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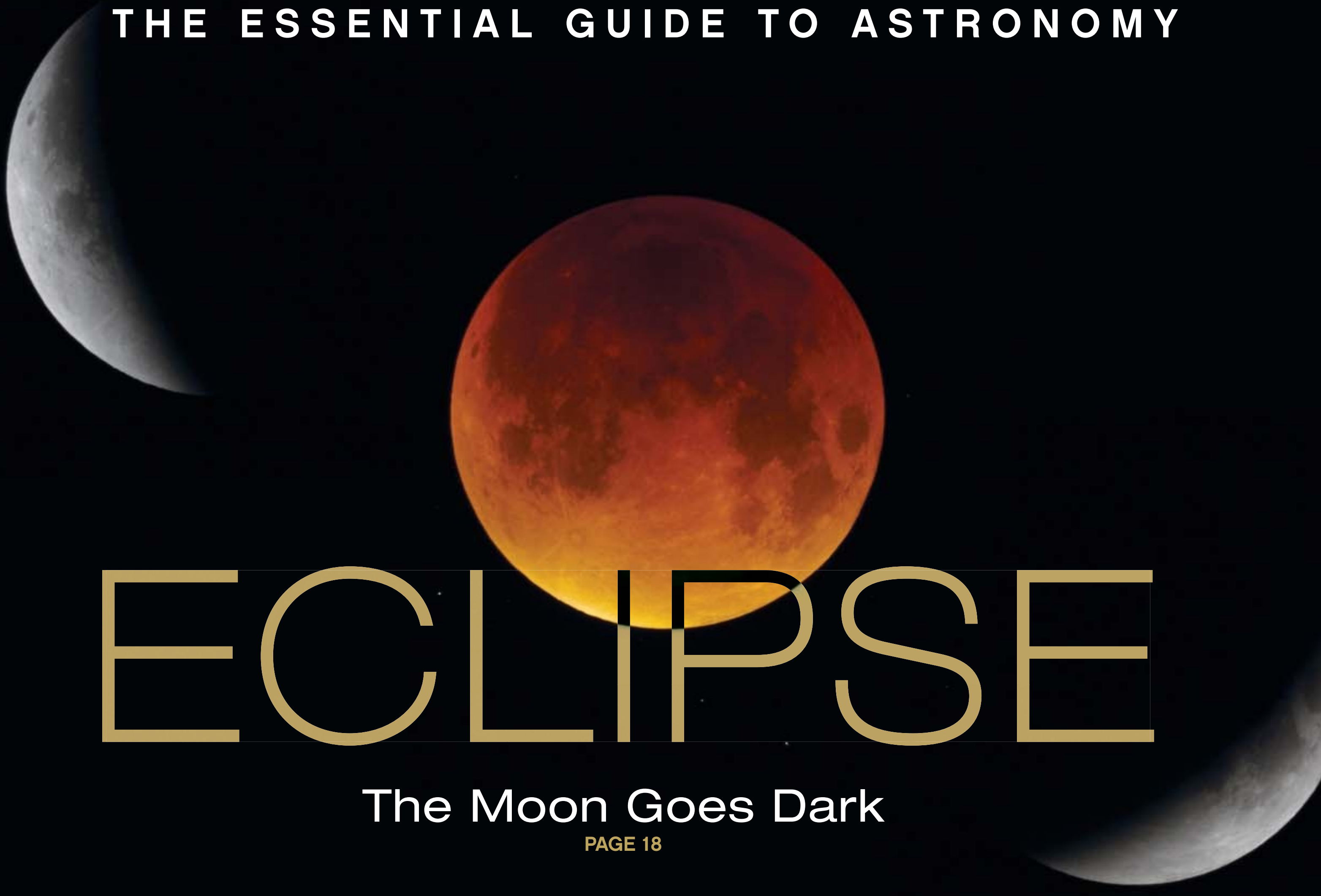
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY



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JANUARY 2019
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THE ESSENTIAL GUIDE TO ASTRONOMY

January 2019 VOL. 137, NO. 1

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This montage shows the September 2015 total lunar eclipse.

PHOTO: SEAN WALKER

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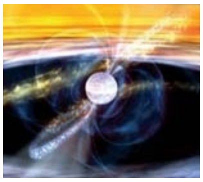
The How and the Why

WHEN IT COMES TO ASTROPHYSICAL studies these days, it's often hard to decide what's more amazing: *how* scientists do them, or *why* scientists do them. Both can boggle the mind.

Take the search for low-frequency gravitational waves. LIGO detected high-frequency gravitational waves from the merger of small black holes (*S&T:* Jan. 2018, p. 10). But LIGO can't observe the longer waves emanating from the most massive black holes of all: supermassive black hole binaries. These are pairs of behemoths each millions to billions of times the mass of our Sun that, after the galaxies that host them merge, wind up orbiting each other and eventually combining. As they circle and when they collide, they generate these low-frequency gravitational waves, which radiate outward at the speed of light and ripple the fabric of spacetime across the universe.



Artist's concept of a pulsar pulling in matter from a nearby star

NASA

These waves have extremely long wavelengths, with a billion seconds (>30 years) between peaks. And their influence when they pass objects like Earth is exceedingly subtle: Even a "strong" gravitational wave will cause an object to stretch or shrink by just one part in a quadrillion.

Facing such challenges, researchers have devised an ingenious solution for how to detect these ripples, as Bob Naeye describes beginning on p. 22. They rely on the exquisitely stable timing of radio flashes from pulsars, a variety of neutron star that whirls like a lighthouse beacon, dispatching its beams into the ocean of space. So predictable are these celestial clocks that astronomers can time, often decades into the future, when radio signals from the most stable pulsars will reach Earth to within a few hundred nanoseconds.

By monitoring across the galaxy a scattering of such cosmic clocks — which together form a *pulsar timing array* — astronomers can use the Milky Way itself as a detector. Consider it a kind of Galaxy Positioning System. The idea is to watch for pulses that arrive at our radio telescopes ever so slightly earlier or ever so slightly later than forecast. In this way, radio astronomers are striving to use pulsars as stellar buoys to reveal the swells of passing gravitational waves.

Why go to all this trouble? Spacetime is full of ripples, warps, and holes that we can't see but we can "hear." Successfully doing so will open up a whole new area of astronomy, allowing us to address questions we can't address any other way. How do galaxies merge and grow over cosmic time? What characterizes the ultra-exotic environments around supermassive black hole binaries? In such environments, we'll be operating at the limits of our understanding. What we find will doubtless challenge us with entirely new, unforeseen discoveries that will lead to even more remarkable hows and whys.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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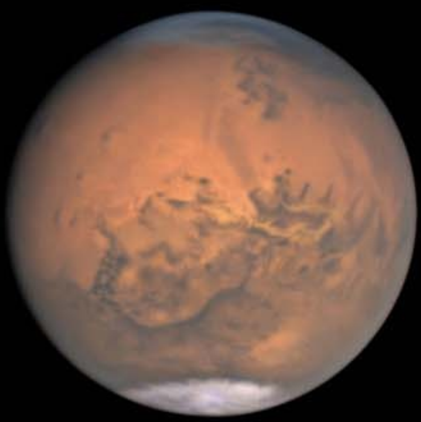

Martian Makeover?

Has the face of Mars been changed forever? The planet's huge dust storm recently, combined with terrible weather all summer here in the Florida panhandle, really messed up the opportunity to observe the best opposition in over a decade. But the few photos I've taken and most of the ones I've seen look nothing like the Mars I knew before the storm. Will the "dust settle," so to speak, and will all be back to normal? Just curious.

Bob Hess
Panama City, Florida

Sean Walker replies: *The dust has pretty much settled out of the atmosphere. There is still some reduced contrast, but it's nearly back to normal. However, there have been some small but noticeable changes in albedo markings, as shown in the accompanying image. You'll find more information about the dust storm on page 52.*

▲ This image of Mars was taken by Damian Peach in early September under near-perfect seeing conditions with the 1-meter Chilescope.

Inside Enceladus

The News Note entitled "Organics Inside Enceladus: Complex Enough for Life?" (*S&T:* Oct. 2018, p. 8) mentions a strain of bacteria that could live on methane under the ice of Enceladus. But perhaps there's another way for life to exist there.

Here on Earth, most life forms get their energy to live by combining the oxygen freely available in the atmosphere with sugars and fats stored in their bodies. But suppose life in the oceans of Enceladus does it backward? In principle, they could use hydrogen and methane dissolved in the water as fuel and store the oxygen in their bodies, in the form of unstable oxides such as hydrogen peroxide or ammonium nitrate. Some creatures on Earth store oxygen-releasing chemicals inside themselves; for example, the bombardier beetle uses hydrogen peroxide to create its noxious sprays.

Hydrothermal vents in Earth's oceans produce all kinds of reactive chemicals, including sulfuric acid. If the vents assumed to be on Enceladus release similar compounds, then those could provide energy to create the oxygen-storage compounds. Or perhaps life there uses the temperature difference between the vents and the ambient water to provide energy. Future space probes should be designed to look for evidence of such "reverse" life forms.

Conan McCann
Fayetteville, Arkansas

Name That Gadget

"Backyard Spectroscopy with *RSpec*" by Rod Mollise (*S&T:* Sept. 2018, p. 68) includes a photograph of a laptop with a device attached to the USB port. What is this device? I'm just starting to get into *RSpec* with the Star Analyser 100.

William Woods
Weyers Cave, Virginia

Rod Mollise replies: *The device is the imaging camera I used to capture the spectra described in the Test Report. Specifically, it's a ZWO ASI120MC, an inexpensive color video-type camera that I find works very well with* RSpec.

Patience Rewarded

I had to chuckle at the letter about telescope delivery times (*S&T:* Aug. 2018, p. 7), because something similar happened to me more than 40 years ago.

My parents and I expected to receive an Edmund Scientific 4.25-inch reflector as a birthday present sometime in December 1973. But we failed to take the arrival of Comet Kohoutek into account. Edmund was inundated with orders from eager would-be astronomers, and we had to wait until February 1974 to get my new scope.

It was frustrating — but worth it. After my dad helped me set it up, I trained it on Saturn and still remember the thrill of seeing those beautiful rings. Even now, after all these years, I get some use out of my old standby.

Dean Christensen
Fresno, California

What's Cooking?

Would you elaborate on the statement in 75, 50 & 25 Years Ago (*S&T:* Sept. 2018, p. 7) that Edward Harrison's model was "cooked-up"? If Harrison's model passed all the major observational tests, why was it cooked up? Could his universe's 35 billion years old be more accurate than the current guesstimate of 13.8 billion?

Curt McCann
Corvallis, Oregon

Monica Young replies: *"Cooked-up" is pretty accurate because Harrison was explicitly trying to come up with an alternative to the Big Bang. So he cooked up his model to do just that, by choosing values for the Hubble constant and the density of the universe today, even though they didn't match observations at the time.*

But 25 years later we have an incredible amount of data that wasn't available then. Harrison had access to blobby COBE data on the cosmic microwave background, but WMAP, which provided a detailed view of the CMB, didn't launch until 2001, and Planck, which provided even more exquisite detail, didn't launch until 2009. The fluctuations measured in the temperatures of the CMB opened the era of precision cosmology and also pinned down the Hubble con-

stant using a very distant source (since the universe emitted the CMB when it was only 370,000 years old). There are still some discrepancies between data sets: The Hubble constant may be 68 kilometers per second per megaparsec or 73 km/s/Mpc, depending whether you measure it from nearby sources or from the CMB. But there's simply no way that current measurements would allow a value of 10 km/s/Mpc, as Harrison proposed, and ultimately a scientific theory must be able to predict our observed reality.

Gravity Doesn't Discriminate

In a sidebar (*S&T:* Sept. 2018, p. 25), Camille Carlisle mentions black holes undergoing the EKL mechanism. Is it also possible for the Hills mechanism to occur, flinging a black hole away from the center of our (or any other) galaxy to travel through intergalactic space? I don't recall seeing this possibility mentioned as a source of dark matter.

Ed Evans
Seneca, South Carolina

Camille Carlisle replies: *Any kind of binary can undergo the Hills mechanism, since in these situations gravity doesn't discriminate among stars, black holes, and other stellar remnants. Unfortunately, a hypervelocity black hole would be immensely difficult to detect. A star emits light, so we can see it and calculate both its proper motion across the sky and its radial velocity along our line of sight, based on the redshift of its spectrum. We couldn't do that with a black hole.*

I'm afraid hypervelocity black holes wouldn't work as a potential explanation for dark matter. For one thing, a hypervelocity black hole would not be bound to the galaxy, so it wouldn't create a big, deep well of gravitationally bound matter for the galaxy to sit in. For another, the Milky Way has roughly 10 times more mass in dark matter than it does in all its stars combined. There just haven't been enough massive stars to make enough black holes to explain all that dark-matter mass.

Here Goes Nothing

"The Void Next Door" (*S&T:* Oct. 2018, p. 12) helps a lot in visualizing our cosmic neighborhood. Over and above the numerous successful large simulations, is there an intuitive picture of why voids, sheets, and filaments are what gravity produces out of Gaussian quantum fluctuations in the early universe?

Ken Wachter
The Sea Ranch, California

Ken Croswell replies: *Voids have a lower density, so they expand faster than the overall universe. I like to think of voids as pushing against the rest of the universe, evicting their galaxies and herding them into the filaments and sheets that crisscross the cosmos.*

SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

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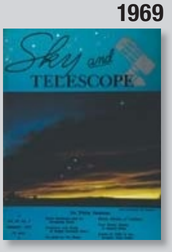
1969



1994

◖ January 1944

Director's Rebuke "[Long ago, on occasion, George Airy would tell an assistant at the Greenwich Observatory,] 'The Royal Observatory was founded for observation of the moon. We get about 300 observations of the moon during the year in all; and the Observatory costs the nation 6,000 pounds a year. Hence each observation of the moon is worth 20 pounds; and by losing one last night you have cost the nation 20 pounds! . . .'

"[That sum] seems pretty high for one observation of the moon's position, whereas Dr. Harlow Shapley figured a few years ago that it cost only a few cents . . . to discover a galaxy!"

This gem is from Roy K. Marshall's ever-popular Astronomical Anecdotes column.

◖ January 1969

Growing Evidence "[T]here may be a close connection between rapidly pulsating radio sources and supernova explosions. Two cases of such association have recently been announced. . . .

"The first of these pulsars [lies] near the midpoint of the extended radio source Vela X [,] believed to be the result of a prehistoric supernova explosion.

[Secondly,] R. B. E. Lovelace and his associates observed [Taurus pulsar] NP 0532 with the 1,000-foot dish at Arecibo, Puerto Rico. Several scans on November 15th placed the pulsar within 10 minutes of arc of the Crab nebula's center. . . . The distance of NP 0532 [from us] agrees fairly well with that of the Crab nebula, [so perhaps] this pulsar is, like the Crab nebula, a product of the supernova observed in A.D. 1054."

The pulsar-supernova link, now amply confirmed, was made just a year after pulsars were discovered.

◖ January 1994

Distant Blinks "Among the exciting astronomical news of last year was David Jewitt and Jane Luu's discovery of objects orbiting the Sun beyond Pluto. . . . They may lie within the Kuiper Belt, the hypothetical reservoir of comets postulated [to exist] just outside the region occupied by planets. . . .

"Is it possible to see [such remote comets] where they live before making their suicidal dives toward the Sun? [Using] reflected sunlight to detect them is hopeless. But there is another way to find comets; it involves looking for dark objects by observing occultations of more distant, bright objects. . . . If we adopt Kuiper's optimistic estimate of the Belt population, 10^{13} bodies, we can calculate that a star is occulted . . . once every two days or so."

Princeton physicist Freeman Dyson, reviving an earlier proposal by Mark E. Bailey, lamented it had been largely ignored. In recent years at least five major observatories have launched occultation surveys of this type, but so far the results are inconclusive.

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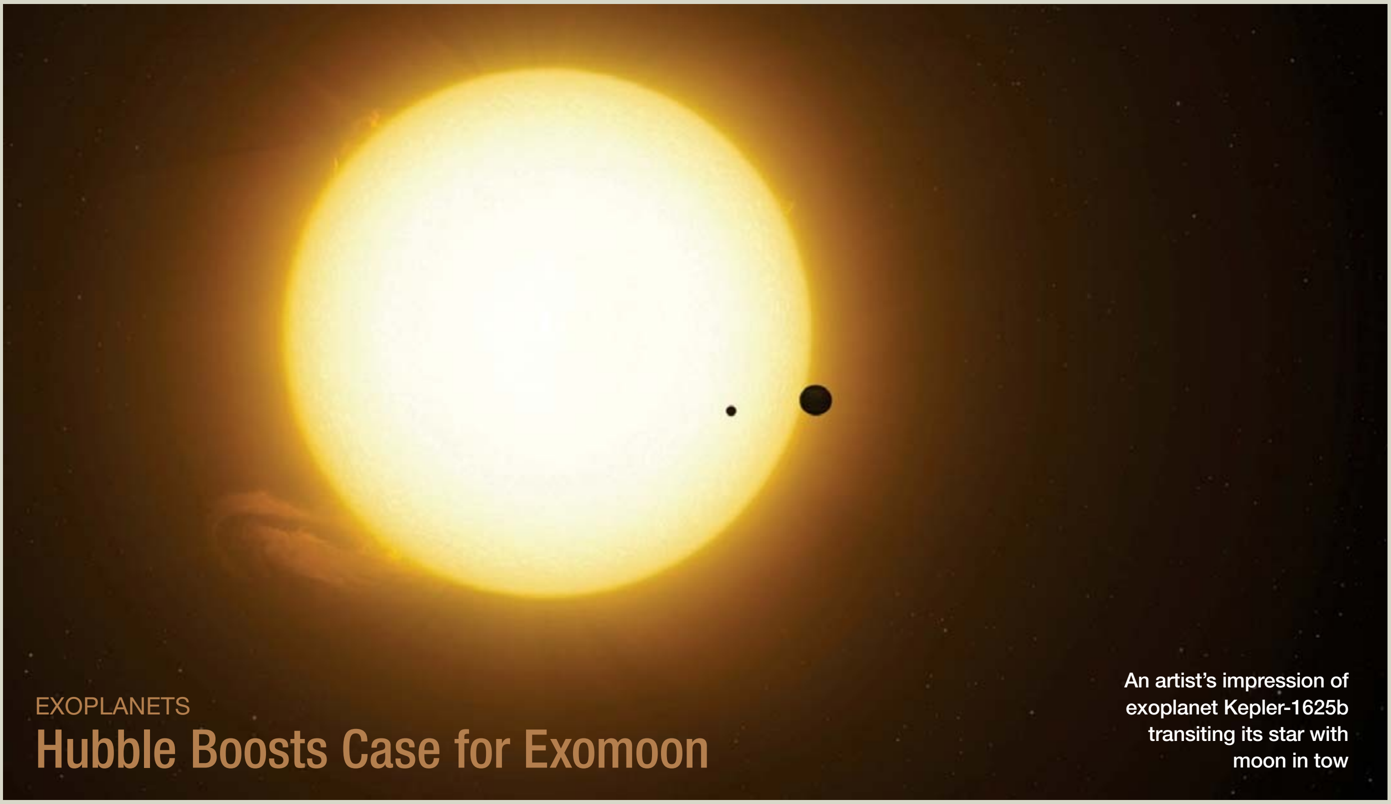


An artist's impression of exoplanet Kepler-1625b transiting its star with moon in tow

EXOPLANETS

Hubble Boosts Case for Exomoon

ASTRONOMERS REPORTED last year that they might have found the first known moon outside our solar system (*S&T:* Dec. 2017, p. 13). Now, those same researchers think their claim just got stronger. New observations from the Hubble Space Telescope lend credence to the idea that a moon roughly the size and mass of Neptune orbits the Jupiter-size exoplanet Kepler-1625b.

"I think we have to be very, very cautious," says Stephen Kane (University of California, Riverside). "But it is very encouraging."

Alex Teachey and David Kipping (Columbia University) got their first hints of an exomoon after looking through data on 284 planetary systems from the Kepler space telescope. The duo found one that looked promising: a gas giant that passes in front of its star every 287 days, paired with a hint of a second, smaller transit from a potential moon. But they needed more data to be sure. So they used the Hubble Space Telescope to look in October 2017, when the planet was expected to transit again.

They weren't disappointed. The hoped-for second transit came a few hours after the exoplanet's. What's more, the planet started its transit earlier than expected, another potential sign of a planet and moon orbiting each other and changing places with time. The team published their findings October 3rd in *Science Advances*.

"[They] did a marvelous job of examining the data," says René Heller (Max Planck Institute for Solar System Research, Germany). As to the existence of the exomoon, "I remain skeptical."

It's not that exomoons are unlikely. And it's not that the signal is too small to be reliable. Being a Neptune-size world, the putative moon blocks an amount of starlight that's on par with many exoplanets already discovered. Heller stresses instead that it is critical to understand all the potential sources of noise in the data — the telescope, the instruments, and the star itself.

The researchers do address many of these issues. One test was to look for the transit in multiple wavelengths. If the star were flickering, then red and blue starlight would dip by different amounts. But these transits look the same in all colors.

There is also the matter of the exomoon's unusual size. While the ratio in masses between the moon and the planet is about the same as that of our Moon and Earth — about 1% — the entire system is roughly 1,000 times as massive as ours.

"[This] is so extraordinarily different from what we're used to," Kane says. "It raises a whole lot of questions about how did this come to be."

There are three presumed vehicles for creating a moon: an impact on a planet, a circumplanetary disk of gas and dust, or capture of a passing body. Each method explains different moons in the solar system, but all three are tough to reconcile with this situation. "This moon, if confirmed, must have formed through a yet-unknown astrophysical mechanism," Heller says.

The next step is to get more data. The researchers have applied for time on Hubble in May 2019, when the planet is expected to transit next. One more transit that confirms the moon is in the right position based on its predicted orbit could clinch the case.

■ CHRISTOPHER CROCKETT

DAN DURDA

SOLAR SYSTEM

Dawn Probes Role of Cryovolcanism on Ceres

NASA'S DAWN MISSION has lifted the veil on Ceres, a dwarf planet in the asteroid belt. Now, a study published September 17th in *Nature Astronomy* has revealed this world's fascinating history of cryovolcanism, the supercold watery equivalent to magma eruptions on our planet.

Led by Michael Sori (University of Arizona), researchers carefully analyzed the appearance and location of 22 domes on Ceres. Using the 4-kilometer-high (2.5-mile-high) mound Ahuna Mons as a reference, the team estimated the ages of the other domes by assuming that they started out as tall piles of cryovolcanic material (like Ahuna Mons) that then slumped into shorter, broader mounds at a predictable rate. The resulting age estimates range from hundreds of millions to 2 billion years old. "We've shown Ceres may have been cryovolcanically active throughout its entire history," Sori says.

The team then used the distribution of domes and their ages to estimate how often cryogenic activity should occur on Ceres. They deduced that a cryovolcano forms on average once every 50 million years. Over time, these eruptions could disgorge about 10,000 cubic meters (350,000 ft^3) of briny slush per year. That's equivalent to four Olympic-size swimming pools — but it's a tiny fraction of the eruption rate on Earth, where volcanoes spew more than 1 billion cubic meters of molten rock each year.

"Cryovolcanism is important on Ceres," says Sori, "but not nearly as dominant or important as rocky volcanism has been on Earth or Mars."

▲ Ahuna Mons, a large mountain on Ceres, is seen in this simulated view based on images from the Dawn spacecraft. Elevation is exaggerated by a factor of two.

The most likely source powering cryovolcanism on Ceres is radioactive decay of certain isotopes in the rocky parts of the tiny world, as happens on other planets. Another more controversial hypothesis is that large impacts on the surface jump-start the process locally.

■ DAVID DICKINSON

MILKY WAY

Star Pattern Suggests Recent Galactic Whack

AN UNUSUAL PATTERN in the motions of the Milky Way's stars suggests that a neighboring galaxy swept by our own within the last billion years.

Reporting in the September 20th *Nature*, Teresa Antoja (University of Barcelona, Spain) and colleagues discovered the pattern when they looked at data on 6 million nearby stars from the Gaia satellite, which is providing precise distances and speeds for more than 1 billion stars. Looking at just the positions of the stars, the astronomers didn't see anything unusual. But when they plotted the stars' altitudes above or below the disk compared to their velocities perpendicular to the disk, a spiral showed up.

This *phase spiral* represents a large-scale gravitational disruption. Something with the size and mass of a small galaxy is the most likely culprit. These types of encounters were probably common when our galaxy was first forming, but the disturbances would have smoothed out over the hundreds of millions of years that followed. Seeing a phase spiral today suggests something jostled the Milky Way's disk relatively recently, between 300 million and 900 million years ago.

Another team led by Joss Bland-Hawthorn (University of Sydney, Australia) studied the phase spiral in a complementary way, using not only the motions of the stars but also their heavy-element content, which is a proxy for age. The researchers estimate that the Milky Way encountered another galaxy roughly 500 million years ago, consistent with the other team's estimate. They published their results September 7th on the astronomy preprint server arXiv.org.

The dwarf Sagittarius Galaxy passed close by the Milky Way about 200 million to 1 billion years ago, making it a good candidate. That encounter is ongoing: Our galaxy is in the process of tearing the dwarf to shreds.

■ JOHN BOCHANSKI

● See a video of the phase spiral at https://is.gd/GalacticWhack

Artist's impression of a perturbation in the velocities of stars in the Milky Way revealed by the European Space Agency's star-mapping mission, Gaia

AHUNA MONS: NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA; GALAXY RIPPLES: ESA / CC BY-SA 3.0 IGO

SOLAR SYSTEM

Jupiter's Magnetic Field Has Weird Structure

◀ Colorful, swirling cloud belts and vortices dominate Jupiter's northern hemisphere in this image captured by NASA's Juno spacecraft.

NASA / JPL-CALTECH / SWRI

JUPITER HAS THE STRONGEST magnetic field of any of the planets in the solar system. Like the field that shelters Earth, Jupiter's shield is essentially dipolar, which means it has a north pole and a south pole, similar to the field created by a bar magnet. A really, really big bar magnet.

Or, at least it kind of does. Reporting in the September 6th *Nature*, Kimberly Moore (Harvard) and colleagues have discovered a strange plume of magnetic field shooting up from a region in Jupiter's northern hemisphere and reentering the planet at its equator. And it's three times stronger than the main dipole field.

