall Creek, WI
cvastro.org/northwoods-starfest

August 6–8
NOVA EAST
Smileys Provincial Park, NS
https://novaeast.rasc.ca

August 7–15
MOUNT KOBAU STAR PARTY
Osoyoos, BC
http://www.mksp.ca

August 8–14
MAINE ASTRONOMY RETREAT
Washington, ME
astronomyretreat.com

August 19–21
ALCON 2021
To be held virtually at:
alconvirtual.org

August 19–22
THEBACHA & WOOD BUFFALO DARK SKY FESTIVAL
Fort Smith, NWT
https://is.gd/tawbas_dark_sky_fest

September 2–6
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

September 3–5
ALBERTA STAR PARTY
Starland County, AB
https://calgary.rasc.ca/asp2021.htm

September 3–5
EASTERN IOWA STAR PARTY
Dixon, IA
https://is.gd/EIowa

September 3–6
MICHIANA STAR PARTY
Vandalia, MI
michiana-astro.org/index.php/msp12

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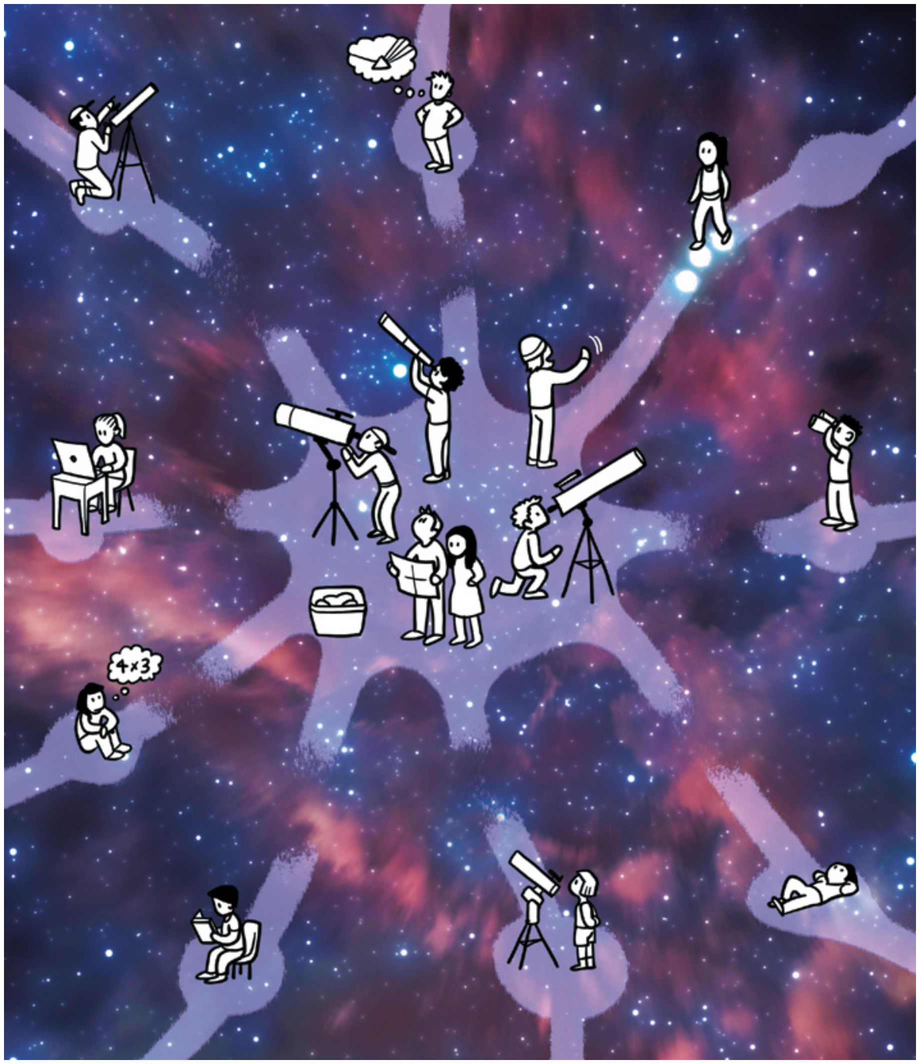
How do we better connect young astronomy enthusiasts to their local clubs?



ONE NIGHT NEARLY half a century ago, as an eight-year-old fishing on a beach with my dad, I asked why the clouds weren't moving. He said it was the Milky Way — stars. After further questions over the coming weeks went largely unanswered, I demanded a telescope. A Sears refractor duly arrived under the Christmas tree, and with it came the rings of Saturn! But without a way to connect with astronomers or astronomy, I became more interested in airplanes, and at 13 I moved onto flying lessons at the local airport.

Now a retired Army pilot in my second career as a systems engineer, I've been able to conduct my own youth outreach since 2004 as a NASA/JPL Solar System Ambassador. Recently I served as a judge for the Texas Space Grant Consortium's STEM Enhancement in Earth Science (SEES) initiative (**https://is.gd/SEESsummer**). This nationally competitive summer STEM program provides opportunities for high school students to work alongside NASA experts analyzing and visualizing data.

Of the 42 student packets I reviewed, 38 transcripts were "straight As." Most of these amazing students were polymathic and exhibited a strong sense of personal responsibility for our world. Four were directly involved in astronomy, but *none* had any exposure to their local astronomy club.

Suspecting a deeper problem, I requested global SEES applicant data to understand the bigger picture for these incredibly gifted students. I received shocking clarity. Of the 730 SEES applicants in 2021, more than 25% had listed astronomy as their first or second career choice. Yet just 0.5% belonged to an astronomy club.

One of my 42 students performed self-directed transit photometry. Another came from a remote community that developed a micro-curriculum for the student, who hoped to work with a real telescope someday. Incredibly, that teenager lived just miles from the meeting place of a historic U.S. amateur astronomy club.

As a former club president, I know that such groups try to attract young people. Also, our federal tax dollars support studies of the engagement problem (see, e.g., **https://is.gd/sharinguniverse**). Yet based on my observations and the 2021 SEES data, we are failing to engage the most talented students.

What to do? One approach might be to encourage industry to back STEM engagements that include an astronomy component. Recently, for instance, I conducted an industry-supported outreach in a local high school robotics class during National Engineers Week.

Another tactic might be for clubs to connect with high school guidance counselors. The clubs could present programs that demonstrate how astronomy outreach can benefit students on college applications. This might stimulate the top end and allow earlier grade entry for interested younger students.

Clearly, to help secure the future of our hobby, we need to fan those sparks.

■ **MAX CORNEAU** is former president of the Texas Astronomical Society of Dallas. Have your own ideas for better connecting kids and clubs? Send them to **letters@skyandtelescope.org**.

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