Combining data from eight flybys of the Juno probe, the scientists confirmed the existence of the bizarre magnetic feature, hints of which had shown up in an analysis in 2017 from Juno's first orbit. The structure looks like a ponytail shooting out from the planet's forehead and reentering through the nose, at a location the team calls the Great Blue Spot (for its color in a map of the planet's field). There's nothing like this ponytail in the southern hemisphere.

"This was a very unexpected result," Moore says. "Why is the field so simple in one hemisphere and so complicated in the other?"

Earth's magnetic field is produced by churning liquid iron in the planet's outer core. But Jupiter doesn't have an iron core — it's unclear if it has a core at all. The source of the magnetic field is instead an overlying mantle of metallic hydrogen (*S&T:* Dec. 2017, p. 14).

The most likely reason for Jupiter's weird field is layering in the metallic hydrogen, the team argues. This could naturally arise if the planet's core is dissolving: Rock and ice mixed in with hydrogen would raise the density, and if that mixing isn't uniform, it could create layers of different densities. These could destabilize the mantle's cyclic convection patterns or spur different convection patterns in distinct layers.

■ CAMILLE M. CARLISLE

IN BRIEF

Voyager 2 Approaches Interstellar Space

Since August, the Voyager 2 spacecraft has detected an uptick in cosmic rays, high-energy particles such as protons impinging on the solar system from deep space. Its sister craft, Voyager 1, saw a similar increase in 2012 about 3 months before it punched through the *heliopause*, the point where the solar wind yields to the tenuous pressure of interstellar gas. Voyager 2 — now roughly 18 billion kilometers (11 billion miles) from home — is inching toward the same milestone. The two Voyager spacecraft left Earth in 1977 for grand tours of the giant planets. Both probes cozied up to Jupiter and Saturn, while Voyager 2 went on to become the first (and only) craft to zoom past Uranus and Neptune. Now both are headed for points beyond the solar system.

Read more about the Voyager journeys at https://is.gd/V2CosmicRays.

■ CHRISTOPHER CROCKETT

TESS Satellite Spots First Exoplanet

Scientists working with data from the recently launched Transiting Exoplanet Survey Satellite (TESS) have discovered a super-Earth in a close orbit around the Sun-like star Pi Mensae. Based on its average density, this planet probably has a rocky or iron core surrounded by an atmosphere of light molecules such as hydrogen, helium, water, or methane. The planet's atmosphere is likely too close to the planet's surface for much starlight to filter through when the world passes in front of its star, so studying it via transit spectroscopy will be difficult. But the planet's proximity to Earth (60 light-years) and the star's brightness (magnitude 5.7) make the system a promising target for other studies. Chelsea Huang (MIT) and colleagues reported the discovery September 16th on the astronomy preprint site arXiv.org. The world is the second discovered in the Pi Men system: The other is a gas giant on a highly elongated orbit. The star is visible to unaided eyes in clear, dark skies.

■ MONICA YOUNG

Dust Storms on Titan

Saturn's moon Titan now joins Earth and Mars among the worlds known to whip up dust into massive storms. In 2009 and 2010, the Cassini spacecraft spied three distinct, short-lived patches of infrared light near the moon's equator. The time scale and spectra of these regions appear to be consistent with dust whipped up by gusts blowing across dunes, Sébastien Rodriguez (Paris Institute of Earth Physics) and colleagues report September 24th in *Nature Geoscience*. The researchers considered several explanations, including cryovolcanoes, lava flows, and methane rainstorms. But none of these were a good match for the infrared spectra or the observed time scales, ranging from 11 hours to 5 weeks. The dust storms point to fairly strong surface winds — or at least, strong for Titan: The roving dust requires gusts of at least 1.4 m/s (3.1 mph), about five times the ambient wind speed. The winds could have accompanied methane squalls expected at the equator during Titan's equinox.

■ CHRISTOPHER CROCKETT

SUPERNOVAE

What Makes Supernovae Superluminous?

A TYPICAL EXPLODING STAR generates up to a billion Suns' worth of light at its peak. But so-called *superluminous supernovae* are in a rare class of their own, shining hundreds of times brighter than their "ordinary" cousins.

Reporting September 10th in *Nature Astronomy*, Ragnhild Lunnan (Stockholm University) and colleagues describe a detailed analysis of one of the most superluminous supernovae known: iPTF16eh, discovered by the Palomar Transient Factory in December 2015. Most importantly, this supernova shows a signature in its spectrum that astronomers haven't seen in its ilk before.

As this star went supernova, the explosion's light reflected off a thick sphere of gas surrounding the star, producing an emission line that the astronomers tracked in the year following the eruption. The gaseous cocoon is expanding so rapidly — 3,300 kilometers per second (7.4 million mph) — that it must be the result of an explosive ejection, rather than the kind of steady wind that precedes the death of other massive stars. Lunnan and colleagues argue that this ejection, which occurred roughly 30 years before the star went boom, points to a particular cause of death: a *pulsational pair-instability* supernova.

As stars more massive than about 100 Suns run out of fuel to burn in their cores, things start to go haywire. Rather than fusing elements, the stellar core produces pairs of electrons and their antimatter partners, positrons. But pair production takes energy away from the star's support system, which causes the core to implode, inducing nuclear fusion. In really massive stars (more than about 130 solar masses), that's enough to cause "rapid unscheduled disassembly" — in other words, the star obliterates itself.

But in stars between roughly 100 and 130 solar masses, explosive results aren't so immediate. Instead, the star pulsates, alternately imploding and burning, before its core catastrophically collapses anywhere from hours to thousands of years later. The pulsations can eject a huge amount of mass, and the researchers argue that an ejection of up to 10 solar masses from a 115 solar-mass star matches the observations.

■ MONICA YOUNG

SOLAR SYSTEM

New Object Found in Far Outer Solar System

THERE'S A NEWLY FOUND body in the extreme backwaters of the solar system. Designated 2015 TG_{387} and nicknamed "The Goblin" by its discoverers, this object resides in the inner Oort Cloud, a vast region beyond the Kuiper Belt that's thought to be a comet reservoir and until now harbored only two other known bodies: the dwarf planet Sedna and the less well-known 2012 VP_{113}.

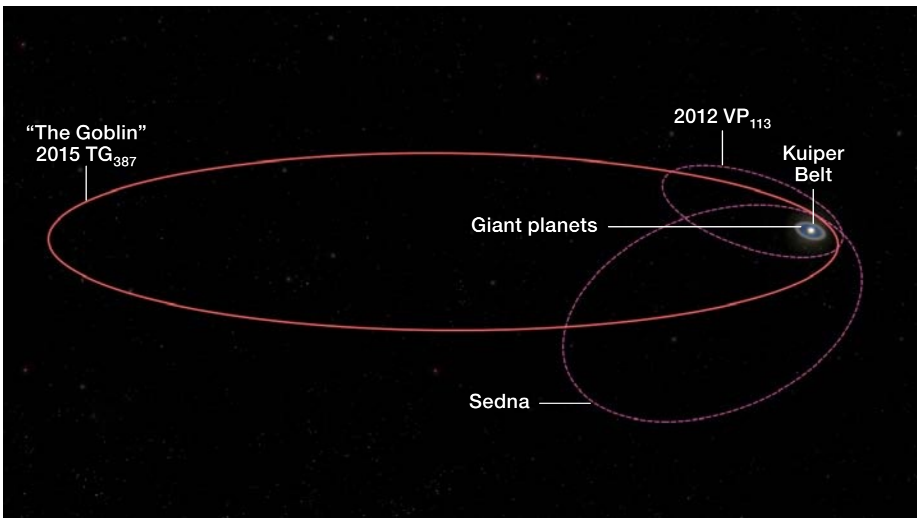
This far-flung body keeps its distance from the Sun, never coming closer than about 65 astronomical units (a.u.), or just under twice Pluto's closest approach. However, that's downright cozy compared to how far out it goes. A highly elongated orbit takes 2015 TG_{387} out to a whopping 2,300 a.u., much farther away than its two comrades in the inner Oort Cloud. The International Astronomical Union's Minor Planet Center announced the discovery on October 2nd.

A team led by Scott Sheppard (Carnegie Institution for Science) discovered 2015 TG_{387} in images acquired in mid-October 2015 at the 8.2-meter Subaru Telescope in Hawai'i. At the time, the body was about 80 a.u. from the Sun. Since then, the observers have used other telescopes to track the object and refine its orbit. They estimate that the tiny world is 300 km wide, roughly the width of Saturn's moon Hyperion.

Extrapolating from the three objects now known to lie in the inner Oort Cloud, the team estimates that this largely unexplored region of space harbors roughly 2 million bodies wider than 40 km. That puts the projected mass of this ensemble on par with that of the Kuiper Belt.

Aligned orbits of bodies in and near the inner Oort Cloud hint at a planet out there. While 2015 TG_{387} doesn't make or break that case, its orbit seems consistent with a planet's presence.

■ CHRISTOPHER CROCKETT



▲ This diagram shows the orbits of the newly discovered body, 2015 TG_{387}, and its fellow inner Oort Cloud objects, 2012 VP_{113} and Sedna, compared with the rest of the solar system.

R. M. CANDANOSA / S. SHEPPARD (CARNEGIE INSTITUTION FOR SCIENCE)

NASA Sends a Signal

After a long hiatus, the space agency gets back into the SETI game.

IN JULY I WROTE ABOUT innovative approaches for the Search for Extraterrestrial Intelligence (*S&T:* July 2018, p. 12). In that column I lamented the fact that NASA support for this field dried up in the 1990s and had not returned, even though astrobiology has since flourished. Many of us felt that the bureaucratically maintained distinction between astrobiology and SETI did not make intellectual sense, and we longed for SETI to be let in from the cold.

Sometimes wishes come true.

As that column went to press I received an email asking if I would help organize a workshop on "technosignatures." The sponsor? NASA. That got my attention. The purpose was to explore how to best use NASA resources in a renewed search for extraterrestrial intelligence. Apparently, Congress's new federal budget mandated that NASA spend $10 million "to search for technosignatures, such as radio transmissions, in order to meet the NASA objective to search for life's origin, evolution, distribution, and future in the universe." Wow!

The workshop, which took place in September, was highly stimulating, and given the renewed government interest in SETI, the mood was bright and optimistic. Along with evaluation of historical and current searches, there was an openness to new ideas born of a kind of humility. We can't really second-guess the properties or motivations of technological aliens, so we have to cast a wide net. In addition to "traditional" SETI searches for radio signals or laser pulses, we must be alert to more passive signs of technological entities that might not be trying to get in touch with anyone. These include possible artifacts beyond or within our own solar system, or planetary atmospheres altered or engineered by industrial activities.

Attendees made an effort to stick to the prosaic questions: What observing programs can we ramp up in the next few years using NASA's current or expected assets and instruments? How can NASA best collaborate with private partners such as the SETI Institute and Breakthrough Listen?

But with SETI it's hard to avoid deep philosophical musings. Some talks at the workshop delved into abstract but necessary puzzles about the properties and behavior of distant, advanced civilizations — even about what we mean by "advanced" and "civilization." SETI has always combined solid engineering, daring speculation, and profound questioning.

This admixture didn't always sit well with some. At the first international SETI conference in Byurakan, Soviet Armenia in 1971, organizers Carl Sagan and Iosif Shklovsky welcomed historians, philosophers, linguists, and social scientists along with the scientists. At the time, one young Soviet astrophysicist asked that the humanities be left out, stating he didn't want to listen to "windbags." A leading American physicist exclaimed, "To hell with philosophy! I came here to learn about observations and instruments . . ."

This historical tension seemed absent from September's workshop. Although our prime directive was to guide NASA in the use of its assets to search for technosignatures, there was respectful discussion of the more esoteric and humanistic questions that are naturally evoked, and a recognition that a mature SETI program going forward will involve more than just telescopes and computer models. Out of this will come new calls for proposals to NASA, and then a new era of federally funded SETI research. May it be long and fruitful.

■ Astrobiologist **DAVID GRINSPOON** spent the fall of 2018 at the Institute for Cross-Disciplinary Engagement at Dartmouth, studying the nature of planetary-scale intelligence.

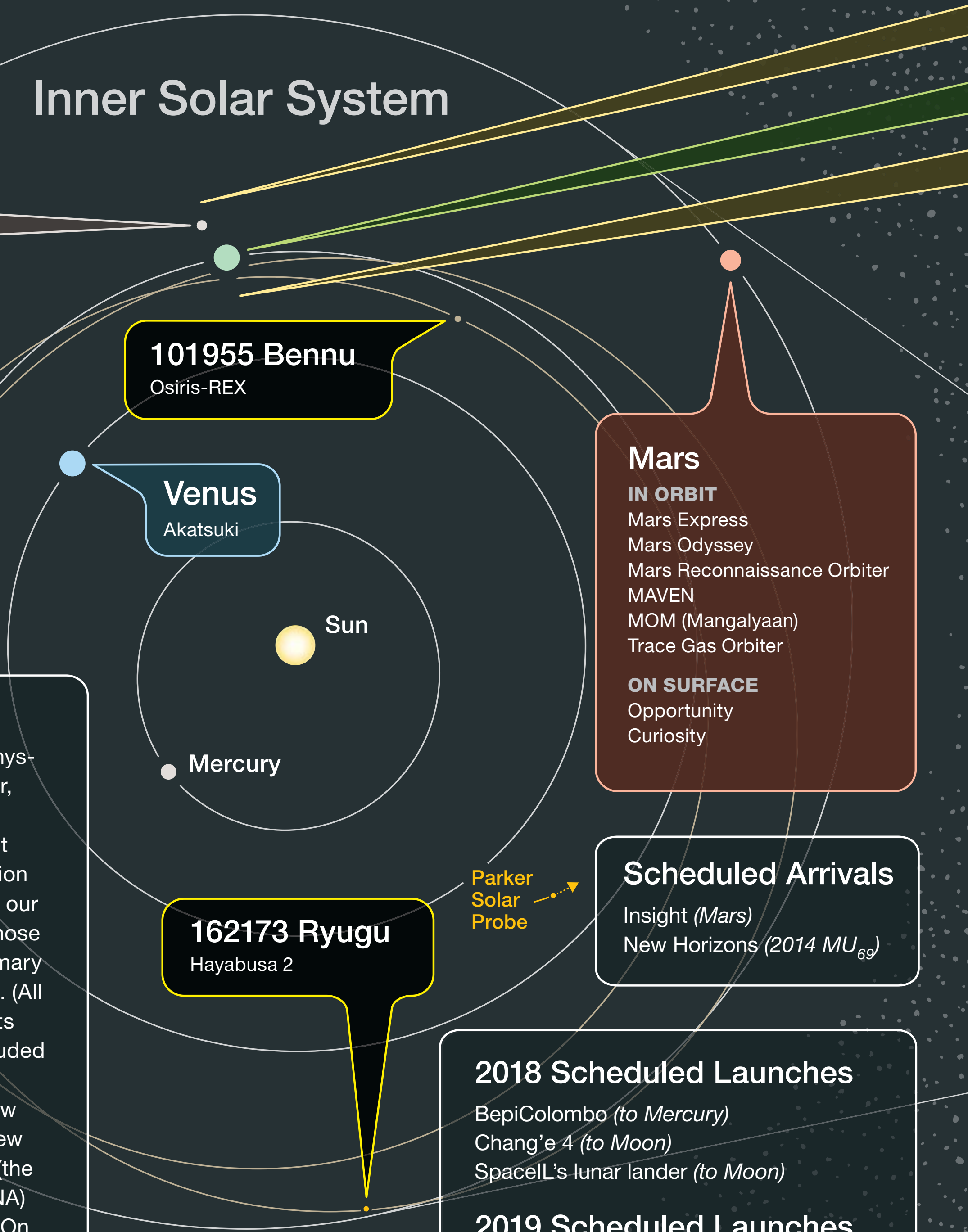
NASA / JPL-CALTECH

▶ With the number of known exoplanets exploding (here, an artist's concept of an Earth-size planet in a binary star system), NASA's renewed interest in the hunt for signs of intelligent life elsewhere is exciting.

Asteroid Belt

Space Missions in 2019

Inner Solar System



Moon
IN ORBIT
Artemis
Chang'e 5 T1
Lunar Reconnaissance Orbiter

ON SURFACE
Chang'e 3

MOON-EARTH L_2 POINT
Queqiao (with Longjiang-2)

101955 Bennu
Osiris-REX

Earth-like Solar Orbit
Kepler
Spitzer
Stereo A

Venus
Akatsuki

Mars
IN ORBIT
Mars Express
Mars Odyssey
Mars Reconnaissance Orbiter
MAVEN
MOM (Mangalyaan)
Trace Gas Orbiter

ON SURFACE
Opportunity
Curiosity

162173 Ryugu
Hayabusa 2

Scheduled Arrivals
Insight *(Mars)*
New Horizons *(2014 MU_{69})*

2018 Scheduled Launches
BepiColombo *(to Mercury)*
Chang'e 4 *(to Moon)*
SpaceIL's lunar lander *(to Moon)*

2019 Scheduled Launches
ALINA *(to Moon)*
Chandrayaan 2 *(to Moon)*
Chang'e 5 *(to Moon)*
Cheops *(exoplanets, Earth orbit)*
Solar Orbiter *(to Sun)*
Spektr-RG *(X-rays, to L_2)*

Here's our digest of active missions in 2019. Included are astrophysics, planetary, solar, space weather, and stellar projects; we omit those that primarily observe Earth. Planet locations are for January 1st; mission statuses are current (to the best of our knowledge) as of October 2018. Those orbiting Earth are classified by primary research topic, which is subjective. (All International Space Station projects are lumped under "ISS.") Also included are planned launches for the year.

The big news of 2019 will be New Horizons' flyby of 2014 MU_{69} on New Year's. Also, two private missions (the unnamed SpaceIL lander and ALINA) hope to touch down on the Moon. On a sadder note, the Kepler spacecraft will run out of fuel in late 2018 or early 2019. When we went to press, it was unclear if Opportunity had survived the Martian dust storm.

—Camille M. Carlisle

GREGG DINDERMAN / S&T

Earth-Sun L_2 point

Gaia

Earth-Orbiting Spacecraft

ASTROPHYSICS
AGILE
Asteria
Astrosat
Chandra
DAMPE (Wukong)
Fermi
HaloSat
Hubble
HXMT (Huiyan)
Integral
ISS
Lomonosov
NUSTAR
RadioAstron (Spektr-R)
Swift
TESS
Tiangong 2 Station
XMM-Newton

PLANETARY
IBEX
Hisaki
NEOSSAT
NEOWISE

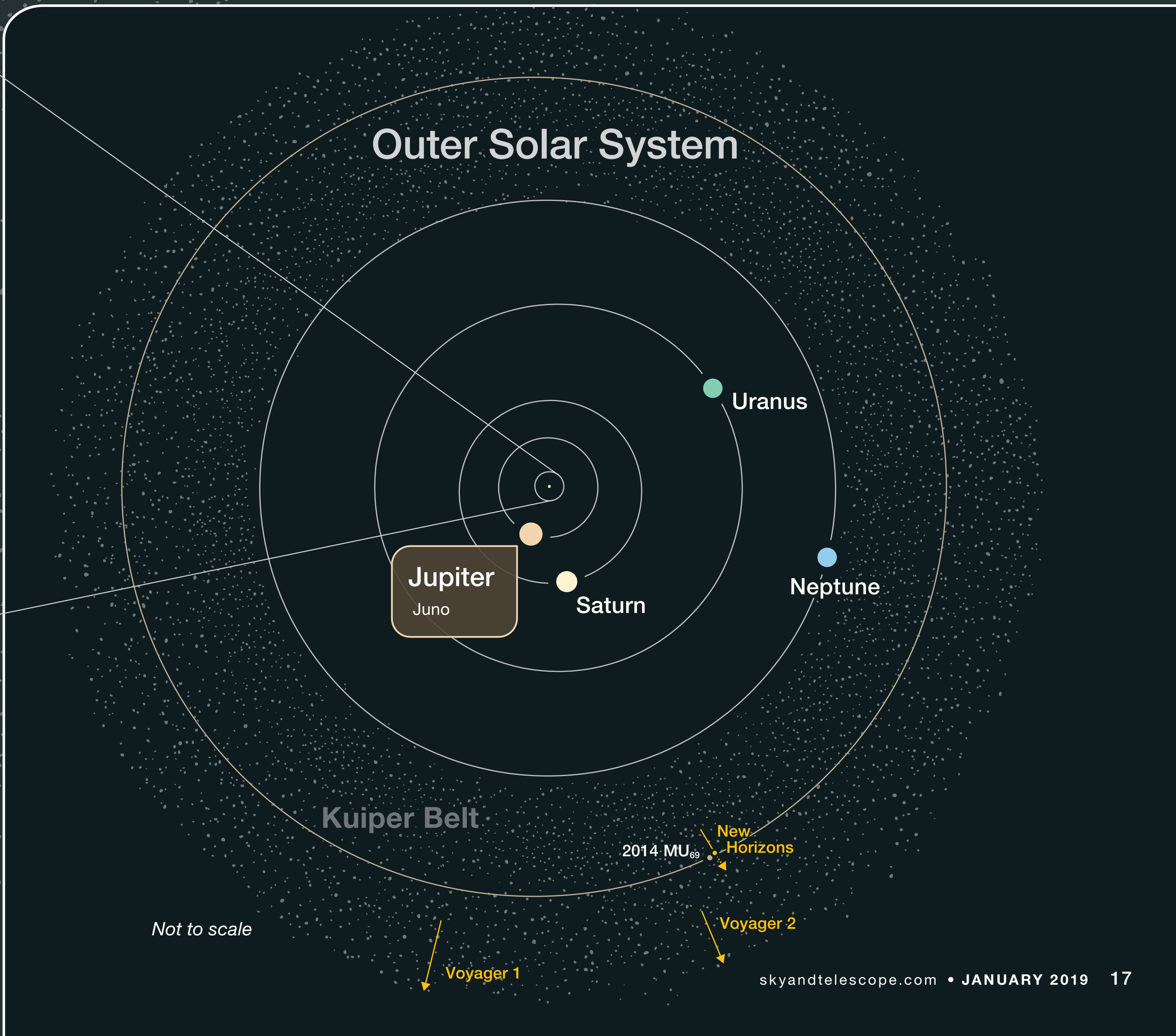
SOLAR
Hinode
IRIS
PROBA 2
SDO

SPACE WEATHER
Geotail
GOES
MMS
THEMIS
Van Allen Probes

STELLAR
BRITE
MOST

Earth-Sun L_1 point

ACE
DSCOVR
SOHO
WIND



JANUARY’S LUNAR BLACKOUT by Joe Rao

The Great American Lunar ECLIPSE

A “disappearing” full Moon in the first weeks of 2019 is wonderfully timed and placed for skywatchers in the Americas.

▲ **UMBRA REVEALED** In Beijing, China, Letian Wang imaged the lunar eclipse of December 10, 2011. His composite of five exposures shows a broad expanse of the southern edge of Earth’s umbral shadow.

On the night of January 20–21, for the third time in less than a year, the Moon will become completely immersed in Earth’s shadow and create one of nature’s most beautiful spectacles: a total lunar eclipse. Last January 31st, the timing of totality favored the lands around the rim of the Pacific Ocean; those in the western U.S. could catch it before moonset. Then, on July 27th, the longest total lunar eclipse until the year 2123 took place over the Eastern Hemisphere, with no part of that celestial event visible from North America.

But soon those in the Western Hemisphere will have ringside seats for the first total lunar eclipse visible in its entirety since 2015. And this will be an exceptional eclipse in more ways than one.

First, it will take place on the Sunday night of a 3-day holiday weekend in the U.S., ensuring that kids of all ages will be able to stay up and watch this sky show no matter how late. As astronomer Fred Espenak points out, “Seeing such an event can spark the imagination and interest of a child — and isn’t that where future scientists come from?”

Second, because this eclipse occurs during northern mid-winter, it occurs eerily high in the sky for northerners. At mid-totality, the Moon will stand 83° above the horizon from Miami and 70° from New York. Farther west, the midpoint occurs 69° high in Houston, 66° in Chicago, 58° in Denver, and 49° in Los Angeles.

Third, as the timetable on the following pages demonstrates, totality commences before midnight across all of the contiguous United States. Eclipse watchers in the Hawaiian Islands will see the Moon climb out of the Pacific Ocean at sunset on the 20th, with roughly half of it already immersed in shadow. Meanwhile, it’s a predawn event on the 21st as seen from western Europe and Africa.

Some Eclipse Projects

A lunar eclipse provides interesting viewing for both young and old, from astronomy neophytes to assiduous amateur astronomers. Here are a few suggestions for January’s event that require only simple equipment — or none at all.

The penumbra: As shown in the diagram on page 20, Earth’s shadow cone has two parts: a *penumbra*, the shadow’s pale fringe; and an *umbra*, the darker central region.

An astronaut standing inside the umbra on the Moon's surface would see the Sun entirely hidden by Earth. But viewed from inside the penumbra, the Sun's disk would be only partly covered — varying from a small scallop as the eclipse begins (with an imperceptible dimming of the lunar landscape) to only a sliver of sunlight just before totality, with the surroundings noticeably darker.

The umbra's diameter averages about 2% larger than called for strictly by the geometry of the eclipse, and yet it can vary from eclipse to eclipse for reasons that are not fully understood.

Hence, the outermost part of the penumbra is so lightly shaded that initially you won't notice any change in the Moon's appearance at all. But by the time the Moon's leading edge gets about two-thirds across the penumbra, about 40 minutes later, you might begin to detect a very weak dimming of the Moon's western limb (the left edge for northerners) — the first visible sign that an eclipse is in progress.

How early can you see this with certainty? As the Moon advances deeper into the penumbra, the shading becomes much stronger and more obvious. Pay attention to the penumbra's color (brown? gray?) and its overall darkness.

With the full Moon so high up this January as seen from the U.S. and Canada, an early penumbral sighting could be especially problematic due to the lunar disk's overpowering glare. It might help to wear dark glasses — really! One trick I've used in the past is to project the Moon's image with binoculars or a telescope onto white paper or cardboard.

Partial stages: The partial eclipse begins when the much darker umbral shadow first touches the lunar limb. The change is dramatic: A dark dent forms on the Moon's western side, and as the minutes tick by the dent becomes a big, rounded bite. The curved edge of the shadow gives a naked-eye indication that Earth is nearly spherical (no shape other than a sphere always casts a circular shadow).

During the eclipse's partial stages, you'll easily see the penumbra as a dusky border to the shadow's dark core. After the last bit of umbra disappears, how much time elapses before the last trace of penumbral shading leaves the eastern (right-hand) edge of the lunar disk?

Enlargement of the umbra: Observers have long realized that the umbra's diameter averages about 2% larger than called for strictly by the geometry of the eclipse, and yet it can vary from eclipse to eclipse for reasons that are not fully understood. The most likely explanation is that it is due to the varying overall transparency of Earth's upper atmosphere.

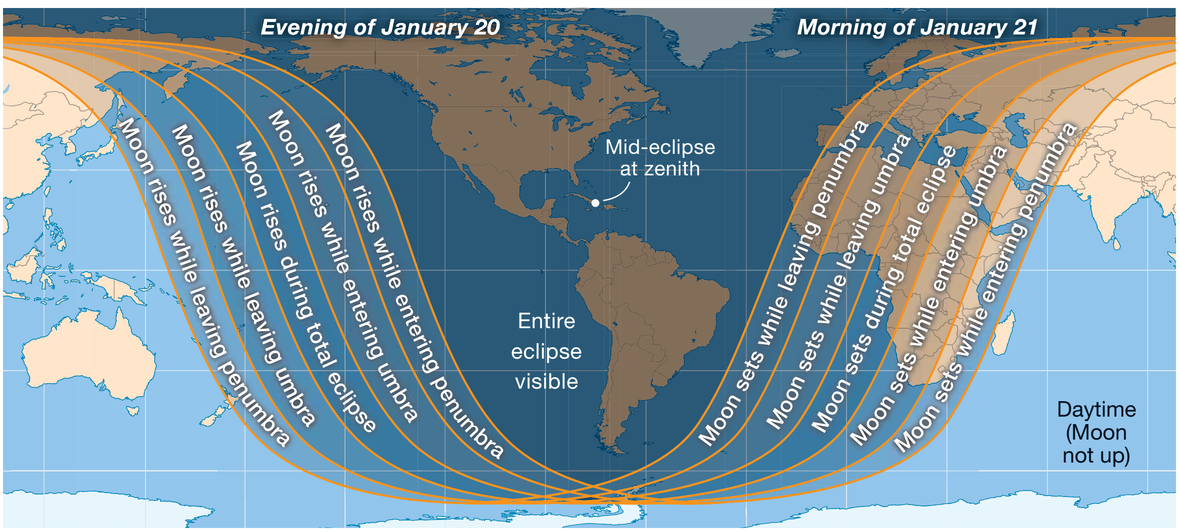
The amount of enlargement during this upcoming eclipse can be deduced after the fact from careful telescope-aided timings of when lunar craters enter or leave the umbra. If your sky is clear, the edge of the advancing or retreating umbra is sharp enough to permit crater timings accurate to a few tenths of a minute.

If you'd like to try this, Senior Contributing Editor Roger Sinnott has prepared predictions of the entrance and exit times for 24 prominent lunar features (listed on page 20).

Note that these are given in Universal Time, so be sure to make the correct offset for your time zone. Also, before the eclipse begins, I would advise anyone unfamiliar with the Moon's features to identify these locations on a lunar map. Just before the eclipse, be sure to set your watch accurately from a cell-phone time app (such as *Emerald Time*) that displays to the nearest second. The listed times refer to each crater's center, so start to watch a given feature several minutes before the prediction.

Record your timings to the nearest 5 seconds, even though your uncertainty might be 10 to 20 seconds or more. Once the eclipse is over, you can email your timings to Sinnott at **rsinnott@post.harvard.edu** to aid his ongoing analysis of these events. In your report, mention your full name, telescope aperture, magnification, and sky conditions.

The total eclipse: The umbra appears quite dark during the opening stages of partial eclipse (or the late stages after



LEAH TISCIONE / *S&T*; SOURCE: FRED ESPENAK

◀ **WORLD VIEW** This map shows where the Moon will rise or set during stages of the eclipse — and, since an eclipsed Moon is always full, the Sun sets or rises at almost the same time on the opposite horizon. For January's event, the sky is dark and the Moon well up across both North and South America during all phases of the eclipse.

Eclipse-Timing Predictions

ENTRANCE (UT)		EXIT (UT)	
Grimaldi	3:36	Harpalus	5:49
Billy	3:40	Aristarchus	5:54
Kepler	3:48	Plato	5:57
Campanus	3:49	Grimaldi	5:58
Aristarchus	3:50	Pico	5:59
Tycho	3:56	Kepler	6:02
Copernicus	3:57	Aristoteles	6:04
Birt	3:57	Billy	6:05
Pytheas	4:00	Pytheas	6:05
Timocharis	4:06	Timocharis	6:05
Harpalus	4:08	Eudoxus	6:07
Manilius	4:13	Copernicus	6:09
Pico	4:15	Campanus	6:17
Dionysius	4:15	Manilius	6:19
Plato	4:18	Menelaus	6:22
Menelaus	4:17	Birt	6:24
Plinius	4:21	Plinius	6:25
Censorinus	4:21	Tycho	6:27
Goclenius	4:24	Dionysius	6:28
Eudoxus	4:25	Proclus	6:32
Aristoteles	4:27	Censorinus	6:35
Taruntius	4:28	Taruntius	6:37
Langrenus	4:29	Goclenius	6:42
Proclus	4:31	Langrenus	6:46

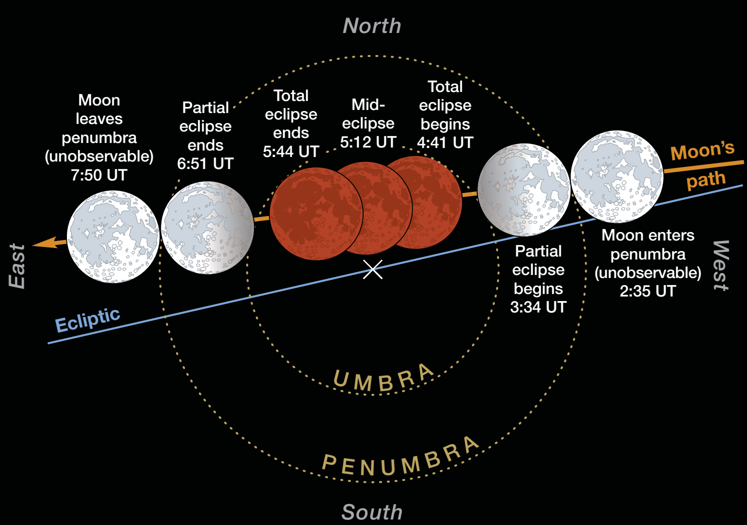
▼ **DARK PASSAGE** The Moon moves through the northern half of Earth's shadow on the night of January 20–21. Universal Times are given below for the event's key stages, though local times are used in the table.

▲ **KEEPING WATCH** This photo identifies 24 well-defined craters and spots that stand out during a total lunar eclipse. North is up, so Earth's shadow will move in and recede from left to right.

totality) when compared with the rest of the lunar disk. But once more than half of the Moon is immersed in shadow, the contrast becomes less extreme and details of the disk within the umbra slowly come into view. Because sunlight is refracted and scattered by atmospheric gases around the limb of Earth, some of it gets redirected into the dark shadow cone and onto the Moon. Red predominates in this light for the same reason that sunrises and sunsets also appear red.

Looking skyward from the lunar surface, our hypothetical astronaut would see the disk of Earth surrounded by a thin, brilliant ring of red — the combined light of all the sunrises and sunsets occurring at that moment worldwide. When the Moon moves into total eclipse, that red-hued light suddenly becomes the only illumination on the lunar landscape. And that's the reason that the Moon tends to look like a ruddy ball once it's completely within the umbra.

MOON'S PATH: LEAH TISCIONE / S&T; SOURCE: FRED ESPENAK; MOON IMAGE: GARY SERONIK



Local Circumstances of the Total Lunar

	HST	AKST	PST
Penumbra first visible?	—	6:10 p.m.	7:10 p.m.
Partial eclipse begins	—	6:34 p.m.	7:34 p.m.
Total eclipse begins	6:41 p.m.	7:41 p.m.	8:41 p.m.
Middle of totality	7:12 p.m.	8:12 p.m.	9:12 p.m.
Total eclipse ends	7:44 p.m.	8:44 p.m.	9:44 p.m.
Partial eclipse ends	8:51 p.m.	9:51 p.m.	10:51 p.m.
Penumbra last visible?	9:15 p.m.	10:15 p.m.	11:15 p.m.

Totality this year will last a bit longer than average: 62 minutes. The Moon will pass north of the center of Earth's shadow, so during the total phase the upper part of the Moon will appear brighter while its lower portion should look noticeably darker and more subdued.

In recent years, the mainstream media have been branding total lunar eclipses as "Blood Moons." But this is a misnomer, for the umbra-covered Moon does not always have a reddish glow. The colors that appear on the Moon solely depend on the state of our atmosphere, a turbulent mélange of clouds and volcanic dust and other contaminants, so it's hard to say in advance exactly how the totally eclipsed Moon might look.

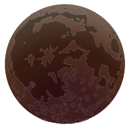
Darkness of totality: In fact, there can be a wide range in the brightness of the Moon from one total eclipse to the next. So will this be a dark eclipse or a bright one, compared to others? In 1921, the French astronomer André-Louis Danjon introduced a five-point scale of luminosity (*L*) to classify total lunar eclipses; the scale's steps are shown at right.

This rating is preferably made near mid-totality with the unaided eye. If you can't decide between two *L* values, say, 1 and 2, split the difference and call it 1.5. I'd like to know your result, so please send your estimate to **skywayinc@aol.com**. Be sure to state the time and the optical means used, if any.

During very bright eclipses, the Moon can resemble a bright copper penny. More than a half century ago (October 1967), an eclipse was so vivid that one California amateur's report to *Sky & Telescope* noted, "A bright bluish rim to the umbra produced a beautiful 'diamond ring' effect, and caused some observers to wonder if the eclipse was really total."

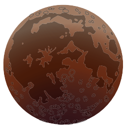
0

Very dark eclipse. Moon almost invisible, especially at mid-totality.



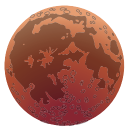
1

Dark eclipse, gray or brownish in coloration. Lunar features are distinguishable only with difficulty.



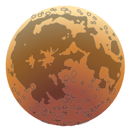
2

Deep red or rust-colored eclipse. Very dark toward center of umbral shadow, though relatively bright at its outer edge.



3

Brick-red eclipse. Umbral shadow usually has a fairly bright gray or yellow rim.



4

Very bright copper-red or orange eclipse. Umbral shadow has a bluish, very bright rim.

▲ **HOW DARK IS DARK?** Use this five-step Danjon scale to judge the darkness of the totally eclipsed Moon.

LEAH TISCIONE / S&T

Conversely, on rare occasions the Moon has almost completely vanished from view, the direct result of major volcanic eruptions on our planet. It is well known that dust suspended in our atmosphere affects the amount of sunlight that is refracted into Earth's umbra. In 1963 debris from the explosion of Mount Agung in Bali caused the Moon to be nearly invisible during totality, and in 1982 and 1991, respectively, the eruptions of El Chichón in Mexico and Mount Pinatubo in the Philippines were later followed by lunar eclipses that also were exceedingly dark.

Last July 27th, the Moon tracked just north of the center of Earth's shadow, resulting in an especially long totality lasting 103 minutes. One might have assumed that such circumstances would result in an abnormally dark eclipse. But observers reported that, while the Moon perhaps appeared somewhat dimmer than normal, overall it was not an exceptionally dark event.

Sky brightness: In just over an hour, the brightness of the sky will change dramatically. Before the eclipse begins, brilliant moonlight will wash out all but the brightest stars. But during totality, chiefly from rural locations, the winter Milky Way and myriad fainter stars will appear. Gemini's "twins," Pollux and Castor, will be a dozen degrees northwest of the darkened Moon, while the famous Beehive Cluster in Cancer lies 7° to the east. Although all but impossible to spot prior to the start of the eclipse, during totality the cluster should be relatively easy to see with the unaided eye. In fact, the Beehive's pairing with the darkened Moon will make for a striking sight through wide-field binoculars.

Sometimes during totality observers catch the occultation of a relatively bright star by the umbra-immersed lunar disk or even a dramatic graze along one of the lunar poles. Not so this time: Only three stars brighter than magnitude 9.0 will be occulted during January's event.

One advantage of a total lunar eclipse, compared to its solar counterpart, is that it's a leisurely affair. In short, should the weather cooperate on the third Sunday night in January, there will be plenty to see and do. Good luck and clear skies!

■ A veteran of 18 total lunar eclipses, *S&T* Contributing Editor **JOE RAO** has served as an Associate at New York City's Hayden Planetarium for more than 30 years. He's an eight-time Emmy-nominated broadcast meteorologist at Verizon FiOS1 News in New York's Lower Hudson Valley.

Eclipse of January 20–21, 2019

MST	CST	EST	AST
8:10 p.m.	9:10 p.m.	10:10 p.m.	11:10 p.m.
8:34 p.m.	9:34 p.m.	10:34 p.m.	11:34 p.m.
9:41 p.m.	10:41 p.m.	11:41 p.m.	12:41 a.m.
10:12 p.m.	11:12 p.m.	12:12 a.m.	1:12 a.m.
10:44 p.m.	11:44 p.m.	12:44 p.m.	1:44 a.m.
11:51 p.m.	12:51 a.m.	1:51 a.m.	2:51 a.m.
12:15 a.m.	1:15 a.m.	2:15 a.m.	3:15 a.m.

THE NEXT GRAVITATIONAL-WAVE REVOLUTION by Robert Naeye

The American-based LIGO project and its European compatriot, Virgo, will forever be hailed for opening up the field of gravitational-wave astronomy. LIGO and Virgo are tuned to a relatively high-frequency band of the gravitational-wave spectrum, giving them the ability to hear chirps coming from the death spirals of neutron stars and relatively low-mass black holes.

But despite their success, both instruments are deaf to the greatest of cosmic cataclysms: the inspiral and merger of two supermassive black holes. In this sense, gravitational-wave science right now can be likened to the era when astronomers could only study visible light.

Fortunately, radio astronomers will soon be opening a new window in the gravitational-wave spectrum, enabling scientists to catch the collisions of much larger objects. Using pulsars scattered across the galaxy, teams based in the U.S., Europe, and Australia have been patiently collecting data for about a decade to look for ripples from supermassive black holes. The international community is rife with optimism that the first detections will be made in the next few years.

"If the universe holds no surprises for us, we should be detecting gravitational waves relatively soon," says radio astronomer Joseph Lazio (Jet Propulsion Laboratory).

Employing Nature's Best Clocks

LIGO and Virgo each detect gravitational waves by measuring the minuscule difference a passing wave creates in the length of each site's two arms. The facilities use an infrared laser as a yardstick, bouncing it off mirrors in the arms multiple times. The beam-bouncing effectively makes the arms more than 1,100 kilometers (680 miles) long, and the arm lengths and mirror reflectivities together determine which wavelengths can be detected: roughly 60 to 15,000 km, corresponding to frequencies of 5 kHz to 20 Hz. This is the "sweet spot" for catching waves from the final inspiral and mergers of low-mass binaries, which contain objects with about one solar mass to a few hundred solar masses.

But what about binaries consisting of black holes with millions or even billions of solar masses? Virtually every large galaxy has at least one monster black hole lurking in its core, and when large galaxies coalesce, their respective black holes should gravitationally sink to the center of the combined galaxy, lock onto each other, and orbit a common center of gravity.

At first, the holes draw closer by interacting with stars through a process called *dynamical friction*, a kind of gravitational braking. Once the black holes are about a light-year apart, their encounters with the stars that cross their paths rob them of angular momentum and help their orbit shrink further. Eventually, they'll venture within a fraction of a light-year of each other, at which point the loss of energy via gravitational-wave emission will drive them together.

These gravitational waves will have wavelengths on the order of a few to tens of light-years, growing shorter as the black holes approach each other. If scientists wanted to build

If scientists wanted to build a LIGO-like instrument to catch these low-frequency spacetime distortions, they would need to construct galaxy-size detectors.

a LIGO-like instrument to catch these low-frequency spacetime distortions, they would need to construct galaxy-size detectors. Good luck getting that through Congress!

Fortunately, there's a much cheaper alternative. In the late 1970s, Soviet astrophysicist Mikhail Vasilievich Sazhin and American physicist Steven Detweiler conceived the idea of timing pulsars. Pulsars are Mother Nature's most precise clocks, neutron stars that spin with near-perfect regularity, beaming radio pulses our way. And those that spin hundreds of times per second, with rotation periods of 1 to 30 milliseconds, are the best clocks of all. Radio astronomers have discovered nearly 300 such millisecond pulsars, spread across the sky at distances of thousands of light-years.

Gravitational waves from inspiraling supermassive black hole binaries radiate outward at light speed, stretching and squeezing spacetime over cosmological distances. As these waves ripple through our galaxy, they subtly shift Earth's position with respect to the millisecond pulsars, so that the pulsars appear like buoys bobbing on a turbulent sea. The regular beats from some pulsars will arrive slightly early and others will arrive slightly late. By timing millisecond pulsars in different directions over many years, radio astronomers should be able to detect these irregularities and which direction the waves are coming from. But the effect is so tiny that an individual pulsar's signal might shift by only about 10 nanoseconds over decades of observation.

Pulsar

In the Background

Three teams have taken up this challenge. The North American Nanohertz Observatory for Gravitational Waves (NANOGrav) times pulsars using three U.S. radio telescopes; the European Pulsar Timing Array (EPTA) uses five telescopes distributed across Europe; and the Parkes Pulsar Timing Array (PPTA) employs the venerable Parkes Telescope in New South Wales, Australia (see map on page 26).

NICOLLE R. FULLER / SCIENCE PHOTO LIBRARY

MAKING WAVES This artist's concept shows two black holes en route to merging. Their inspiral creates ripples in the fabric of spacetime that propagate out from their location at the speed of light.

Timing Arrays

Astronomers are watching dozens of cosmic timepieces for signs of spacetime ripples passing through.

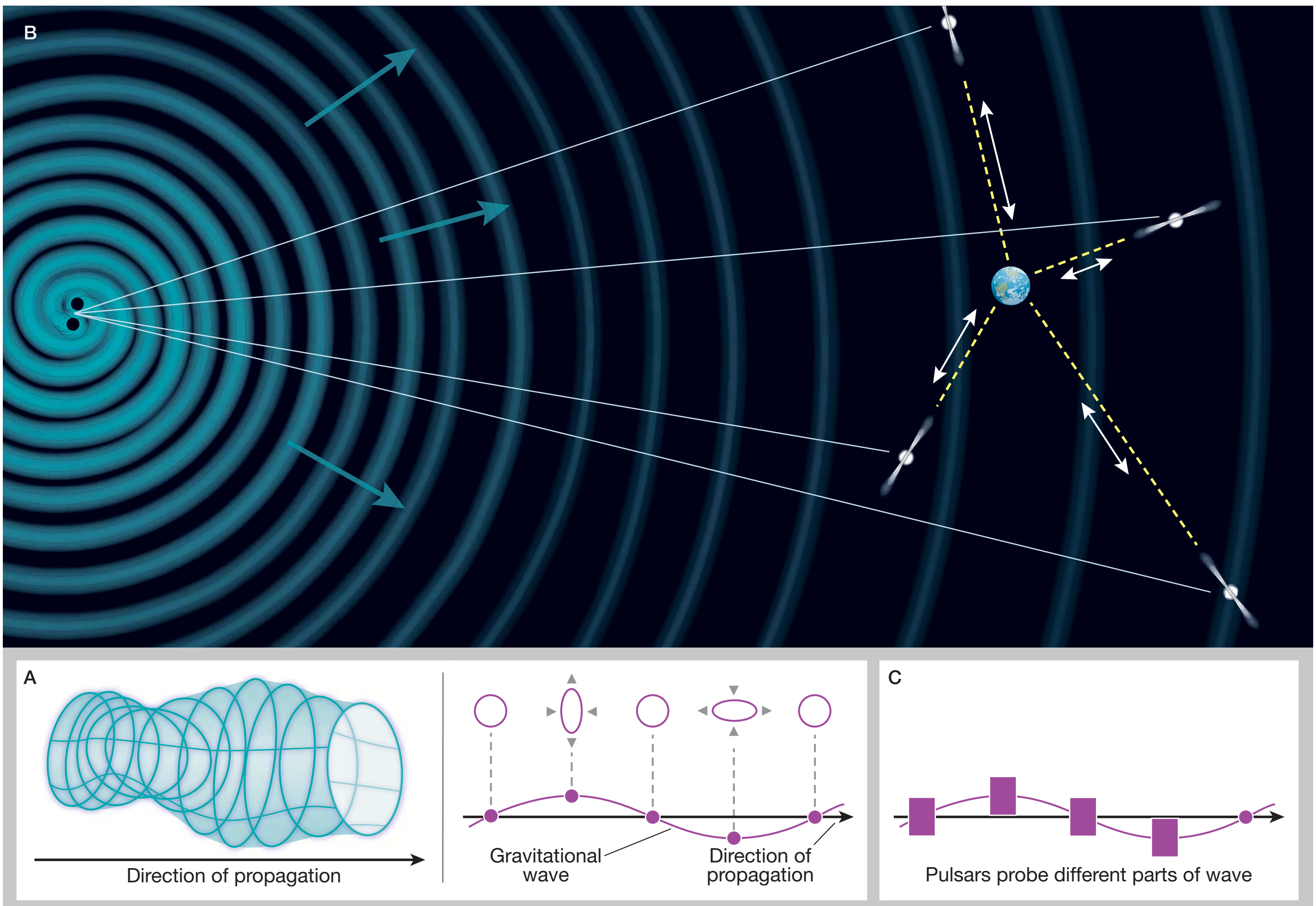
All three projects started collecting pulsar timing data at least a decade ago, and all have relatively similar capabilities and sensitivities. An array's frequency range depends on how long it's been operational; currently, the arrays span nanohertz to millihertz wavelengths, with a sweet spot between 3 and 10 nHz, says Alberto Sesana (University of Birmingham, UK). NANOGrav and EPTA observe many of the same Northern Hemisphere pulsars, whereas PPTA concentrates on those visible from the Southern Hemisphere. Combined, they currently watch roughly 75 pulsars, adding several new ones each year.

NANOGrav, EPTA, and PPTA are on the lookout for two different kinds of sources. They can all catch the rumbles of individual black hole binaries within several hundred million light-years. But NANOGrav team member Scott Ransom (National Radio Astronomy Observatory) says individual sources probably won't be their first detection.

Instead, it'll be the combined gravitational-wave signal of all the inspiraling supermassive black hole binaries over time, called the *stochastic background*. The stochastic background is like a cacophony of voices in a football stadium, where it's impossible to distinguish any single conversation. The contributing binaries will typically have black holes containing 100 million to 10 billion solar masses, with separations of just a few thousandths of a light-year, and orbital periods measured in years to decades.

Teasing out this background signal is an exceedingly difficult task, because it consists of the superposition of gravitational waves of different strengths and wavelengths coursing through our corner of the galaxy from all directions. The signal looks very different than waves from a specific binary, which have a unique shape determined by the system's characteristics, including its distance (see facing page).

▼ **HOW IT WORKS** Gravitational waves ripple out from an inspiraling pair of supermassive black holes, slightly stretching and squeezing the spatial dimensions that are perpendicular to the waves' direction of motion (A, in 3D then with 2D cross sections). When these waves pass Earth and nearby pulsars, they change the distance between each pulsar and Earth (B, as seen looking down on the crests in A). The white arrows in the main graphic indicate how much the distance changes for each pulsar, determined by the angle with respect to the wave's direction of motion. As a pulsar's distance oscillates, the arrival times of its signals change (see facing page). Because the pulsars lie at different distances from both Earth and the waves' source (white lines), different parts of the wave hit each pulsar at any given time. This difference means that each pulsar's timing shift probes a distinct slice of the gravitational wave pattern (C). By combining the changes in arrival times for many pulsars in different parts of the sky, astronomers should be able to determine where the gravitational waves came from and what created them.



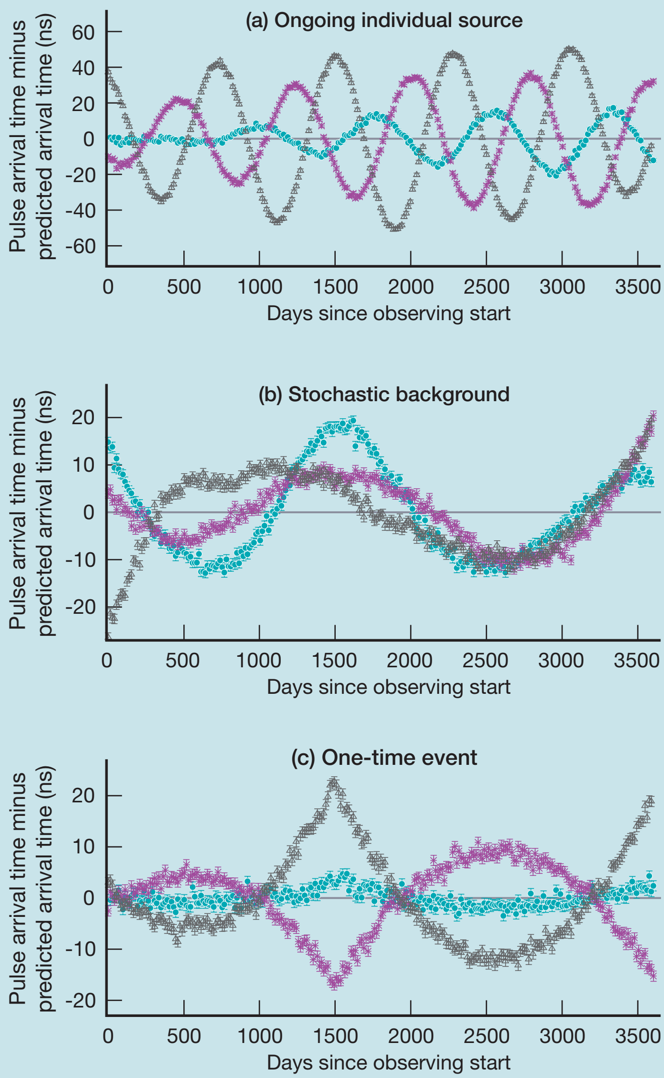
LEAH TISCIONE / *S&T*

In order to find the background signal, astronomers need a lot of pulsar pairs, Sesana explains. When a gravitational wave passes, it stretches space in one direction and squeezes it perpendicular to that direction. “So if two pulsars are observed at a 90° angle, the pulse will arrive later from one pulsar and earlier from the other,” he says. By making many such correlations between pulsar pairs, and also seeing signals from pulsars close together on the sky being affected the same way, the PTA teams will eventually be able to tease out the stochastic background signal.

Adding to the complexity, team members have to disentangle subtle gravitational-wave signals from myriad sources of noise. For example, despite the fact that millisecond pulsars beat with a precise regularity similar to humanity’s best atomic clocks, individual pulsars exhibit slight jitters that must be accounted for. Electrons in interstellar space also slightly delay the arrival of low-frequency radio waves.

Another source of noise stems from the fact that astronomers’ reference point for pulsar timing is not Earth’s position but the solar system’s center of mass, called the *barycenter*. The barycenter’s exact location has to be known to incredibly high precision for this work, because an error of just a few dozen meters changes a pulsar’s timing by several nanoseconds. Slight errors in the barycenter’s position can thus partially mimic the stochastic background’s signal. “Our knowledge of the planetary motions in the solar system is now effectively a limiting factor for us, which is quite astonishing,” says Ransom (see “The Solar System Barycenter,” page 27).

Astronomers debate whether they’re already seeing hints of the stochastic background in their data, and one or more of the PTAs will probably detect it within the next five years. But the real payoff will come after scientists watch the signal build up over time. By disentangling all the complexities in the signal, scientists will learn about the distribution of black hole masses and the eccentricity of binary orbits. Perhaps more important, astrophysicists should be able to discern a great deal about the rate of black hole mergers as a function of redshift, which in turn will be a proxy for how the galaxy merger rate has changed over cosmic history. In fact, the failure to detect the background by now seems to be ruling out the most optimistic models in which the collision of two large galaxies always produces a black hole merger.



▲ **EXAMPLES OF SOURCES** Different gravitational-wave sources will create distinct signals in pulsar data, and each pulsar gives a slightly different view of the signal. Shown here are three simulated examples using the periods of three real pulsars (three colors): an ongoing signal from a pair of billion-solar-mass black holes lying about 140 million light-years away (a); a background signal combining many sources (b); and the signal from a single event, such as a black hole merger, passing Earth on day 1,500 (c). The graphs show what the data look like after astronomers remove the effects of each pulsar’s spin and other things that affect the signal along its path from the pulsar to Earth.

LEAH TISCIONE / *S&T*, SOURCE: SARAH BURKE-SPOLAOR

Detecting Individual Sources

Detecting one or more individual black hole binaries remains the ultimate goal of those who use pulsar timing arrays. “It would be like detecting a continuous wave, or tone,” JPL’s Lazio says. “Much like if you are standing close to somebody at a party, you can hear that person’s voice.”

Based on infrared survey data and cosmological simulations, Chiara Mingarelli (Flatiron Institute) and colleagues estimate that there should be several dozen nHz sources within 730 million light-years of Earth. These inspiraling black holes will be detectable for a long time in human terms. “A typical binary will spend about 25 million years in the PTA band, which is in stark contrast to LIGO sources!” she says.

How long a binary is detectable depends on its mass, Mingarelli explains. More massive binaries produce stronger (and thus more easily detectable) gravitational waves. But more powerful waves drive a faster inspiral rate, so the systems are visible for shorter time periods. For example, more massive galaxies have more massive black holes, so a black hole inspi-

▲ **WORLDWIDE EFFORT** Astronomers use 12 radio observatories to track roughly 75 millisecond pulsars. Of these facilities, three — CHIME in Canada, FAST in China, and MeerKAT in South Africa — are new participants; the others have been involved for at least 10 years.

MAP: GREGG DINDERMAN / S&T; BARYCENTER: LARRY MCNISH / CALGARY CENTER OF THE ROYAL ASTRONOMICAL SOCIETY OF CANADA

ral in a galaxy such as the gigantic elliptical M87 would emit detectable gravitational waves for 4 million years. But a humbler black hole pair in a smaller galaxy, such as the Sombrero (M104), would offer a 160-million-year window. The odds that a very massive binary is sending out gravitational waves during the time that PTAs are observing is thus lower.

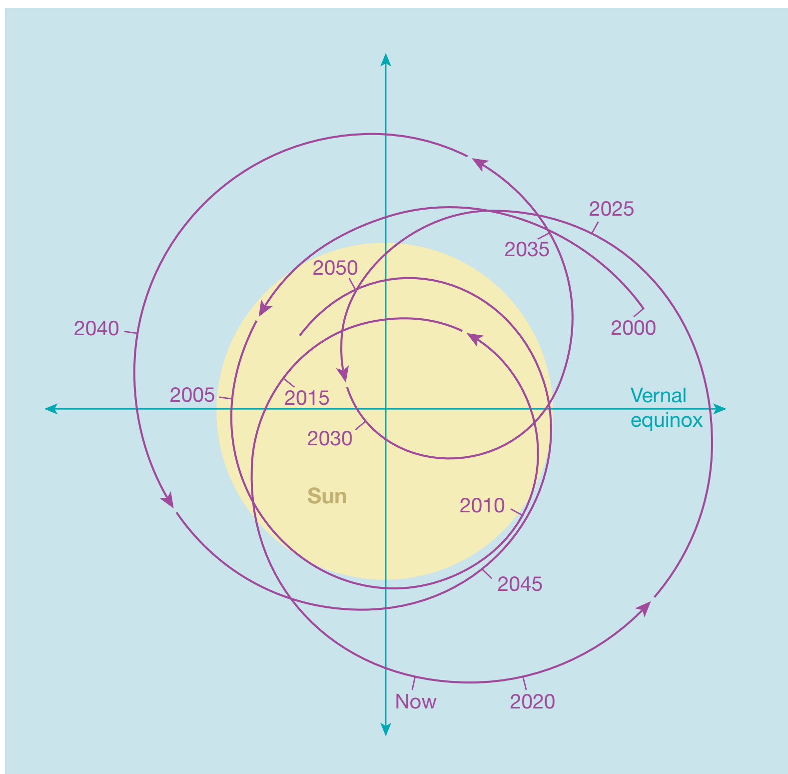
Unless we're really lucky, it will probably take 10 to 15 years to build up enough data to see deep enough into space to detect an individual binary. Theorists expect the gravitational waveform from a single binary to be a very simple sinusoid, and because the binary system will likely have an orbital period of several decades, the signal will change very little over many years.

The longer baseline could make electromagnetic follow-up easier. If the inspiraling and merging black holes are embedded in disks of gas — and recent work suggests that this could be true for supermassive binaries, unlike the smaller ones that LIGO and Virgo detect — then they would also produce light. "If a loud individual source is detected, PTAs will give its sky localization, opening the possibility to identify the host galaxy and carry out multimessenger observations of the system, pretty much as it happened with the LIGO neutron star binary GW170817," Sesana says (*S&T:* Feb. 2018, p. 32). "The difference is that with PTAs, everything builds up slowly over the course of the years, and you don't hit the jackpot in a snap."

Going Global

Adding to the growing optimism is the fact that scientists from all three teams are now combining their data sets to form an even more powerful network: the International Pulsar Timing Array (IPTA). The IPTA enables scientists to analyze data from most of the observed pulsars, including from facilities in both hemispheres. Having more observations means shorter time gaps in data, which increases sensitivity to shorter-wavelength gravitational waves. All of this works to increase sensitivity to both the stochastic background and individual binaries.

But progress has been slow for a variety of reasons, from planning across time zones and work cultures to accounting for each telescope's individual quirks. There's also the all-too-human tension of each team wanting for itself the glory of making the first confirmed detection.



"Gradually we are breaking down those barriers and learning how to successfully work together and push science forward," says Michael Kramer (Max Planck Institute for Radio Astronomy, Germany).

And the IPTA will only get better with the recent addition of three new instruments: the Five-hundred-meter Aperture Spherical Radio Telescope (FAST) in China, the MeerKAT Radio Telescope in South Africa, and the Canadian Hydrogen Intensity Mapping Experiment (CHIME) array in Canada.

Looking Ahead

In their quest to advance the field, scientists have devised additional methods for detecting gravitational waves. Astronomers will look for signs of gravitational waves in data taken by the European Space Agency's (ESA's) Gaia satellite. From its perch in space 1.5 million km beyond Earth, Gaia is making extremely precise measurements of the positions and motions of about 1 billion stars. Subtle shifts over many years will indicate that Earth is bobbing on passing gravitational waves, changing its position with respect to the stars.

"The drawback here is that Gaia's data set will only be as long as the mission, which is expected to be at most 10 years," Mingarelli says. "This limits the detection capabilities to binaries with gravitational-wave periods of 5 years or less, which is very restrictive." A pair of billion-solar-mass black holes with this period has "only" another 200,000 years or so before it merges, she explains; those detectable with pulsar timing arrays, on the other hand, will be circling each other for another 25 million years. Statistically speaking, 200,000 years is not much of a window to catch the binary's nanohertz gravitational waves.

And looking further afield, ESA is planning to launch the Laser Interferometer Space Antenna (LISA) in the 2030s. LISA will consist of three spacecraft orbiting the Sun in an equilateral-triangle formation, each craft separated by 2.5 million kilometers. LISA is specifically tuned to catch the spacetime ripples from merging black holes with masses of roughly 10,000 to 10 million solar masses. ESA's recent LISA Pathfinder mission exceeded its performance goals, proving LISA's technological feasibility.

Taken together, these projects — ground-based interferometers, pulsar timing arrays, Gaia, and LISA — promise to usher in a revolutionary era of gravitational-wave astronomy. By hearing gravitational rumbles across a broad spectrum, scientists will piece together a story of the universe's most extreme objects, in a way that they could not obtain by any other means.

> **Unless we're really lucky, it will probably take 10 to 15 years to build up enough data to detect an individual binary.**

■ Senior Contributing Editor **ROBERT NAEYE** was *S&T*'s editor in chief from 2008 to 2014.

The Solar System Barycenter

At first glance, gravitational-wave detection would seem to have very little to do with planetary science. But when it comes to precise timing of radio pulses from millisecond pulsars, the more stationary the reference point, the easier. That's why all the pulsar timing arrays (PTAs) use the solar system's center of mass (the barycenter) rather than Earth, which orbits the barycenter at a speed of about 30 km per second (67,000 mph).

The barycenter is always located inside or near the Sun, but it moves around as the planets orbit our star. For years, the PTAs used an *ephemeris* (the table of coordinates, etc., for celestial bodies) calculated by JPL based on the positions, velocities, and masses of the planets. But the PTA teams came to realize that the JPL ephemeris is not precise enough for pulsar timing, where changes to the barycenter of a few hundred meters in light travel time add up to hundreds of nanoseconds. Such errors can partially mimic the effect of low-frequency gravitational waves passing through our solar system, making it a limiting factor in the teams' ability to detect the stochastic background.

PTA radio astronomers are now working closely with JPL to refine its ephemeris, and the pulsar data are actually helping to improve our knowledge of the barycenter. "We have been able to figure out a way to mostly deal with the errors in the solar system ephemeris, albeit at a small cost to our gravitational-wave sensitivity," says NANOGrav team member Scott Ransom (NRAO). The Juno mission will help further, he adds, by nailing down the orbit and mass of Jupiter. Because it's so massive, the giant planet has a big effect on the location of the solar system's center of mass, including in its indirect gravitational effects on the other outer planets.

◀ **BARYCENTER** The Sun and planets technically orbit their mutual center of mass, called the *solar system barycenter*. The barycenter's location moves as the planets follow their elliptical orbits around the Sun. Sometimes it's inside the Sun (diameter marked by yellow circle), other times (including now) it lies outside the photosphere. The positive *x*-axis points in the direction of the vernal equinox.

HOT PRODUCTS 2019

Each year, *S&T* editors scour the marketplace searching for what we consider to be the year's most interesting new products. To make our list, a product should introduce new (or improve upon existing) technologies, provide a solution to an old problem, or simply deliver exceptional value. Our Hot Products list for 2019 includes a variety of telescopes and accessories for visual observers who love being out under a starry sky, as well as cameras, software, and gizmos tuned for the expanding hobby of astrophotography. As is often the case, this year some products caught our eye because of their extraordinary value — equipment offering features and performance at a cost well below that of similar items in the past. We hope you enjoy reading about these innovative products that piqued our interest.

SKY-SWEEPING ASTROGRAPHS

Celestron ♦ celestron.com

Building on the success of its 11-inch Rowe-Ackermann Schmidt Astrograph (RASA for short), Celestron has introduced 8-inch f/2 and 14-inch f/2.2 RASAs for 2019. These specialized instruments are strictly for imaging with cameras that mount on the astrographs' front corrector plates (see the Celestron website for detailed specifications of each instrument). Their incredibly fast optical speeds allow deep-sky imaging with short exposures, opening up a new world of scientific- and recreational-astrophotography possibilities.

U.S. price: $1,699 and $13,999 (8- and 14-inch, respectively)

BACKGROUND TEXTURE: VIJAY KUMAR / DIGITALVISION VECTORS / GETTY IMAGES

HIGH-SPEED SCIENTIFIC CMOS CAMERAS

Finger Lakes Instrumentation ♦ flicamera.com

Featuring extremely high sensitivity, very low noise, and exceptionally fast frame rates, the new line of Kepler scientific cameras with cooled sCMOS detectors from Finger Lakes Instrumentation are, according to the manufacturer, bringing "a game-changing price-to-performance ratio" to the world of astronomical imaging and challenging the fields dominated by conventional CCD cameras.

U.S. price: from $9,995

PORTABLE ROBOTIC EYE

Lunático Astronomia ♦ tienda.lunatico.es

We've seen a variety of sky monitors designed for permanent observatory installation, but the PocketCloudWatcher is the first we know of made for observers who set up in the field. About the size of a deck of playing cards and powered by an internal battery, the device sends alerts to a smartphone app when clouds roll in, offering a little peace of mind for those of us who occasionally doze off during long exposures.

U.S. price: $275

HYPERSTAR COLLIMATOR

Hotech ♦ hotechusa.com

Starizona's HyperStar optical system transforms select 6- through 14-inch Celestron Schmidt-Cassegrain telescopes into f/2 astrographs. But optimum performance requires precise optical collimation, and that's where Hotech's new HyperStar Laser Collimator comes into play. Used before heading out under the stars, it simplifies the process of getting the HyperStar dialed in to produce pinpoint star images across the field of view.

U.S. price: $515

COMPACT SPECTROGRAPH

Starlight Xpress ♦ sxccd.com

Starlight Xpress, a company serving the amateur market since the earliest days of the CCD revolution, has made its foray into the world of spectroscopy with the SX Spectrograph that produces a 31-mm-long spectrum ranging from 340 nm in the blue to 900 nm in the near infrared. It also features a built-in guide camera and argon light source for calibration. It works with a wide range of astronomical cameras made by Starlight Xpress and other manufacturers.

U.S. price: $3,395

EMISSION-NEBULAE FILTER

Oceanside Photo and Telescopes ♦ optcorp.com

The OPT Triad Tri-band Narrowband Filter passes the light of ionized oxygen and hydrogen (at 493- and 656.3-nm wavelengths, respectively) while blocking the rest of the visual spectrum. It is specially designed for shooting color images of deep-sky emission nebulae with DSLR and one-shot color astronomical cameras under light-polluted skies.

U.S. price: $375 and $775 (1¼- and 2-inch filters, respectively)

MULTI-PURPOSE CMOS CAMERA

Meade ♦ meade.com

Based on a cooled 16-megapixel Panasonic CMOS detector with a high-speed USB 3.0 computer connection, Meade's new Deep Sky Imager IV (or DSI-IV for short) is suited to lunar, planetary, and deep-sky imaging. Versions are available for either monochrome or one-shot color imaging, and the DSI-IV comes with its own camera-control software for Windows, Mac, and Linux operating systems as well as ASCOM drivers for other popular image-capture software. Look for our Test Report on the DSI-IV later this year.

U.S. price: $1,199

WIND-UP CAMERA TRACKER

Omegon ♦ omegon.eu

No aspect of astrophotography has been revolutionized more by digital photography than wide-field nightscapes that show star-filled skies over dramatic foregrounds with short exposures. The best nightscape images often involve a small camera tracker, and the new Omegon Mount Mini Track LX2 is among the most compact and least expensive we've seen. And its wind-up drive mechanism certainly fits within the simplicity of this astrophotography niche. Watch for our Test Report on the LX2 in the coming months.

U.S. price: starting at $129

SMARTPHONE CAMERA ADAPTER

Celestron ♦ celestron.com

We've said it before — there's no shortage of devices made to hold a smartphone camera up to the eyepiece of a telescope or binocular. But Celestron's NexYZ 3-Axis Universal Smartphone Adapter is the first we've seen with the ability to precisely tweak the camera's distance from the eyepiece and thus allows capturing the optimum field of view. It works with eyepieces, including those for microscopes, from 35 to 60 mm in diameter.

U.S. price: $59.95

PHOTO-VISUAL APO REFRACTOR

Stellarvue ♦ stellarvue.com

While this 80-mm f/6 apo refractor features a three-element objective for uncompromising visual performance, it was designed from the get-go as a wide-field astrograph. Among the SV80-3SV's features are a massive 3-inch, dual-speed focuser and an optional dedicated field flattener optimized for full-frame DSLR cameras. And there's a dedicated 0.74× focal reducer/flattener in the works that yields a 355-mm focal length at f/4.5.

U.S. price: $1,995

SOLAR TELESCOPE

Daystar ♦ daystarfilters.com

Daystar's new SS60-ds Solar Scout offers one of the best price-to-performance ratios we've ever seen for a scope that delivers tunable sub-angstrom hydrogen-alpha views of the Sun. The 60-mm scope is designed for visual and photographic work, and there's an optional $200 bundle that includes a 1¼-inch diagonal and 25-mm eyepiece, universal AC adapter, and a rechargeable battery for powering the scope's Quark filter in the field.

U.S. price: from $675

FULL-FIELD AUTOGUIDING

Innovations Foresight ♦ innovationsforesight.com

The *SkyGuide* software program is ASCOM-compliant and works with *Maxim DL* to eliminate the need to single out one star to track in the image from your autoguiding camera. Rather, the software uses advanced algorithms to analyze the entire field for tracking, thus improving the overall signal-to-noise ratio (a huge benefit when there are no bright stars in the field) and minimizing guiding errors caused by seeing-induced star motion.

U.S. price: $50

ZERO BACK FOCUS BINOVIEWER

Orion Telescopes & Binoculars ♦ oriontelescopes.com

You don't have to hunt far on the internet to find observers waxing poetic about using binoviewers for two-eyed gazing through telescopes. What makes the new Premium Linear BinoViewer for Telescopes special is that it's the first we've seen that requires zero additional back focus without changing a telescope's magnification. As such, it will work with any telescope and matching eyepiece combination that already reaches focus without the viewer.

U.S. price: $499.99

LOW-PROFILE FOCUSER FOR IMAGING

Optec ♦ optecinc.com

Optec wrote the book on temperature-compensated focusers that automatically keep cameras in perfect focus as telescope optics vary because of changing nighttime temperatures. Its new TCF-Leo Low-Profile Focuser has a robust 3-inch aperture and is designed to work with telescopes that have tight restrictions on the distance between the focuser's mounting point and the camera's detector (for example, the Celestron EdgeHD models).

U.S. price: $1,295

BACKGROUND TEXTURE: VIJAY KUMAR / DIGITALVISION VECTORS / GETTY IMAGES

PALM-SIZE GO TO MOUNT

Sky-Watcher ♦ skywatcherusa.com

Small enough to fit in your hand, but beefy enough to carry a telescope weighing up to 11 pounds, the AZ-GTi is one of the most compact Go To mounts we've ever seen. It's powered by eight internal AA batteries and controlled by a smartphone app, eliminating the need for an external power source and hand controller while still having all the features you'd expect from a mount with Go To pointing and tracking. Look for our Test Report on the AZ-GTi in the coming months.

U.S. price: $379

BIG BINOCULAR OBSERVING PACKAGE

Orion Telescopes & Binoculars ♦ oriontelescopes.com

Large binoculars and heavy-duty parallelogram binocular mounts are well-established products in the amateur-astronomy market. But Orion's Monster Mount & 25×100 Binocular Kit has them paired together, including a solid tripod for the mount at a very remarkable price, and that's what caught our eye in this year's search for Hot Products.

U.S. price: $799.99

GO TO HEAVYWEIGHT

iOptron ♦ ioptron.com

The CEM120 is the largest and most-advanced equatorial mount in iOptron's expanding line of Go To telescope mounts. Rated for instruments weighing up to 115 pounds (52kg) and capable of remote operation, the mount is a candidate for permanent installations, especially when fitted with optional high-resolution encoders. But when mated to its optional Tri-pier 360 it is equally well-suited for portable use in the field. Our detailed review of the CEM120 appears in the November 2018 issue, page 66.

U.S. price: starting at $3,999

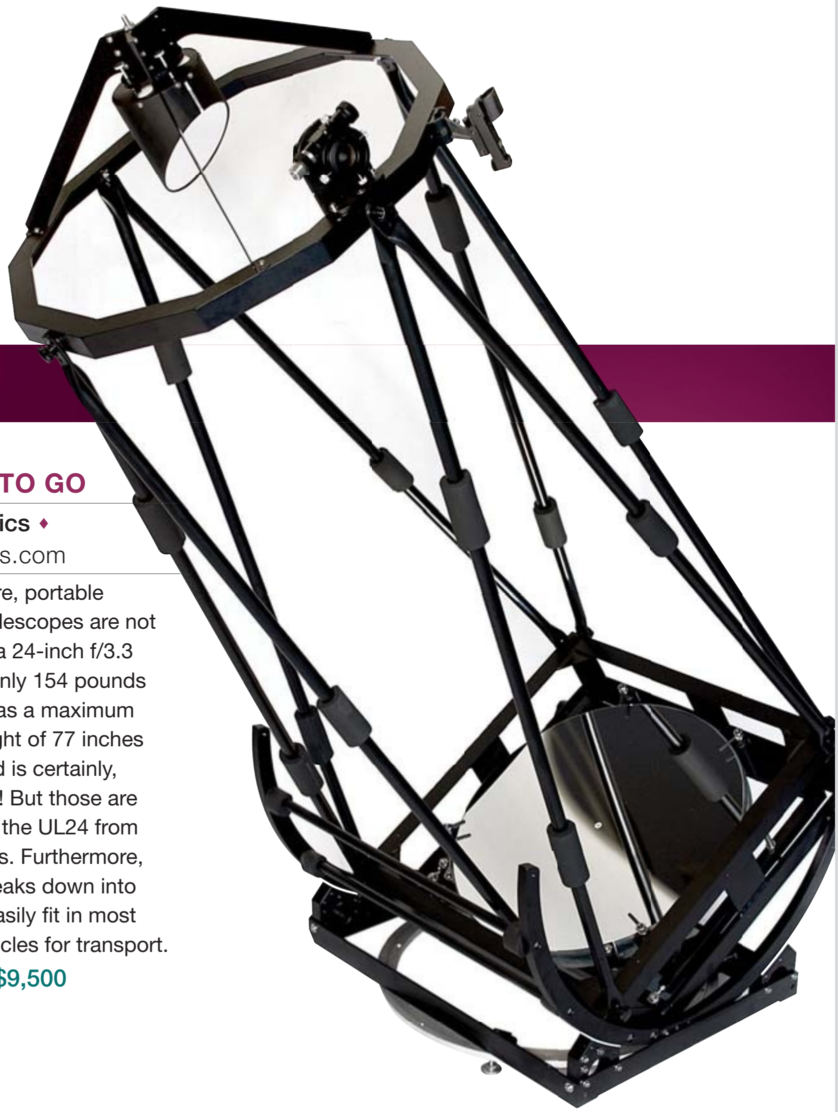
BACKGROUND TEXTURE: VIJAY KUMAR / DIGITALVISION VECTORS / GETTY IMAGES

PREMIUM APO REFRACTOR

Explore Scientific ♦
explorescientificusa.com

From the tip of its carbon-fiber dew shield to the back of its massive 3-inch HEX focuser, the 165mm FPL-53 Apochromatic Refractor is packed with features for discriminating observers. The 165-mm (6½-inch) f/7 air-spaced, three-element objective promises outstanding performance. It comes with tube rings and a Losmandy-style dovetail plate, 2-inch star diagonal, and a hard-sided transport case.

U.S. price: $9,999.99



BIG DOB TO GO

Hubble Optics ♦
hubbleoptics.com

Large-aperture, portable Dobsonian telescopes are not unusual, but a 24-inch f/3.3 that weighs only 154 pounds (70 kg) and has a maximum eyepiece height of 77 inches off the ground is certainly, well, different! But those are the specs for the UL24 from Hubble Optics. Furthermore, the scope breaks down into pieces that easily fit in most compact vehicles for transport.

U.S. price: $9,500

VERSATILE ASTRONOMY CAMERA

MallinCam ♦ mallincam.net

What most caught our attention about the MallinCam SkyRaider DC10c is the manufacturer's comments about it being designed with the Celestron RASA astrographs in mind (see page 28). This one-shot color CMOS camera with a high-sensitivity, back-illuminated Sony sensor is packed with features, including an on-the-fly stacking algorithm that automatically aligns images made with telescopes operating in altazimuth-tracking mode.

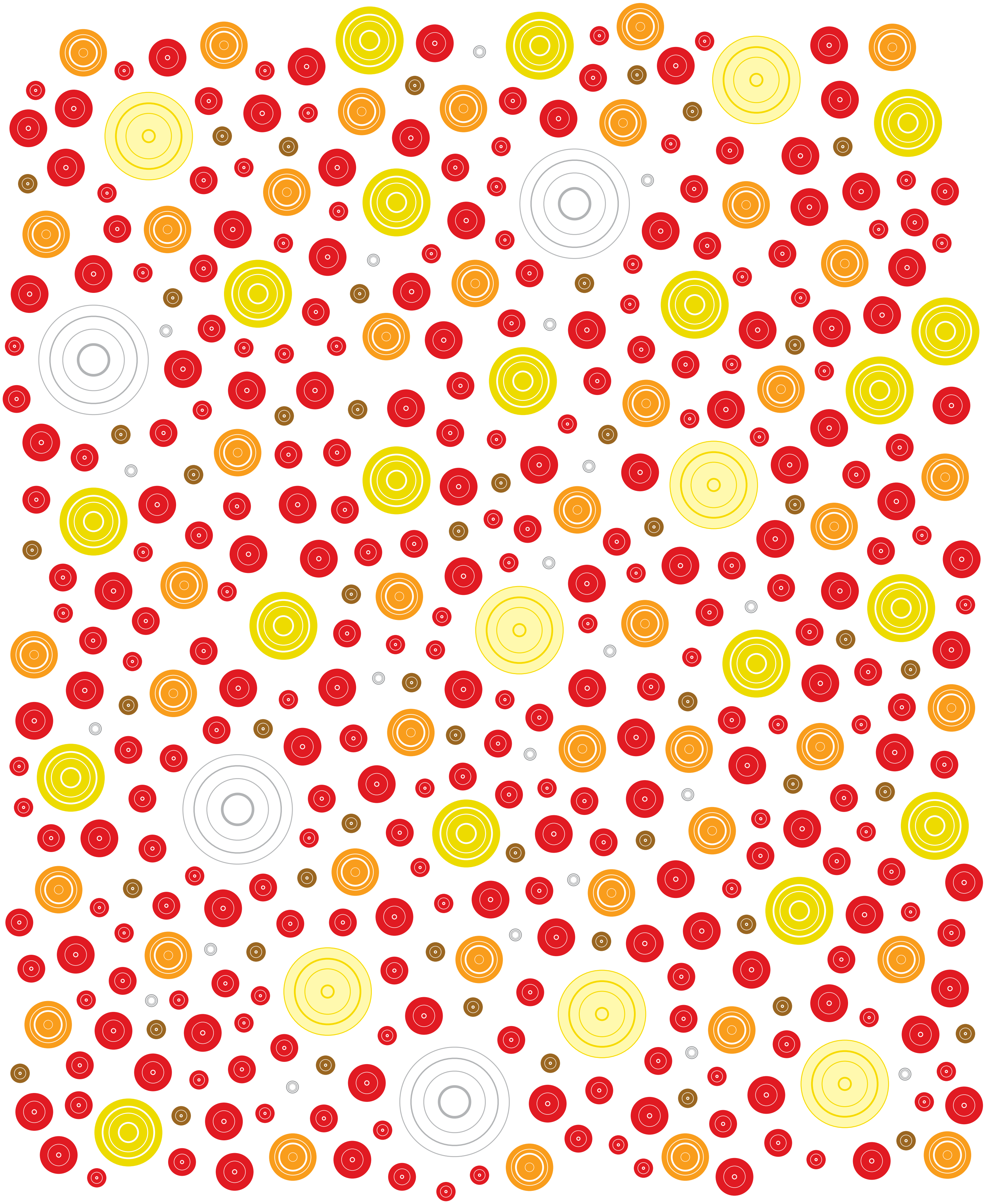
U.S. price: $929.99

STAND ALONE DEEP-SKY SMARTCAMERAS

Astrel Instruments ♦
astrel-instruments.com

A new line of high-performance astronomical CCD cameras from the Italian firm Astrel Instruments does away with the need for external computers to capture and process deep-sky images. The camera's built-in WiFi link, 1000 MHz processor (for operating the camera and processing images), and up to 64 Gb of storage are controlled by a remote desktop app on any network-connected device, including smartphones, tablets, and PCs.

U.S. price: from 1,600€ (about $1,850)



Meet the Neighbors

Astronomers are compiling a census of the nearest stars to discover what we know — and what we don't — about our stellar neighbors.

If history had turned out a little differently, Todd Henry might have become a leading light in the search for extra-terrestrial intelligence. Instead, for the last quarter of a century he's been leading the charge to learn all that we can about the nearest stars.

Henry graduated from Cornell in the 1980s, where one of his advisors had been none other than Carl Sagan. With such inspiration, it's little surprise that after completing his PhD he opted to join NASA's SETI project, which was to be a huge 10-year quest to search for signals from extraterrestrial civilizations. Yet just a year after observations began, the rug was pulled out from under the project as Congress cancelled its funding.

Still, the questions that SETI posed remained with Henry. If life exists on other worlds, where are those worlds? The closest stars would seem to be a reasonable place to start.

However, our stellar neighbors just didn't seem to interest most astronomers. "The nearby stars just haven't been sexy for all that long," says Henry (Georgia State University). To remedy this, in 1994 he formed RECONS, the Research Consortium On Nearby Stars, with the primary goal of mapping and characterizing all the stars within 10 parsecs (i.e., 32.6 light-years), and later extending that to 25 and 100 pc (81.5 and 326 light-years, respectively).

Obtaining funding was difficult at first. Henry had to constantly emphasize that the nearest stars *are* worth studying, particularly since no one else was really looking at them. By 2003, though, his team was able to take over the 0.9-meter at the Cerro Tololo Inter-American Observatory in Chile. Most of RECONS's work has since been performed on that telescope.

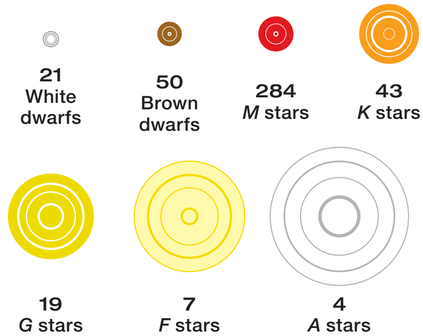
In 2018, the RECONS team released their latest census of everything currently known within 10 pc — every star, every brown dwarf, and every planet. Split among 317 different star systems (including our own), they and other astronomers have found 378 stars and white dwarfs, 50 brown dwarfs, and more than 50 planets. There have been surprises, though, from missing brown dwarfs to the sheer wealth of small stars, and vital information about the secrets of star formation.

Stars of All Kinds

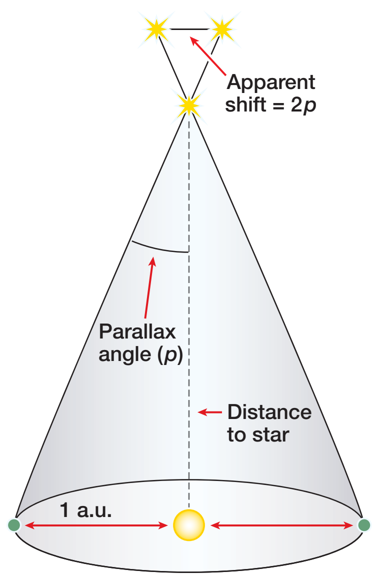
Our nearest stars are a motley bunch. Spread randomly and uniformly across space, our neighbors show no discernible clustering, with an average distance between star systems of 3 to 4 light-years. The fact that our closest star, Proxima Centauri, is 4.2 light-years away, might mean that we're a tad more remote than average.

While star systems generally keep a polite distance from one another, about a quarter of systems are multiples —

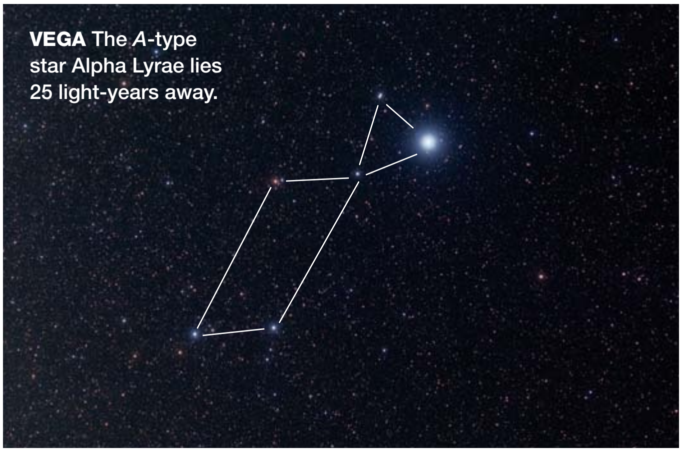
THE CENSUS As of mid-2017, astronomers had tallied 428 stars, white dwarfs, and brown dwarfs within 10 parsecs of our solar system. Each dot represents a star and is sized and color-coded by type. The tally includes the Sun.



WHAT IS A PARSEC? Astronomers' distance unit of choice is the parsec, which is based on parallax. Parallax is the shift in an object's position against the background scene when viewed from two different locations. Nearby stars have measurable parallaxes due to Earth's motion around the Sun, which astronomers can use to calculate the stars' distances. A parsec is the distance at which the difference between a star's apparent location as seen from Earth would be 1 arcsecond different than its apparent location as seen from the Sun (an arcsecond is $\frac{1}{3{,}600}$°). Another way to think about it is that the parsec is how far away you'd have to be for the distance between the Sun and Earth to span 1 arcsecond. One parsec is 3.26 light-years.



CENSUS: TERRI DUBÉ / *S&T*; PARSEC: LEAH TISCIONE / *S&T*



VEGA The *A*-type star Alpha Lyrae lies 25 light-years away.

doubles and triples (or more) of closely orbiting stars or brown dwarfs. Thus, while at least half of the census stars are in multiple systems, most systems are not multiples.

The list of our stellar neighbors illustrates perfectly the *initial mass function* (IMF), which describes the frequency with which stars of different masses form. The IMF predicts that the most massive stars are much rarer than lower-mass stars. It therefore comes as no surprise to find that most of our neighbors are fairly modest stars, with our Sun actually standing out as one of the more impressive.

Within 10 pc there are no *O*- or *B*-type stars, which are the hottest, brightest, and most massive stars on the main sequence. The next class down is the *A*-type stars, with surface temperatures between 7600 and 11,500 kelvin. There are four of these nearby, all of which amateur astronomers will know well: Altair, Sirius, Vega, and Fomalhaut.

Next are the *F*-type stars, a little cooler than the *A*-types but a little warmer than the Sun, and there are seven of these, including Procyon in Canis Minor. The Sun belongs to the *G*-type stars and, again, there are more of these than the *F*-types, including our star, Alpha Centauri A, Tau Ceti, and 16 others. Cooler than the Sun are the *K*-type stars; these outnumber all the *A*-, *F*-, and *G*-type stars put together. They include Alpha Centauri B, both members of 61 Cygni, Epsilon Eridani, and 39 others filling their ranks.

However, the most intriguing finding over the last 24 years of RECONS is the ubiquity of *M*-type stars, often referred to as *M* dwarfs or red dwarfs. These are the smallest, coolest, and faintest stars, with a surface temperature less than 4000K and masses from half a solar mass down to just 7.5% of the Sun's mass. When RECONS began, it was thought that *M* dwarfs might account for half of all the stars in the galaxy. However, thanks in part to the work RECONS has done, we now know that they are even more common, making up three-quarters of all stars.

"Three out of four is an awful lot of stars," says Henry. "That's a bit of a surprise."

There are also 21 "dead" stars, the cooling stellar cores named white dwarfs, with the closest being Sirius B, 8.6 light-years away.

A Shortage of Failed Stars

The other key result relates to brown dwarfs. Smaller than red dwarfs but larger than gas giant planets, brown dwarfs are the awkward in-betweeners, not quite massive enough to generate the required temperatures and pressures to ignite the nuclear fusion of hydrogen within their cores.

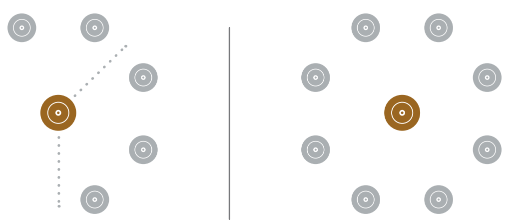
Since discovering the first of these failed stars in the 1990s, astronomers have suspected that brown dwarfs form the same way that stars do, condensing from fragmenting clouds of molecular gas. In that case, one might expect them to follow the IMF trend and be found even more frequently than red dwarfs.

But that belief was not data-driven, Henry explains. "In the early days people would get very excited about brown dwarfs and say there are more brown dwarfs than there are stars," he says. "And I thought, 'Based on what?'"

Henry's skepticism has since been borne out. The RECONS data show that there are 8 times more stars within 10 pc than there are brown dwarfs.

Yet there appears to be a disparity between the number of brown dwarfs in the local neighborhood and those farther afield. Astronomers are now routinely detecting them in young star clusters, with the Substellar Objects in Nearby Young Clusters (SONYC) team, led by Alexander Scholz (Uni-

Ratio of Brown Dwarfs to Stars



1:2 to 1:5
SONYC star-forming regions

1:8
RECONS solar neighborhood

▼ SEEING DOUBLE (OR TRIPLE, OR . . .) Of the 317 star systems in the solar neighborhood, 85 have more than one component — with "component" meaning either star or brown dwarf. That's a multiplicity fraction of 27%.

1% — **2** systems with

1% — **3** systems with

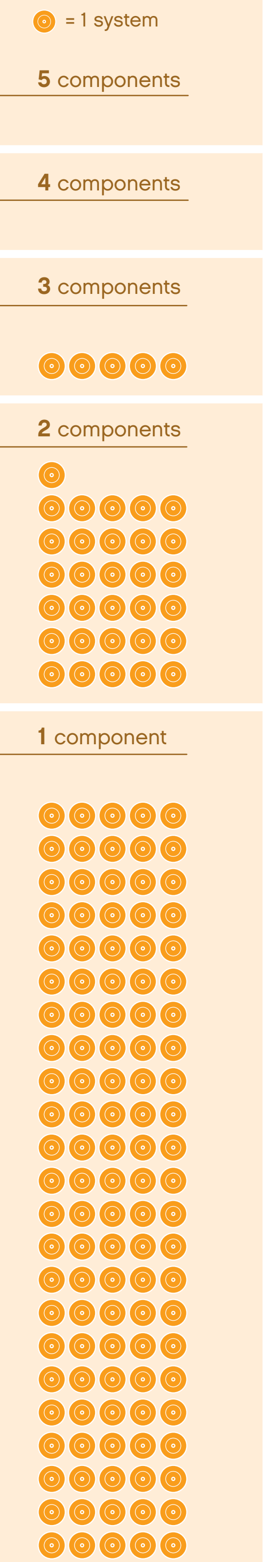
4% — **14** systems with

21% — **66** systems with

73% — **232** systems with

VEGA: AKIRA FUJII; MULTIPLICITY AND RATIO INFOGRAPHICS: TERRI DUBÉ / S&T

The mystery behind this dearth of nearby brown dwarfs deeply puzzles Sergio Dieterich. "Trying to understand why this happens is something I lose sleep on."



versity of St. Andrews, UK), at the forefront of these searches. SONYC's studies of the star-forming regions NGC 1333 in Perseus and RCW 38 in Vela, as well as of the Rho Ophiuchus cloud complex, have turned up a brown dwarf-to-star ratio of between 0.2 and 0.5. In other words, for every brown dwarf in this region, there are two to five stars. The number of brown dwarfs could be higher if some of the stars host brown dwarf companions that have yet to be detected.

Extrapolating from this, Scholz's group calculates that there could be as many as 100 billion brown dwarfs inhabiting the Milky Way Galaxy. Yet these numbers fail to add up in the Sun's neighborhood, where the ratio of brown dwarfs to stars is just 0.13, or about 1 to 8.

The mystery behind this dearth of nearby brown dwarfs deeply puzzles Sergio Dieterich (Carnegie Institution for Science), who is also a member of the RECONS consortium. "Trying to understand why this happens is something I lose sleep on," he says.

In an effort to reconcile the observations, Dieterich is modeling the cooling rates of brown dwarfs to figure out if there could be more brown dwarfs in the Sun's neighborhood that remain undetected because they are too cold to emit at the observed wavelengths. Brown dwarfs spend their entire lives cooling after they form, and those that RECONS and SONYC see have temperatures in the 1500K to 3000K range, which means they must be fairly young.

However, NASA's Wide-field Infrared Survey Explorer (WISE) was optimized to find cool objects. The coldest brown dwarf yet discovered is WISE 0855−0714, which has a surface temperature of some 250K (–23°C). Yet WISE's 2012 survey may support the RECONS findings, by detecting on average just one brown dwarf for every six stars in the solar neighborhood.

If there are many, much older brown dwarfs that have cooled to become too faint for even WISE to see, maybe Scholz is correct and there are more brown dwarfs out there.

▲ **NGC 1333** This composite image combines X-ray (pink), infrared (red), and optical data (red, green, blue) of the cluster NGC 1333, populated with stars that are less than 2 million years old. The X-ray data reveal 95 young stars, 41 of which had not been identified in infrared because there was no glow from a surrounding disk.

SIRIUS At apparent magnitude –1.46, Alpha Canis Majoris is the brightest star in the sky and lies 8.6 light-years from Earth.

NGC 1333: X-RAY: NASA / CXC / SAO / S. WOLK ET AL., OPTICAL: DSS & NOAO / AURA / NSF, INFRARED: NASA / JPL-CALTECH; SIRIUS: AKIRA FUJII

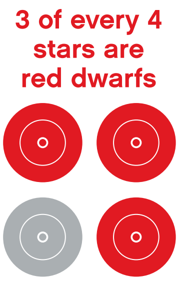
"This is possible, but the theorists would really be wrong by a large stretch," says Dieterich. Brown dwarfs should not be able to cool fast enough to create that huge, invisible reservoir. However, he admits, "there is very tentative evidence that there may exist more very cool brown dwarfs than what the WISE results indicate."

The Dividing Line

Just beyond the limit of the 10 pc survey is a seemingly unassuming star, named 2MASS J0523–1403 — let's call it J0523 for short — that could turn out to be one of the most important red dwarfs yet discovered.

Lying 40 light-years away, J0523 is the smallest and dimmest of the nearby stars, with a surface temperature of about 2100K and a radius just 8.6% solar. This star marks a turning point in a diagram comparing the radii and temperatures of red and brown dwarfs. As you look at smaller and smaller stars on the plot, the temperatures go down, until you reach J0523.

"There is then a sudden jump to higher radii as the objects become cooler and less luminous," says Dieterich. Brown dwarfs glow with the heat of their contraction, with smaller brown dwarfs warmer than larger ones. Furthermore, to be this warm the brown dwarfs must still be fairly young and therefore puffy, making them larger than the smallest stars. The result is a clear disconnect on the diagram. "I believe that 2MASS J0523–1403 is representative of the smallest possible stars, and that everything cooler than it must be a brown dwarf."

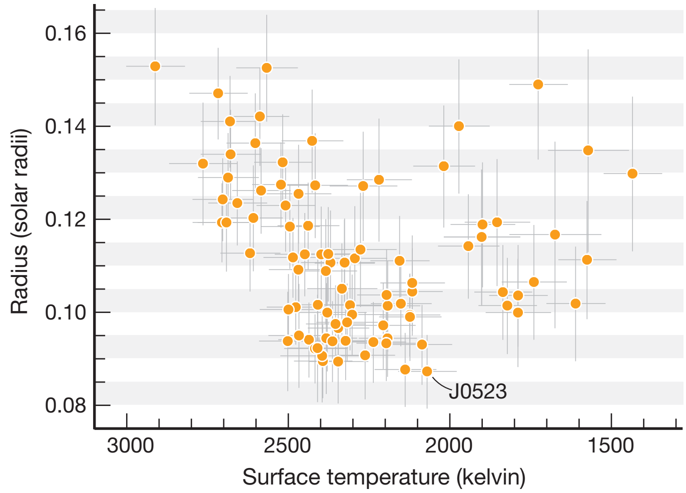


If Dieterich is right, then RECONS has identified the boundary between full-fledged stars and brown dwarfs. Not everyone agrees; his results have produced "a chorus of complaints" from theorists, he says, because some stellar models predict that there should be even cooler stars before we enter the realm of the brown dwarfs. He's working on figuring out where the theories might be going wrong.

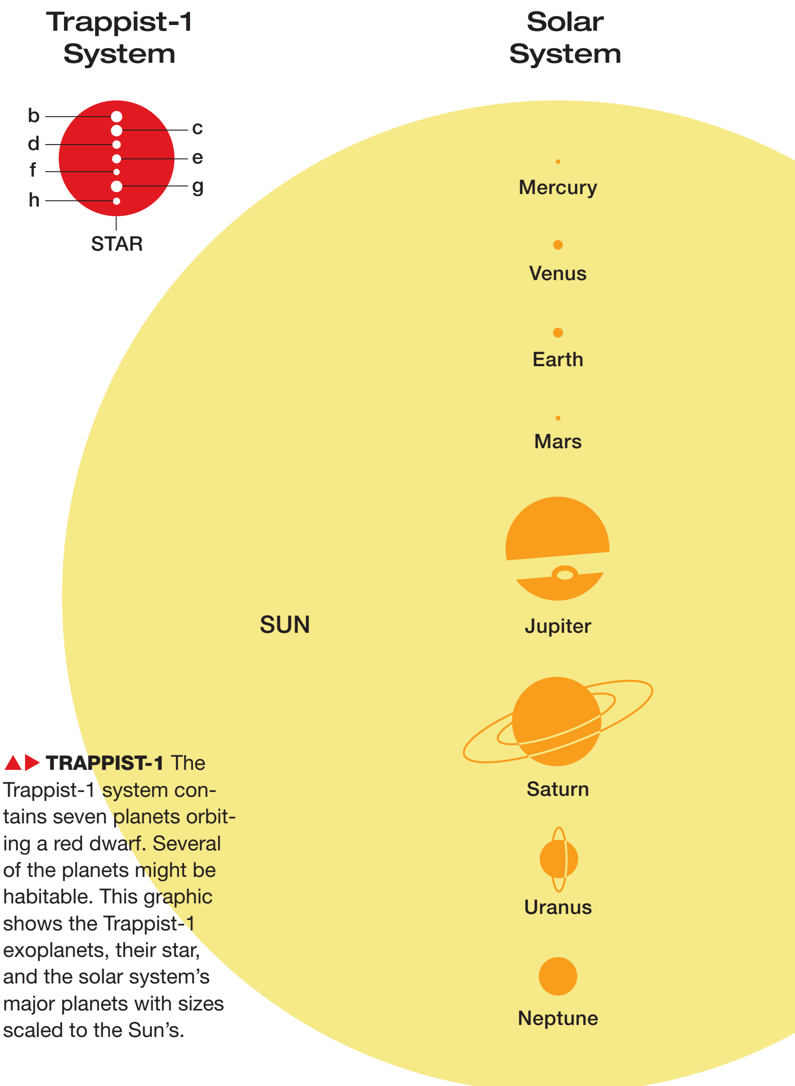
Planet Popularity

In some ways, just as SETI motivated Todd Henry to start looking at the nearest stars, the search for extraterrestrial life is also encouraging researchers to look at the stars that are closest to us. "Because the exoplanet game has gotten so popular, the nearby stars are back in vogue, in particular the small red dwarfs," says Henry.

NASA's Kepler Space Telescope has taught us that, on average, there is at least one planet for every star. But only 28 of the closest 317 known star systems (including the Sun's) are known to have planets — that's less than 9%. Recently discovered planetary systems, such as those belonging to the *M* dwarfs Ross 128, Trappist-1, and LHS 1140 (the latter two at 12 pc), could be just the tip of the iceberg, says Henry. "There are likely hundreds more solar systems to find among our nearest neighboring systems."



▲ **THE SMALLEST STAR?** Plotting a collection of nearby red and brown dwarfs by their radii and surface temperatures reveals a turn: Suddenly, the stars stop shrinking. The RECONS team thinks the smallest star in their sample, informally called J0523, might mark the limit of roughly how small a star can be. Objects to the right of it are young brown dwarfs, still warm and puffy from their formation.



▲▶ **TRAPPIST-1** The Trappist-1 system contains seven planets orbiting a red dwarf. Several of the planets might be habitable. This graphic shows the Trappist-1 exoplanets, their star, and the solar system's major planets with sizes scaled to the Sun's.

GRAPH: LEAH TISCIONE / *S&T*, SOURCE SERGIO DIETERICH; TRAPPIST-1: AMANDA SMITH / INSTITUTE OF ASTRONOMY, UNIV. OF CAMBRIDGE

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That will now be the task of NASA's Transiting Exoplanet Survey Satellite (TESS), which launched in April 2018 and is going to focus on the 200,000 nearest stars (*S&T:* Mar. 2018, p. 22). That's important because, as TESS's principal investigator George Ricker (Massachusetts Institute of Technology) points out, they're close enough for instruments such as the upcoming James Webb Space Telescope to perform follow-up studies to look at atmospheric compositions.

"There's some pretty demanding but conclusive observations that can be made with the Webb telescope" on the TESS targets, he says. "But if you were to only have the Kepler objects, it would take a 65-meter telescope in space!"

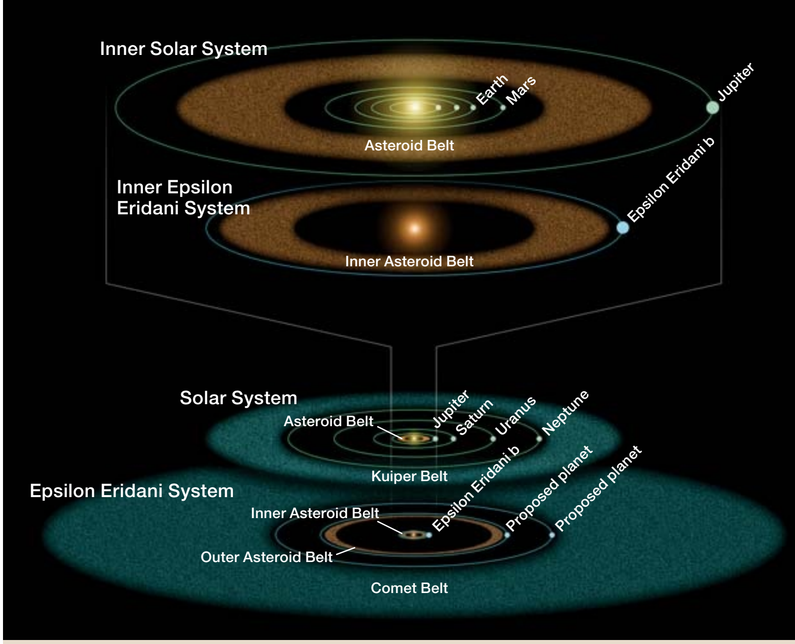
TESS should find several dozen new Earth-size rocky exoplanets, many of them within 50 pc of our solar system. However, it has already been beaten in the race to discover a planet around the nearest star to the Sun, the red dwarf Proxima Centauri (Alpha Cen C).

It took more than 20 years following the discovery of the first exoplanets for astronomers to identify a planet orbiting Proxima Cen. The world, Proxima Cen b, was discovered in 2016 by astronomers led by Guillem Anglada-Escudé (Queen Mary University of London; *S&T:* Dec. 2016, p. 10). Now they are embarking on the Red Dots campaign to search for planets around not just Proxima but also two other nearby *M* dwarfs, Barnard's Star and Ross 154. The three stars were chosen because they can be observed together on the same nights. In the future, the campaign will look at other nearby *M* dwarfs, such as Wolf 359.

The Alpha Cen system is a prime example of how much we still don't know about the nearest stars. "Have you ever looked at the fundamental measurements we have for Alpha Centauri A or B?" asks Tabetha Boyajian (Louisiana State University). "For Alpha Centauri A, the literature lists spectral types ranging from *F*8 to *G*5, and temperatures range from 5519 to 5939 kelvin. Magnitudes are all over the place, too. It's just sad!"

Looking Farther Afield

There's still much work for RECONS to do. The second data release from the European Space Agency's astrometric satellite, Gaia, provided a huge amount of data to churn through. "It will take us quite a bit more time to sort through the 1,722 objects *reported* to be within 10 parsecs," says Henry, who reckons that three-quarters of them will turn out to be false positives. That's a surprising number, but the objects are exceptionally faint, leading to high levels of uncertainty in the distance measurements, he explains — at least one of the "nearby" objects has already proved to be a galaxy. Once the



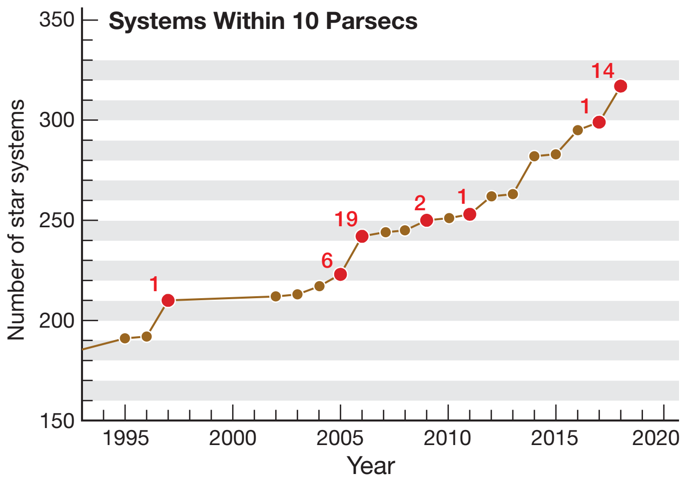
Rogues Gallery

Of the 378 stars in the RECONS 10-parsec census, which ones stand out? Here are five of our most interesting stellar neighbors:

- **Epsilon Eridani** Todd Henry flags Epsilon Eridani as being a particularly interesting *K*-type star. Just 10.5 light-years away, it is a young replica of what our own solar system may have looked like when it was less than a billion years old. It's known to have at least one giant planet as well as two dust belts and a comet belt, which could be home to asteroids or comet-like icy bodies.
- **Epsilon Indi** Epsilon Indi is actually a triple system, 12 light-years away, with a *K*-type star orbited by a binary system of brown dwarfs, as well as a giant planet on a wide orbit.
- **SCR 1845-6357** This binary system 12.6 light-years away comprises a red dwarf with about 8% the mass of the Sun and a brown dwarf with 50 times the mass of Jupiter and a temperature of about 950K (675°C). Todd Henry says the system is one of his favorites, because astronomers can use it to explore how these different objects evolve.
- **Sirius** The famous Dog Star might be the brightest star in the sky, but it also hosts a white dwarf, the closest to us at 8.6 light-years. The white dwarf is the remnant of a star that was five times more massive than the Sun, while Sirius itself is twice as massive as the Sun.
- **Ross 128** At 11 light-years away, this red dwarf star is the 11th-closest system to the solar system. It was considered a fairly unremarkable star with only the odd flare to speak of, until astronomers discovered a potentially habitable planet orbiting it in 2017.

▲ **EPSILON ERIDANI** Only 800 million years old, Epsilon Eri has two dusty belts and an outer cold belt, reminiscent of the belts in our solar system. Astronomers have discovered one Jupiter-mass planet and suspect there might be two more farther out that carve the edges of the outer belts.

NASA / JPL-CALTECH



◀ **BUILDING THE CENSUS** In 1995, the Yale Parallax Catalog contained fewer than 200 stars within 10 pc of Earth. That number jumped slightly in 1997 with the Hipparcos mission data, and since 2002 the count has risen by at least one star each year. Red points mark years in which RECONS added the number of systems indicated with red digits.

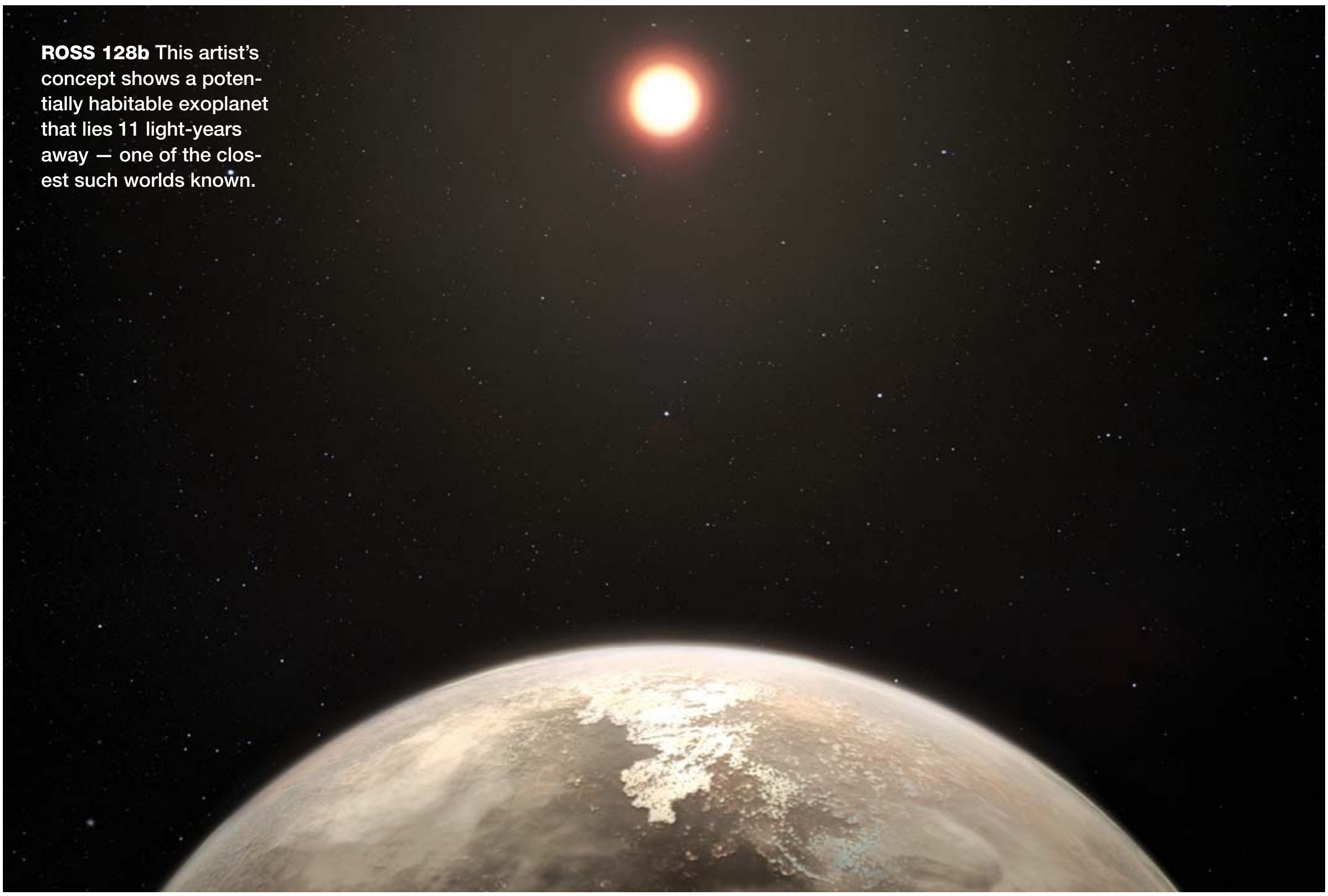
team subtracts the 378 stars already known, Gaia might add just a few objects at the boundary, he estimates.

After the Gaia data have been double-checked, Henry will turn his attention back to the wide 25 and 100 pc surveys. "We have probably identified about 90% of the nearest 500 stars, but only about 60% of the nearest 5,000 stars," he says.

Mapping the stars is only the beginning. Astronomers still do not know much about the magnetic cycles of some of these stars, which can affect their activity and any planets' habitability. The upcoming Large Synoptic Survey Telescope, which will scrutinize the southern sky from Chile, will be able to help here by watching the same stars for many years. A separate RECONS project will explore the orange *K* stars, which are in the class of stars between our Sun and the red dwarfs.

Ultimately, learning about our nearest stars also helps to put our solar system in context. We often refer to our Sun as average, because it's partway between smaller stars and larger stars. Yet compared to all the stars in its neighborhood, it's remarkable: Its temperature, luminosity, and mass put it in the 90th percentile — far hotter, brighter, and heftier than the more common little stars. In the end, it's all just a matter of perspective.

■ **KEITH COOPER** is the editor of both *Astronomy Now* magazine and *Astrobiology Magazine* (**astrobio.net**). His book *The Contact Paradox: Challenging Assumptions in the Search for Extraterrestrial Intelligence* will be published in October.



ROSS 128b This artist's concept shows a potentially habitable exoplanet that lies 11 light-years away — one of the closest such worlds known.

GRAPH: LEAH TISCIONE / *S&T*, SOURCE T. J. HENRY ET AL. / *ASTRONOMICAL JOURNAL* 2018; ROSS 128: ESO / M. KORNMESSER

OBSERVING
January 2019

1 DAWN: The first morning of the year opens with dazzling Venus and the waning crescent Moon in Libra. Look toward the southeast to see the ever-thinning Moon glide past Jupiter during the next few mornings.

3 EARTH is at perihelion, closest to the Sun for 2019, at a distance of 147,099,761 kilometers.

EVENING: The short-lived Quadrantids peak for North America. Observe as the radiant climbs higher in the northeast — the waning crescent Moon should not interfere with viewing. Read more on page 48.

5–6 DAYTIME: A deep partial solar eclipse is visible in the afternoon hours of the 5th in the north Pacific, and in the morning hours of the 6th in northeast Asia.

11–12 NIGHT: Algol shines at minimum brightness for roughly two hours centered at 10:21 p.m. PST (1:21 a.m. EST); see page 50.

14 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:10 p.m. EST (7:10 p.m. PST).

17 EVENING: Algol shines at minimum brightness for roughly two hours centered at 6:59 p.m. EST.

20–21 NIGHT: The Moon, approaching perigee, will be eclipsed for all of the Americas, with Europe and most of Africa seeing partial phases on the morning of the 21st.

22 DAWN: Venus, which has been closing in on Jupiter the past few mornings, passes less than 2½° from the giant world in the early morning hours. Red Antares jostles for attention a little more than 8° right of the planetary pair.

23 DAWN: Just before sunrise, Saturn makes its reappearance very low in the southeast. Binoculars will help spot the ringed planet. Visibility improves as the month comes to a close.

30 DAWN: Venus and Jupiter are flanked by the waning crescent Moon and Saturn. The following morning, the Moon inserts itself between the two brighter planets, while Saturn hovers lower in the southeast.
— DIANA HANNIKAINEN

▼ A montage of five photos of the full Moon taken every five minutes reveals the silhouette of Mount Miaron, of the Cridola Group in the Dolomites of northeast Italy. The peak is 5 kilometers away as the crow flies, and the cross is approximately 3 meters tall.
GIORGIA HOFER

JANUARY 2019 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

NEW MOON
January 6
01:28 UT

FIRST QUARTER
January 14
06:46 UT

FULL MOON
January 21
05:16 UT

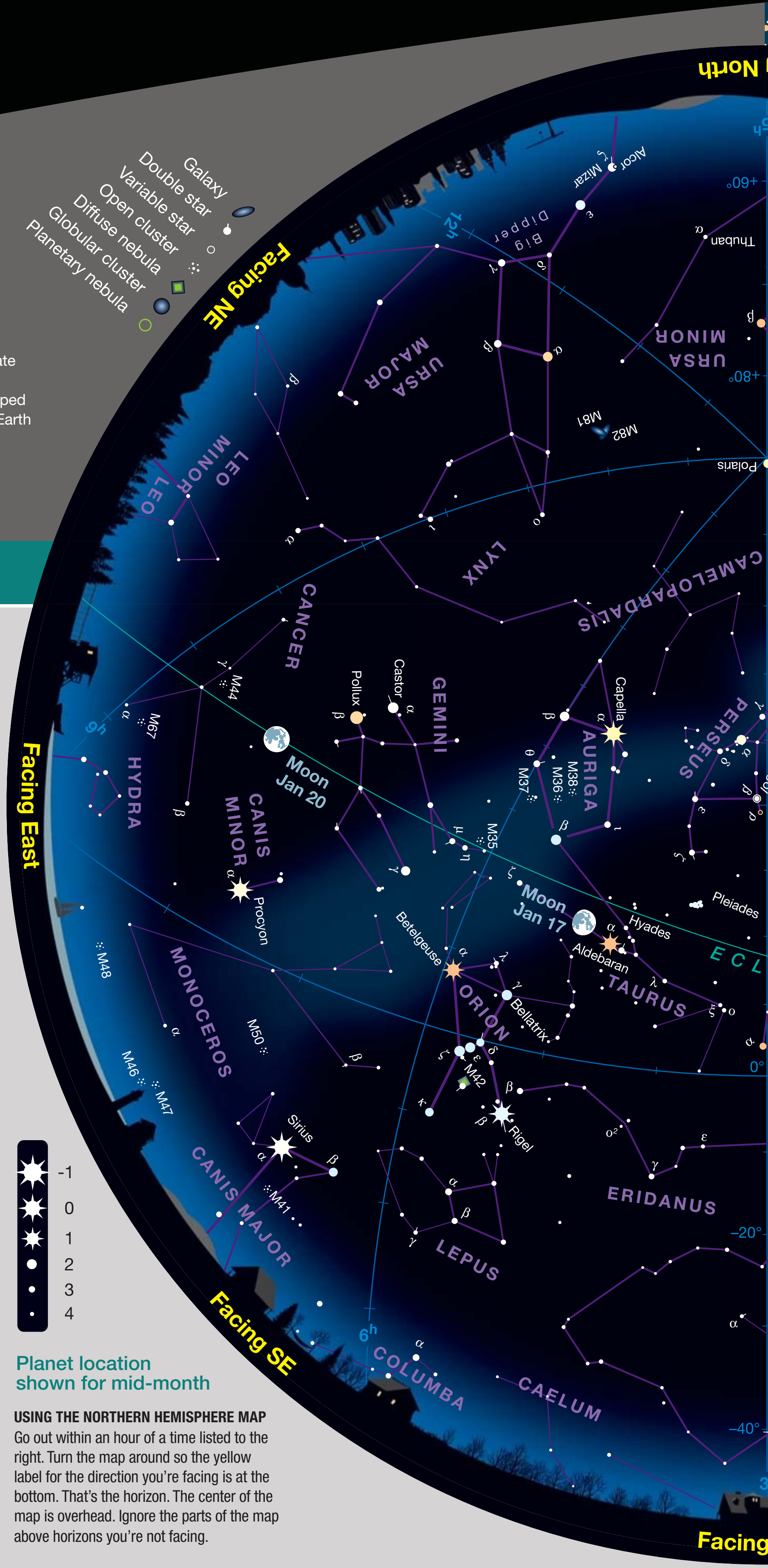
LAST QUARTER
January 27
21:10 UT

DISTANCES

Apogee	January 9, 04^h UT
406,117 km	Diameter 29′ 25″
Perigee	January 21, 20^h UT
357,342 km	Diameter 33′ 26″

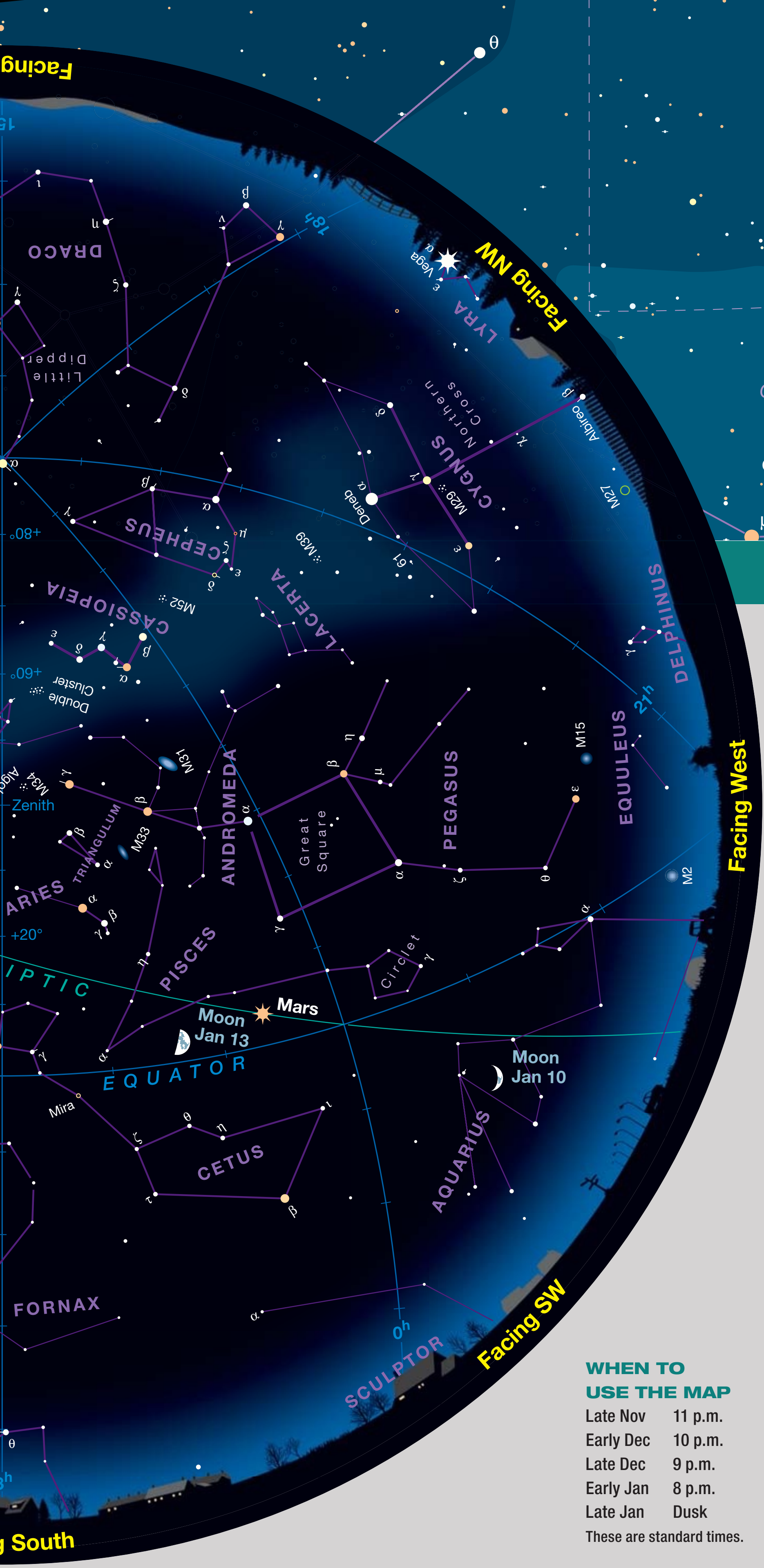
FAVORABLE LIBRATIONS

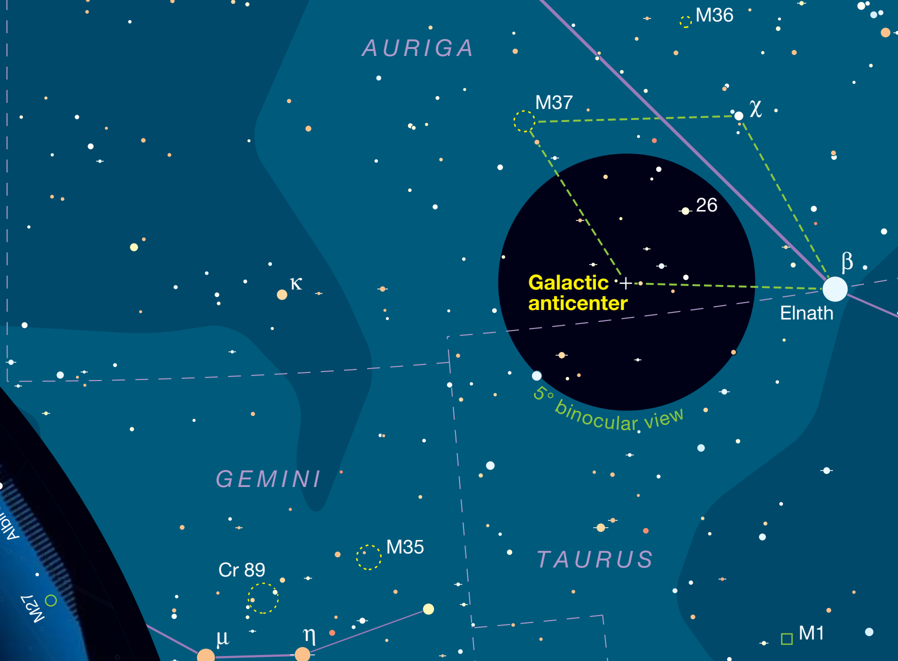
- Schluter Crater — January 21
- Le Gentil Crater — January 22
- Boussingault Crater — January 23



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.





Binocular Highlight by Mathew Wedel

The Galactic Rim

In the summer, we look galactically inward, toward the inner arms and core of the Milky Way. Like someone lying down in a meadow and gazing at nearby mountains, we see first the closest stars and clusters (the grass), then the more distant stars, clusters, and nebulae that define the inner spiral arms (the trees), and finally the galaxy's vast central bulge looming in the distance (the mountains).

In the winter Milky Way, we look in the opposite direction, outward toward the edge of the galaxy. The galaxy has only one center, but for every observer it also has an *anticenter*, the point 180° around the sky from the galactic core. For us, that point lies in the constellation Auriga, the Charioteer. No bright star marks this galactic antipode, but it's easy to find. Imagine a flattened diamond, 7° across, with three corners marked by the open cluster M37 and the stars Chi (χ) Aurigae and Beta (β) Tauri (Elnath). The invisible fourth corner, opposite Chi Aurigae, is the position of the galactic anticenter.

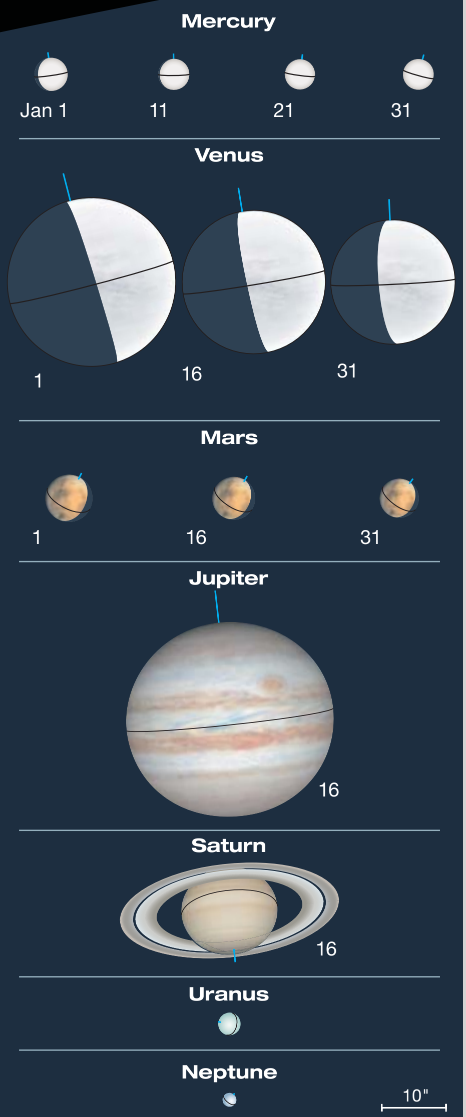
Almost all of the visible stars in this direction, and many of the open clusters, belong to our own Orion Spur — they're grass, or maybe shrubs. The forest beyond is the Perseus Arm, the backbone of which lies a little more than 6,000 light-years away. As a rough rule of thumb, objects closer than 3,000 light-years are our neighbors in the Orion Spur, including the clusters M35 and Collinder 89 in Gemini, and virtually all the clusters in Taurus, the Bull. In contrast, objects that lie 4,000 or more light-years away belong to the Perseus Arm, which encompasses the Messier trio of M37, M36, and M38 in Auriga, and M1 in Taurus. This is as simple as the Milky Way gets — and it's still a lot to take in.

■ **MATT WEDEL** is exploring "down under," galactically speaking. G'day, mates — or rather, g'night!

WHEN TO USE THE MAP

Late Nov	11 p.m.
Early Dec	10 p.m.
Late Dec	9 p.m.
Early Jan	8 p.m.
Late Jan	Dusk

These are standard times.



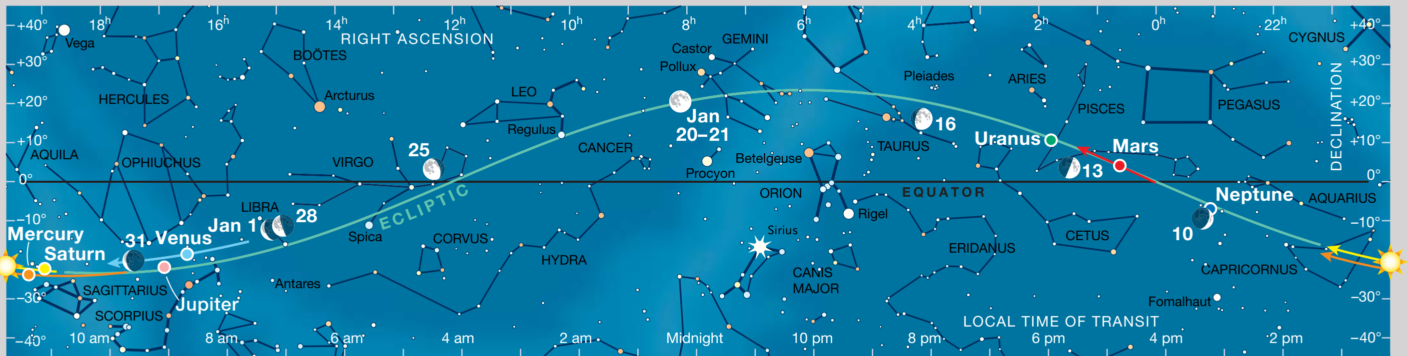
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY **Mercury:** visible at dawn through the 3rd • **Venus:** visible at dawn all month • **Mars:** visible at dusk, sets before midnight • **Jupiter:** visible at dawn all month • **Saturn:** visible at dawn after the 23rd

January Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	18^h 43.5^m	–23° 04′	—	–26.8	32′ 32″	—	0.983
	31	20^h 52.0^m	–17° 36′	—	–26.8	32′ 28″	—	0.985
Mercury	1	17^h 32.1^m	–23° 09′	16° Mo	–0.4	5.2″	89%	1.296
	11	18^h 37.8^m	–24° 10′	12° Mo	–0.6	4.8″	95%	1.386
	21	19^h 46.7^m	–23° 00′	6° Mo	–0.9	4.7″	99%	1.422
	31	20^h 56.9^m	–19° 25′	2° Ev	–1.5	4.8″	100%	1.403
Venus	1	15^h 27.0^m	–15° 15′	47° Mo	–4.6	26.3″	47%	0.635
	11	16^h 08.2^m	–17° 31′	47° Mo	–4.5	23.5″	53%	0.711
	21	16^h 52.7^m	–19° 25′	46° Mo	–4.4	21.2″	57%	0.786
	31	17^h 39.8^m	–20° 43′	45° Mo	–4.3	19.4″	62%	0.861
Mars	1	23^h 59.3^m	–0° 24′	80° Ev	+0.5	7.4″	87%	1.261
	16	0^h 36.0^m	+3° 54′	75° Ev	+0.7	6.7″	88%	1.389
	31	1^h 13.3^m	+8° 03′	69° Ev	+0.9	6.2″	89%	1.518
Jupiter	1	16^h 40.3^m	–21° 32′	28° Mo	–1.8	31.8″	100%	6.194
	31	17^h 05.2^m	–22° 13′	53° Mo	–1.9	33.6″	99%	5.872
Saturn	1	18^h 48.2^m	–22° 29′	1° Ev	+0.5	15.0″	100%	11.043
	31	19^h 03.1^m	–22° 11′	26° Mo	+0.6	15.2″	100%	10.935
Uranus	16	1^h 46.2^m	+10° 24′	93° Ev	+5.8	3.6″	100%	19.783
Neptune	16	23^h 03.2^m	–7° 07′	49° Ev	+7.9	2.2″	100%	30.576

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



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

The Many Directions of Winter

January offers ample opportunities for many celestial scenes.


Comet Tago-Sato-Kosaka

SKY & TELESCOPE ARCHIVE

How can you go out on a clear dark January evening and *not* look at Orion and his surrounding host of brilliant constellations? Sirius, the Pleiades, Orion's Belt, Betelgeuse and Rigel, Aldebaran and the Hyades, Pollux and Castor, the gleam in Orion's sword that is the Orion Nebula . . . all are sights that immediately vie for your rapt attention. This mere eighth or so of the currently visible sky is like a cymbal crash of stellar splendor on a January evening.

But shouldn't we also listen to more subtle strains of "music" from other parts of the orchestra of the January evening sky? Let's mostly consider the state of the sky at just one time on January evenings: the time when the sky looks as it does on the all-sky map at the center of the magazine.

The Perseus-pinnacled sky. The Pleiades are just short of the meridian on our map, but the constellation figure whose extended foot points to the cluster is right at the zenith for viewers near latitude 40° north. I'm referring to one of the brightest of all constellations, one that's also the most important in the biggest and arguably richest myth in all the heavens.

This constellation, of course, is Perseus, "the hero" or "the champion." At the time of our sky map, Perseus is overhead and surrounded by all the other neighboring constellations that represent figures in his myth: Andromeda (his wife-to-be); Cassiopeia and Cepheus (eventually his mother-in-law and father-in-law); Pegasus (the winged horse he released from captivity); and Cetus (officially the Whale but anciently known as a sea monster of unspecified type that Perseus slew to rescue Andromeda). And Beta (β) Persei, the renowned variable star Algol, marks the severed head of Medusa, held by Perseus as he floats at the top of the sky.

Perseus encompasses several naked-eye star clusters, the Little Dumbbell Nebula (M76), the huge, elusive California Nebula (NGC 1499), and more. And at the time of our map — 8 p.m. local time in early January and dusk in late January — Perseus is at the very pinnacle of the sky.

Of course, not everyone wants to crane their neck or wrestle with their alt-azimuth mount at its most awkward position to study sights near the zenith. But at the very least it's grand to be aware that while Orion flames about halfway up the southeastern sky, Perseus's nest of brightness and interest sparkles directly over our heads.

Embers of summer in winter. If you don't want to look straight up on a January evening, how about looking towards the remnants of summer? Even in January, Cygnus, the Swan, can be observed in the early evening with its Northern Cross asterism standing upright on the horizon just south of northwest. And at the time of our map, summer's brilliant blue-white Vega is setting almost exactly in the northwest while winter's brilliant blue-white Sirius is low almost in the due southeast. These two stars aren't far from the exact forward viewpoint (Vega) and exact backward viewpoint (Sirius) out of our galaxy-orbiting solar system.

Every first-magnitude star in one night? The sky visible on a January evening at the time of our map is interesting enough. But if we gaze, at least off and on, through the entirety of a long January night we can survey several seasons' worth of sights. Can you even observe every first-magnitude (and brighter) star visible from around 40° north in the course of one of these nights? At dawn, Antares is certainly visible (near Venus and Jupiter this month). But can you catch Altair at dusk or dawn? I know Fomalhaut is visible at some January dusks because I saw my first comet, with both telescope and naked eye, below Fomalhaut in January 1970. That object was Comet Tago-Sato-Kosaka, the precursor of spring 1970's much greater Comet Bennett.

■ Contributing Editor **FRED SCHAAF** is the author of 13 books, including *The Brightest Stars*.

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

Evening Eclipse and Morning Planets

There's a lot happening in the skies during this first month of 2019.

The New Year opens with an unusual and exciting month for observers of the Sun, Moon, and planets. A total eclipse of the Moon is visible in the convenient evening hours of January 20th for the Americas and the pre-dawn hours of January 21st for Europe and Africa. Mars is the sole bright planet in the evening sky. But the opening days of the year begin with the crescent Moon walking down a stair of dawn planets: first, Venus (near greatest elongation); next, Jupiter; last, Mercury. By the second half of January ringed Saturn appears, replacing Mercury low in morning twilight — and Jupiter lofts up for a close meeting with Venus, not far from Antares. The amazing month ends with the waning lunar crescent returning to pass Jupiter and have a spectacular close conjunction with Venus.

DUSK AND EVENING

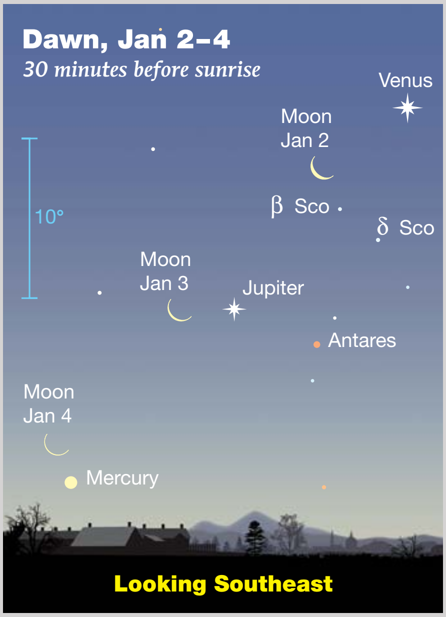
Mars, which spends the month crossing Pisces, shines about halfway up the southwestern sky a few hours after sunset. Its brightness fades from magnitude +0.5 to +0.9 in January, while its disk shrinks from almost 7½″ to little more than 6″ wide. Mars sets around 11:20 p.m. on January 1st and only about 20 minutes earlier on January 31st. Preceding Mars in the nightly journey of the stars and planets across the heavens is **Neptune**, still in Aquarius. Trailing Mars during the night is **Uranus**, in extreme eastern Pisces. Finder charts for these distant ice giants appear in the September 2018 issue, pages 48–49.

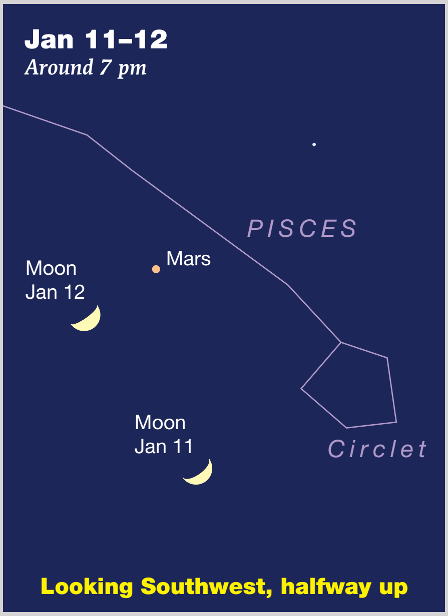
PRE-DAWN

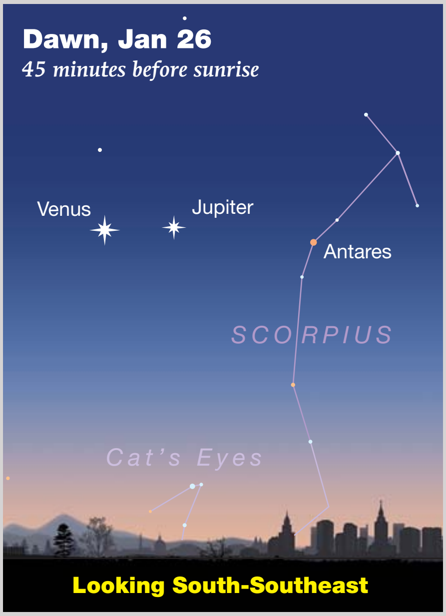
Venus rises a little after 3:30 a.m. at year's beginning, more than four hours after the setting of Mars leaves the sky devoid of bright planets. The time of Venus-rise on New Year's Day is more than 3½ hours before sunup (for observers around latitude 40° north). That's an impressively large interval, and indeed Venus is at its greatest western elongation of 47° from the Sun on January 6th. However, the sunrise altitude of Venus decreases significantly from nearly 31° to 23° during January.

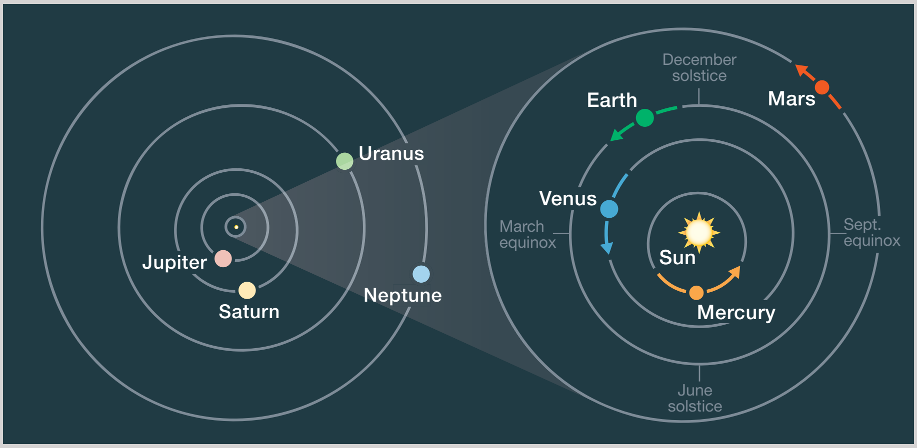
Venus also dims in January, from –4.6 to –4.3. But the planet is still spectacular, especially in its close pairings with the Moon this month. As exciting, and more long-lasting, is Venus's pairing with another object — the second-brightest planet, Jupiter.

Jupiter starts the month and year rising after 5 a.m., about an hour and a half after Venus. Jupiter brightens from magnitude –1.8 to –1.9 in January, but what's really notable is how









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

Venus appears to plummet past Jupiter, from Libra down through Scorpius. Around January 12th, Venus passes by Scorpius's head and forms the peak of a tall triangle with Jupiter and Antares as the base corners of the triangle. Then, around January 19th, Venus is 3¾° above Jupiter, with Antares at just about the same altitude as Jupiter, forming a squat right triangle.

Venus and Jupiter are a minimum of 2½° apart on January 22nd. Telescopes then show Venus's dazzlingly bright form as 21″ across and about 60% lit. Jupiter's much duller but fully lit disk is 33″ wide.

On January 26th viewers at mid-northern latitudes can see Venus, Jupiter, and Antares form a horizontal line, with a little more than 4° separating the two planets and twice again that distance between Jupiter and the star. By January 31st, the gap between Venus and Jupiter has widened to 9½°, with Jupiter to the upper right of Venus, rising almost half an hour before Venus.

DAWN

Mercury glimmers around 5½° high in the southeast a mere 30 minutes before sunrise on the opening days of 2019. It then shines as the bottom-left planet in a long diagonal line equally spaced with Venus and Jupiter. Mercury brightens, from magnitude –0.4 to –0.7, in the first half of January but is simply too low in strong twilight glow to be seen after the 3rd or 4th. Mercury reaches superior conjunction with the Sun on the night of January 29–30.

Saturn is in conjunction with the Sun on January 2nd so isn't visible when it passes less than 2° from Mercury on January 13th. The ringed planet emerges into visibility in morning twilight around the third week of the month. The +0.6-magnitude world has increased its lead on the Sun to more than 1½ hours by month's end.

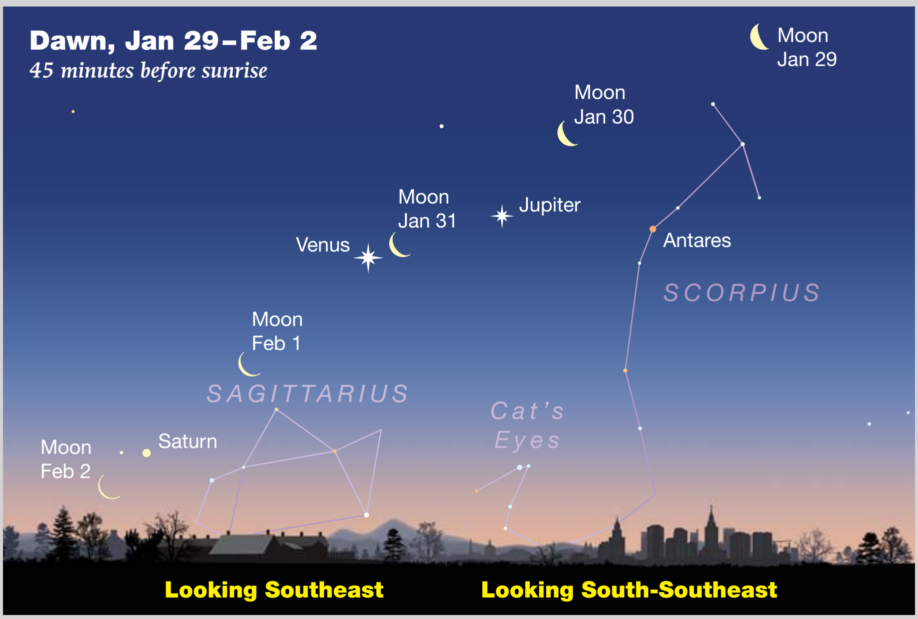
EARTH, SUN, AND MOON

Earth comes to perihelion, a minimum of 0.98 a.u. (specifically, 147,099,761 km) from the Sun, at 5^h UT on January 3rd.

The Sun is partially eclipsed for observers in parts of eastern Asia, Micronesia, and the Aleutian Islands on January 5–6 (see page 50 for details).

The Moon is totally eclipsed on the night of January 20–21; for full information, see page 18. The waning lunar crescent is 5° upper right of Venus on January 1st and slightly farther, around 7°, lower left the next morning. The slim lunar sliver is 3° to 4° left of Jupiter on January 3rd and around 3° above a low Mercury a mere half-hour before sunrise on January 4th. The thick waxing crescent Moon is some 5° lower left of Mars on January 12th. The waning Moon crescent is 6° to 7° upper right of Jupiter on January 30th and the next morning between Jupiter and Venus, around 2° to the right of Venus.

▼ 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.



■ Contributing Editor FRED SCHAAF was six years old when he saw his first lunar eclipse (one that at the time was officially listed as total) in August 1961.

The Odd Quads

We're still learning the secrets of this young and mysterious meteor shower.

Astrophotographer Frankie Lucena caught this rare view of a Quadrantid meteor on January 2, 2003, just a few months before Peter Jenniskens identified the asteroid 2003 EH_1 as the probable parent body for the shower. It's unusual for Quadrantids to travel so far south, but this one was spotted streaming across the top of Crux, the Southern Cross. To the right of Crux is Eta Carinae. The meteor was captured with a 30-second exposure taken with a film camera at ISO 800 and a 50-mm lens at f/1.8.

The January meteor shower known as the Quadrantids is an anomaly among major meteor events. It's a young shower — sightings of its component meteoroids were first noted in January 1835, quite late compared to the Lyrids, for instance, which have been on record since at least 687 BC. The Quadrantid shower is also the shortest of the major showers, with a peak lasting only four hours or so. This short viewing window suggests Earth passes through a narrow stream that's no more than 500 years old. Due to the relatively young age of the stream, the dust and particles haven't had much time to disperse into a broader lane of dust.

As recently as 15 years ago, scientists could only speculate as to the origin of the Quadrantids. There was no obvious parent for the debris stream, making it the only major shower without a known source. Various models offered various possibilities, of which two stood out as the most reasonable: a stream left by Comet 96P/Machholz 1 between 2,000 and 5,000 years ago, and one left by Comet C/1490 Y1 as many as 5,000 years ago. Or perhaps both. The shower could have developed from a wide complex of dust trails left by two or more passing comets, with the streams merging only in the last 150–200 years.

It wasn't until 2003, with the discovery of the near-Earth asteroid 2003 EH$_1$, that the shower's parentage was revealed. Detected during the Lowell Observatory Near-Earth Object Search (LONEOS), 2003 EH$_1$ follows an orbit much like the one proposed for the Quadrantids and is likely an extinct Jupiter-family comet or the remnant of a disintegrated comet nucleus. Peter Jenniskens (NASA Ames, now at the SETI Institute) suspects that the large total mass of the shower (10^{13} kg, which is much higher than the 10^{10} kg expected to be produced by a comet during a single return) could be explained by the recent breakup of a larger active body. The massive remnants may have acted like small comets soon after the breakup, feeding the fresh stream, but they're now extinct, or at least dormant.

In 2015, Toshihiro Kasuga (Chiba Institute of Technology, now at National Astronomical Observatory of Japan) and David Jewitt (Kitt Peak National Observatory/UCLA) confirmed that 2003 EH$_1$ showed no ongoing mass loss, and that the total mass loss of the object over the course of the 200– to 500-year age of the shower is too small to produce the reported 10^{13} kg stream mass. They detected no sublimation of ice, nor did it appear that 2003 EH$_1$ released dust due to heat fracture when it's closest to the Sun (as does the rock comet 3200 Phaethon). Subsequently, they suggested that another source has fed the stream, or that 2003 EH$_1$ isn't completely extinct, but dormant. It only episodically releases material.

This somewhat mysterious origin seems appropriate for such a poorly observed shower. According to the International Meteor Organization (IMO), only 32 observers submitted data for the 2018 Quadrantids; compare that to the 203 individuals who filed observational data for the 2018 Perseids. This low participation can probably be explained by the shower's short peak, a poorly placed radiant, and the potential for the peak to fall during bad weather in northern climes.

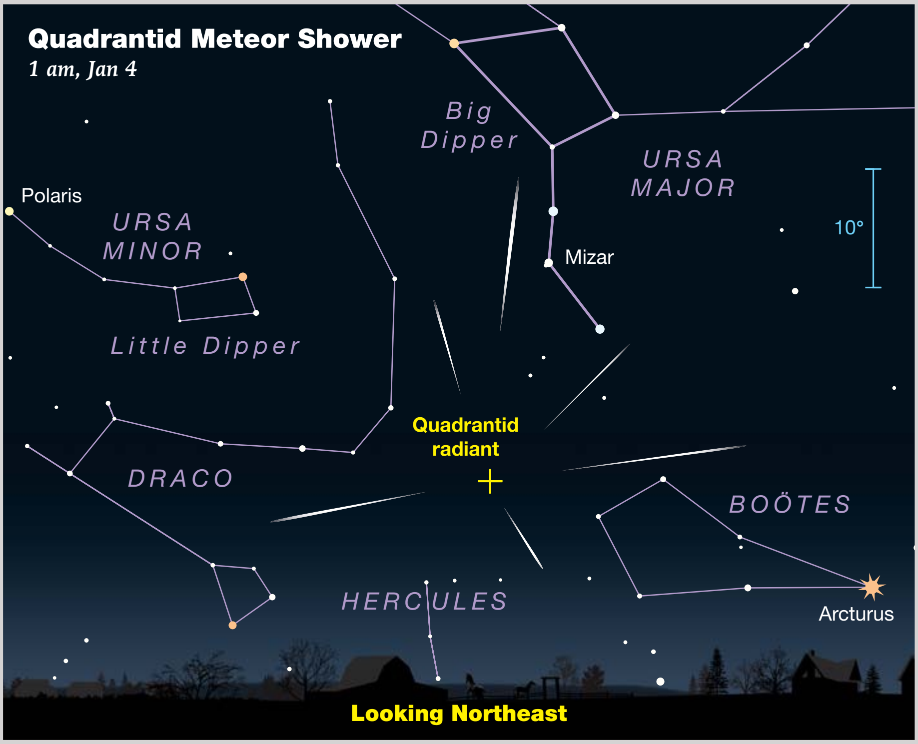
This year offers a mix of conditions for the Quadrantids. New Moon falls on January 6th, so won't interfere with observations. But maximum is predicted for 02^h UT January 4th (9 p.m. EST January 3rd), when the radiant in northern Boötes is only just peeking above the horizon in the north-northeast. The radiant climbs higher throughout the evening, but by the time it's decently placed, around 1 a.m. local time, the shower is wrapping up. The weather during maximum? That's anybody's guess.

The Quadrantid stream appears well-sorted by mass. A small peak for fainter objects (radio or telescopic meteors) may occur up to 14 hours before visual and photographic maximum, when anywhere between 60 and 200 meteoroids could be detected per hour. On a few returns, the peak for radio meteors occurred 9 to 12 hours after visual. The IMO encourages observers to watch through the predicted period of maximum as well as at the outer range of the shower, so if you are clouded out at actual peak, try again 6 or 8 hours later. For more detailed instructions regarding recording and reporting, visit the IMO Visual Observations page (**https://is.gd/IMOvisual**).

The Quadrantids are occasionally referred to as the Boötids, as the shower's radiant lies in the modern constellation of Boötes. When the shower was first witnessed in 1835, however, that part of the sky still belonged to Quadrans Muralis, the Mural Quadrant, a constellation created by the French astronomer Jérôme Lalande in 1795.

Shower Sources

Shower	Parent Object
Quadrantids	2003 EH$_1$
Lyrids	Comet Thatcher (C/1861 G1)
Eta Aquariids	Comet 1P/Halley
Delta Aquariids	Comet 96P/Machholz
Perseids	Comet 109P/Swift-Tuttle
Orionids	Comet 1P/Halley
Leonids	Comet 55P/Tempel-Tuttle
Geminids	3200 Phaethon



▶ By 1 a.m. local time the Quadrantid shower's radiant in northern Boötes is well above the horizon for observers at mid-northern latitudes.

Shadow Play

THE SUN, MOON, AND EARTH line up in space to create two eclipse events this month (as seen from Earth). The first, on January 5–6, is a partial solar eclipse, when the Moon passes between Earth and Sun and appears to take a deep "bite" out of our star. Wear proper eye protection or use a solar projector to view this event. Visibility is best for East Asia, though the Sun is low at that time of year. For Vladivostok the eclipse begins at 9:38 a.m. local time, with the Sun just 7° high at the moment the Moon makes "first contact" with it. Eclipse maximum occurs at 10:57 a.m. As the Moon says its final farewell at 12:24 p.m., the Sun has risen only 23° above the horizon.

Visibility in North America is limited to parts of Alaska. In Adak, the event begins on January 5th at 3:01 p.m. HAST, reaches eclipse maximum at 4:25 p.m., and concludes at 5:42 p.m. In Unalaska, first contact occurs at 4:16 p.m. with the deepest point of the eclipse reached at 5:33 p.m. The Sun sets at 6:00 p.m., so the final stage of the eclipse is lost to view. (The eclipse ends at 6:43 p.m. local time.)

This partial solar eclipse is followed by a total lunar eclipse on January 21, 2019. Totality is visible throughout

▲ A total solar eclipse occurred on March 20, 2015. It was viewed through clouds as a partial eclipse from Kavala, Greece.

North and South America, as well as for some of Europe and Africa. Partial stages are visible in large parts of the world. Central, South, and Southeast Asia, and Australia miss out on this one. See page 18 for more details.

Minima of Algol

Dec.	UT	Jan.	UT
3	2:53	3	15:53
5	23:42	6	12:42
8	20:31	9	9:32
11	17:20	12	6:21
14	14:09	15	3:10
17	10:58	17	23:59
20	7:47	20	20:49
23	4:36	23	17:38
26	1:26	26	14:27
28	22:15	29	11:17
31	19:04		

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.com/algol**.

Action at Jupiter

JUPITER RISES JUST AFTER 5 a.m. local standard time at the beginning of January and reaches an altitude of about 15° before it disappears in brightening twilight. In practical terms, the window of observability is only about an hour long, and that's assuming you have an open horizon to the southeast. Observing conditions improve with each passing morning, however. By the end of January, the observing window is closer to two hours long, and Jupiter stands around 22° high in the southeast when it's lost to sunlight.

Any telescope shows the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them at any date and time.

The January interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter is at its highest in the early morning hours.

Here are the times, in Universal Time, when the Great Red Spot should cross Jupiter's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.)

Dec. 1, 2:26, 12:22, 22:18; **2,** 8:13, 18:09; **3,** 4:05, 14:01, 23:57; **4,** 9:53, 19:48; **5,** 5:44, 15:40; **6,** 1:36, 11:32, 21:27; **7,** 7:23, 17:19; **8,** 3:15, 13:11, 23:07; **9,** 9:02, 18:58; **10,** 4:54, 14:50; **11,** 0:46, 10:41, 20:37; **12,** 6:33, 16:29; **13,** 2:25, 12:21, 22:16; **14,** 8:12, 18:08; **15,** 4:04, 14:00, 23:55; **16,** 9:51, 19:47; **17,** 5:43, 15:39; **18,** 1:34, 11:30, 21:26; **19,** 7:22, 17:18; **20,** 3:13, 13:09, 23:05; **21,** 9:01, 18:57; **22,** 4:53, 14:48; **23,** 0:44, 10:40, 20:36; **24,** 6:32, 16:27; **25,** 2:23, 12:19, 22:15; **26,** 8:11, 18:06; **27,** 4:02, 13:58, 23:54; **28,** 9:50, 19:45; **29,** 5:41, 15:37; **30,** 1:33, 11:29, 21:24; **31,** 7:20, 17:16.

Jan. 1, 3:12, 13:07, 23:03; **2,** 8:59, 18:55; **3,** 4:51, 14:46; **4,** 0:42, 10:38, 20:34; **5,** 6:30, 16:25; **6,** 2:21, 12:17, 22:13; **7,** 8:09, 18:04; **8,** 4:00, 13:56, 23:52; **9,** 9:47, 19:43; **10,** 5:39, 15:35; **11,** 1:31, 11:26, 21:22; **12,** 7:18, 17:14; **13,** 3:09, 13:05, 23:01; **14,** 8:57, 18:53; **15,** 4:48, 14:44; **16,** 0:40, 10:36, 20:31;

MAVROUDAKIS FOTIS PHOTOGRAPHY / MOMENT / GETTY IMAGES

17, 6:27, 16:23; **18,** 2:19, 12:15, 22:10; **19,** 8:06, 18:02; **20,** 3:58, 13:53, 23:49; **21,** 9:45, 19:41; **22,** 5:36, 15:32; **23,** 1:28, 11:24, 21:20; **24,** 7:15, 17:11; **25,** 3:07, 13:03, 22:58; **26,** 8:54, 18:50; **27,** 4:46, 14:41; **28,** 0:37, 10:33, 20:29; **29,** 6:24, 16:20; **30,** 2:16, 12:12, 22:07; **31,** 8:03, 17:59.

These times assume that the spot will be centered at System II longitude 294°. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 294° and 1⅔ minutes later for each degree more than 294°.

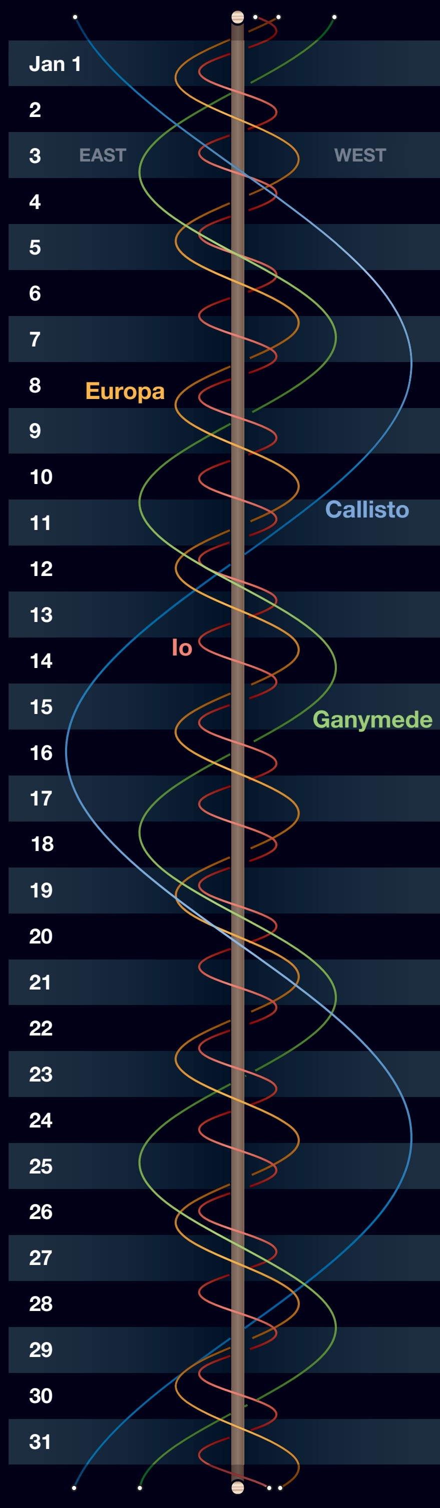
Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter increases the contrast and visibility of Jupiter's reddish and brownish markings.

Phenomena of Jupiter's Moons, January 2019

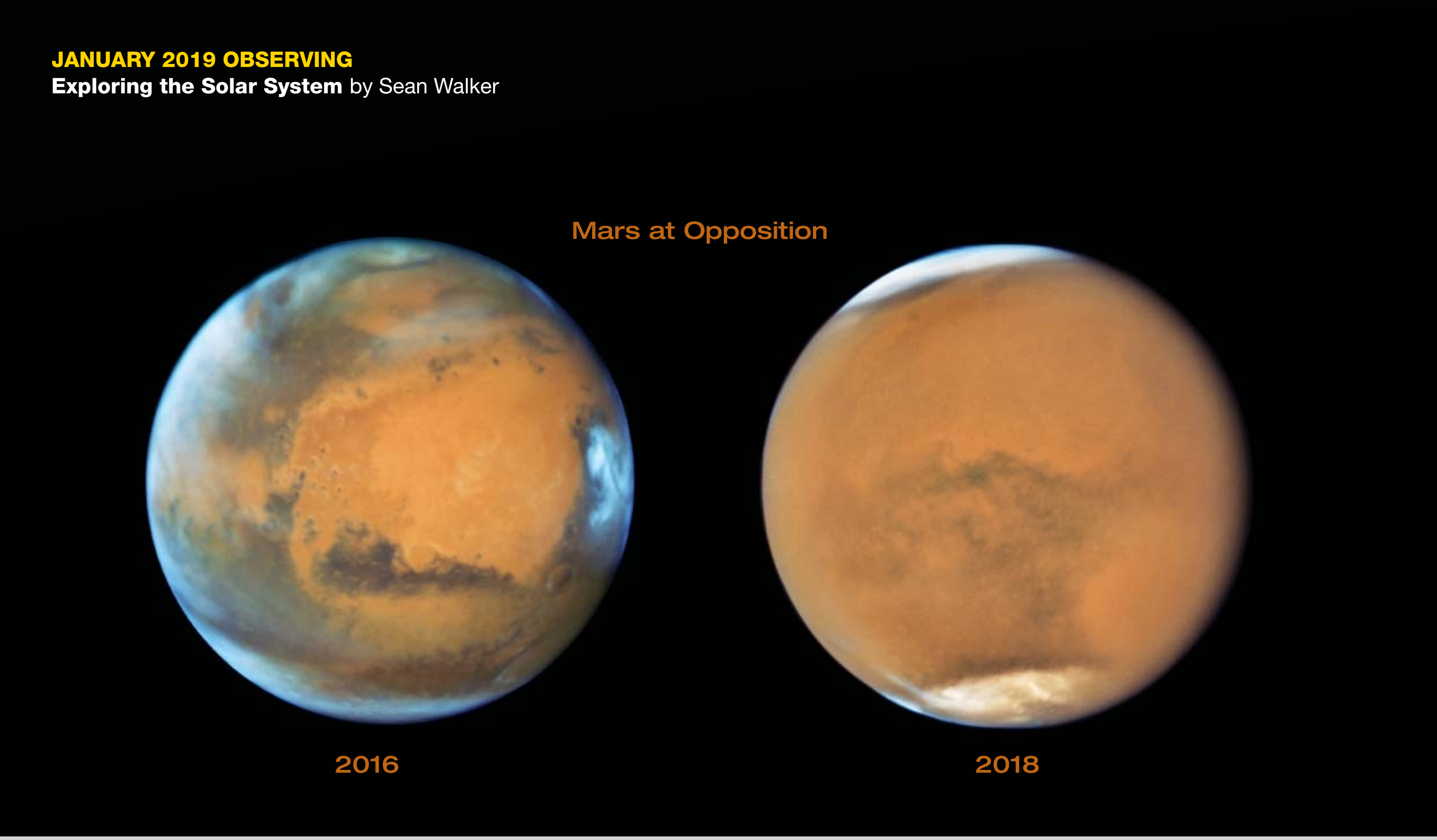
Jan. 1	4:08	I.Ec.D
	6:55	I.Oc.R
	22:37	III.Ec.D
Jan. 2	0:36	III.Ec.R
	1:01	III.Oc.D
	1:16	I.Sh.I
	1:52	I.Tr.I
	3:09	III.Oc.R
	3:27	I.Sh.E
	4:04	I.Tr.E
	14:43	II.Sh.I
	15:56	II.Tr.I
	17:03	II.Sh.E
	18:18	II.Tr.E
	22:36	I.Ec.D
Jan. 3	1:25	I.Oc.R
	19:45	I.Sh.I
	20:23	I.Tr.I
	21:55	I.Sh.E
	22:34	I.Tr.E
Jan.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

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

Jupiter's Moons



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



A Dusty Apparition

Mars was bustling with activity during the close opposition of 2018.

▲ Mars normally sports high-contrast albedo features and white clouds near opposition (left), but the global dust storm that erupted in late May 2018 (right) obscured many of the familiar features around Sinus Meridiani, seen at center in both of these Hubble Space Telescope images.

NASA / ESA / STSCI

Mars continues to grace the evening skies, long past its perihelic opposition last July. Although the Red Planet has shrunk to a diminutive 7.4 arcseconds diameter, at the time of this writing in mid-October it's still showing off lots of detail in the eyepiece. That wasn't the case in the months before its closest approach in 15 years. As the planet was poised to put on a great show for observers at opposition with a respectable disk size of 24.3 arcseconds, its atmosphere had other plans, at least for a while.

When the planet was transitioning from a morning to an evening target in the last days of May, observers spotted a yellowish dust storm over the dark albedo feature Mare Acidalium. While Martian dust storms are not an uncommon occurrence, they most often tend to kick up during the summer months in the planet's Southern Hemisphere. At the time, the planet had just experienced equinox days before, with the north entering autumn while its south began its long spring. Seasons on Mars last roughly twice as long as we experience them here on Earth.

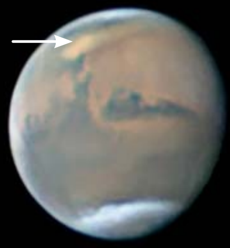
Within days, the storm moved south and spread out, obscuring most of Sinus Meridiani, Oxia Palus, and Margaritifer Sinus. Dust storms are a double-edged sword, at least from an observer's perspective. While it's exciting to spot these unpredictable changes in a telescope, they can often grow strong enough to encircle the entire planet, rendering it a featureless, salmon-hued ball. But on the positive side, these storms paradoxically can make hard-to-discern features easily visible for a short time. For example, as the storm poured into the great canyon system of Valles Marineris, it rendered this normally invisible feature cutting across Aurorae Sinus visible in even small telescopes. Amateurs with telescope apertures as small as 6 inches were able to clearly resolve the dust-choked valleys as conditions permitted in early June.

For several weeks, the storm grew to global proportions, completely encircling the planet in the north, while some albedo features remained visible in the south, particularly in the region of Mare Cimmerium. Glimpses of Syrtis Major were had throughout late June and into early July. The South Polar Cap, hidden from view by its seasonal polar hood of fog and clouds in May, became visible by the start of July, though it too was streaked by dust, producing a dimmed appearance compared to its usual brilliant white. The Tharsis volcanoes, including Olympus Mons, each stood out as readily discernible dark spots from the monochromatic surroundings below them.

By early July, most observers had written off the planet's 2018 opposition as a bust, steeling themselves for disappointing views of a bright but bland, unadorned ball. But fortunately, things quickly began to turn around.

In mid-July, reports of a clearing atmosphere began spreading throughout the observing community. While the planet displayed a distinctly reduced contrast overall, familiar albedo features, including Solis Lacus and the small albedo extensions from Mare Cimmerium known as Gomer Sinus, were readily visible. Planetary imager Damian Peach noted "a dark albedo feature across Phasis-Daedalia [part of Solis Lacus] which was not visible before the storm (though has appeared following dust events in the past)." Both Peach and French amateur Christophe Pellier spotted several small storms within Solis Lacus in the last week of the month as opposition approached, though fortunately none of these lasted more than a day or two.

Following opposition on July 27th and closest approach a few days later, the Red Planet's atmosphere slowly continued to clear, producing detailed (though low-contrast) views for dedicated and casual planetary observers alike. Additional subtle changes of albedo features have been observed, but none as drastic as those that occurred following the great dust storm of 1956, which erased the large, dark feature known as Thoth-Nepenthes (*S&T:* March 2014, p. 54).



◀ This image shows a small but bright dust storm captured on the morning of May 31st by New England amateur John Boudreau using a 14¼-inch Dall-Kirkham reflector.

◀ Dust fills the gigantic canyon system Valles Marineris on the morning of June 13th, enabling Darren Ellemor to record this enigmatic feature with just a 6-inch Schmidt-Cassegrain.

◀ By the time of opposition, the dust was noticeably settling out of the Martian atmosphere. This produced low-contrast but recognizable albedo features. This image by Anthony Wesley is very similar to the view at the eyepiece.

◀ In early August, observers began to recognize changes in the planet's albedo features. The dark marking in the Solis Lacus region in this image is a feature sometimes seen after a large dust storm, as noted in the text.

BOTTOM IMAGE OF MARS: DAMIAN PEACH / CHILESCOPE

Some minor global changes have been recorded following the storm. A general reduction in contrast implies that some light dust remains suspended in the upper atmosphere. Additionally, the thin white clouds of water vapor that treated observers each apparition over the past 15 years have been completely absent so far in the latter half of 2018.

The storm was unusual in several respects compared to events of the past. As mentioned earlier, it started in a region that, while known for producing small regional storms throughout the past decade, had not generated a storm of this magnitude to date. Additionally, the storm grew quickly and spread mostly across the northern hemisphere but never completely obscured the entire planet. While classified as a global dust storm, it didn't become quite as opaque as the last big storm that scuttled the tail-end of the 2001 apparition.

And just a little more than two months after erupting into view, it was mostly gone. The planet seemed to give observers a reprieve, with good views of major albedo markings returning just following opposition.

Mars is one of the most interesting planets from an observational standpoint. As the most Earthlike planet, it displays weather similar to ours. And it's the only terrestrial planet besides Earth on which amateurs can easily see the surface and recognize known features. For many of us, tracking the development of regional dust storms, for example, or watching for water vapor clouds along the planet's limb and clinging to the slopes of the Tharsis volcanoes makes the planet particularly attractive. So from that point of view, the 2018 apparition wasn't a complete bust for observers — in fact, it stands out as one of the more exciting ones in recent memory.

■ Associate Editor **SEAN WALKER** observes the planets using a 12½-inch f/5 Newtonian reflector.

Meridian Observing

Viewing is at its best when an object is at its highest in the night sky.

▲ NGC 869 and NGC 884, together known as the Double Cluster, are approximately the same age (14 million years old) and lie about the same distance (7,500 light-years) from Earth. These measurements suggest that the two clusters formed in the same stellar nursery.

The celestial meridian is an imaginary line in the sky that runs due north to due south and passes through a point straight overhead. For those of us in the Northern Hemisphere, the wonders of the night sky are best witnessed when they traverse the meridian between Polaris and the southern horizon. That's when they're highest in our sky and least diminished by Earth's atmosphere. This month's deep-sky tour will showcase marvels berthed near the meridian on the all-sky chart at the center of this magazine.

Our first stop is the outstanding Double Cluster in Perseus, **NGC 869** and **NGC 884**. The pair is easily seen as a gauzy smudge to the unaided eye from my semirural home. It was likely familiar to the ancients, but the earliest known record comes from the Greek astronomer Hipparchus of Nicaea, who lived during the second century BC.

The Double Cluster is breathtaking through my 130-mm refractor at 48×. NGC 869's central concentration holds about 25 stars, including a U-shaped group of five stars that looks like a big smile with a bright nose star west-northwest. At least 60 additional suns plump out the cluster. NGC 884 is less concentrated with only 10 or so stars clumped in the core and about 70 stars strewn around them. Together the clusters span nearly 1°, their edges blending gradually into the background sky.

Most of the cluster stars gleam white to blue-white, but some strikingly red-orange stars adorn the area, all variables. One of these vermillion jewels (BU Per) hovers north of NGC 869, and another (AD Per) rests in the southern reaches of the pair, about halfway between the clusters. FZ Per colors NGC 884's western outskirts, while V0439 and V0403 Per shine in the east-northeast. The smoldering ember RS Per burns east-southeast of the sparse core.

The Double Cluster nearly bridges the field through my 10-inch scope at 68×, yet the view is astounding, with each cluster flaunting more than 100 stars. NGC 869's smile and nose gain a pair of batlike ears to the north-northwest, the smiling bat covering about 3′.

Recent studies indicate the clusters are not merely a line-of-sight coincidence. According to a 2010 paper by Thayne Currie and colleagues in the *Astrophysical Journal Supplement Series*, these youthful clusters are approximately 14 million years old. Four different estimates loosely place NGC 869 in a realm 7,650 light-years away from us, but with NGC 884 systematically in the foreground by about 176 light-years.

▶ The light from the open cluster M34 takes about 1,500 years to reach Earth. M34 lies about halfway between the stars Alpha (α) and Beta (β) Persei.

Also in Perseus, **Messier 34** is an odd-looking open cluster through the 130-mm scope at 37×. The outer boundary looks boxy, but with a rounded southwestern corner. Bright stars near the middle of the northern and southern borders shine orange and deep yellow, respectively. There's a bizarre pattern of stars in the core, like a bug-eyed guy running in terror with his arms flung wide. His eyes blaze a bit northwest of the cluster's center, and his bent legs stretch southeastward. About 75 stars lodge within ½° of sky.

M34 was most likely discovered by Giovanni Battista Hodierna, as mentioned in the text of his 1654 *De Admirandis Coeli Characteribus* (On the Admirable

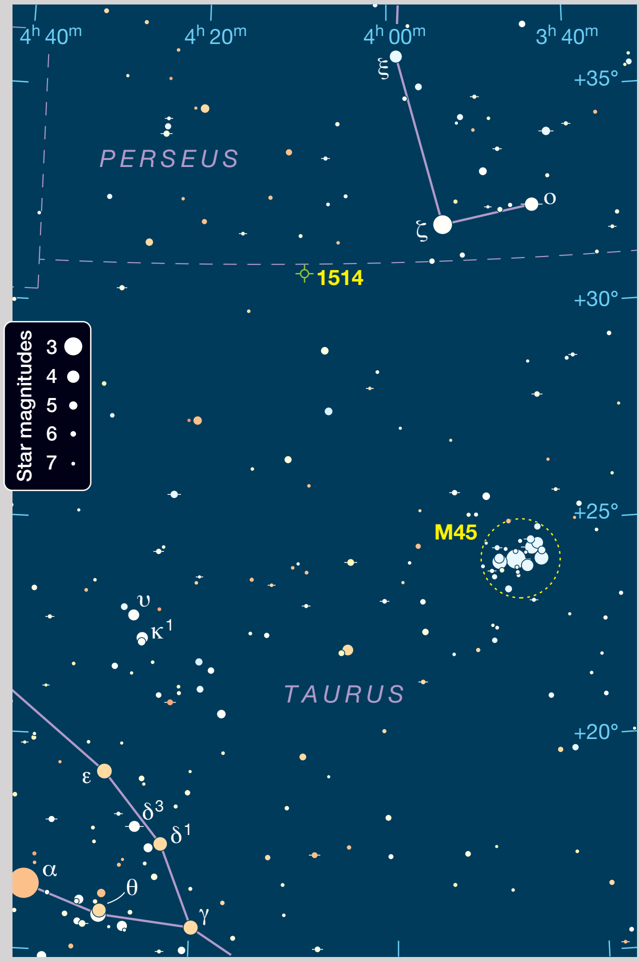
DOUBLE CLUSTER: STOCKTREK IMAGES / GETTY IMAGES; M34: SCOTT MACNEILL

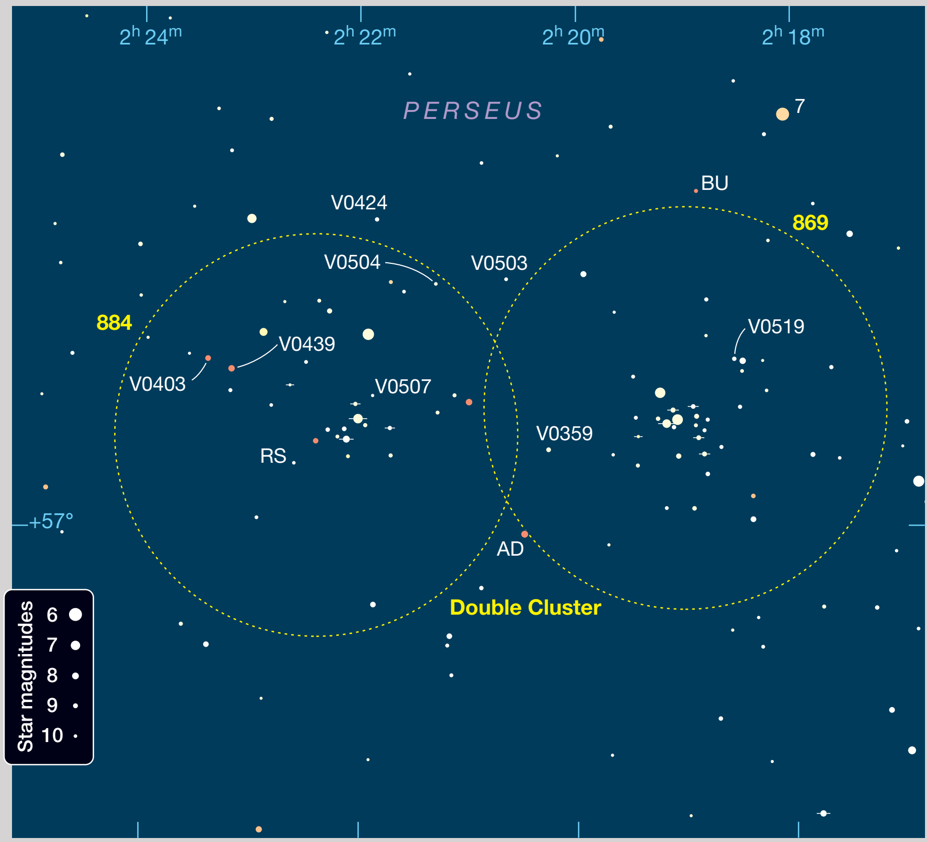
Objects of the Sky). This long-forgotten work was finally dragged back into the light of day by G. Foderà Serio and colleagues (*Journal for the History of Astronomy*, 1985). The authors considered the identification of M34 with the object in Hodierna's text tentative, but Fredi de Maria of ORSAPA claims doubt can be cast aside when taking into account an error Hodierna made at one place in his text.

Northward in Camelopardalis, the spiral galaxy **IC 342** is an intriguing target. Even though it's relatively nearby (around 11 million light-years) and its luminosity rivals our own galaxy, IC 342 exhibits low surface brightness because its face-on orientation smears its light over a large area of the sky, and because we view this attenuated light through the dusty plane of our own galaxy. Nonetheless, its apparent size makes it a viable target for small telescopes, since large dim objects are easier to perceive than small ones. A 30′-tall, M-shaped group of stars north of IC 342 makes the galaxy surprisingly easy to spot through the 130-mm refractor at 23×. A 9.9-magnitude star hovers near its northern edge and some fainter stars are superimposed. A magnification of 48× gives a better view, showing a small core with a brighter center ensconced in a 4′ wedge of four stars. The rest of the galaxy is a diffuse glow about 14′ across, accompanied by several stars huddled close to its edge. In the 10-inch scope at 88×, the galaxy's brightness is softly uneven in a pattern that suggests spiral arms unwinding clockwise, as shown in my sketch on page 56.

IC 342 is the dominant member of a small galaxy group that bears its name. It and the closely associated Maffei group form the IC 342/Maffei complex, one of the closest galaxy groups to our own. According to NGC/IC researcher Wolfgang Steinicke, Edward Emerson Barnard visually discovered this galaxy with Lick Observatory's 12-inch Clark refractor in 1890 and recorded it in the observatory's logbook.

Southward in Taurus, the **Pleiades** (Messier 45) are simply magnificent in the 130-mm scope at 23×, boasting 100 stars spread across 2°. Although about nine times as old as the Double Cluster, M45's brightest stars are also icy blue-white diamonds, arrayed in a miniature dipper shape. A few colored stars stand out from the crowd. Inside the dipper's bowl, the northwestern component of the double star **South 437** glows orange. The dogleg of stars south of Alcyone wears a few tinted stars. The one at the bend is pale yellow and the two southernmost shine gold. An orange, 6th-magnitude star sits well north of the cluster's main mass. The lovely Merope Nebula is clearly airbrushed on the sky, enfolding and





spreading southward from its namesake star. Contrary to what early sources claim, the tatters of nebulosity that swathe the Pleiades are not the dusty remains of their birth. Cluster and clouds journey different celestial pathways and weren't together when the Pleiades formed, but their chance meeting creates a sight of delicate beauty enjoyed from a neighborly distance of only 440 light-years.

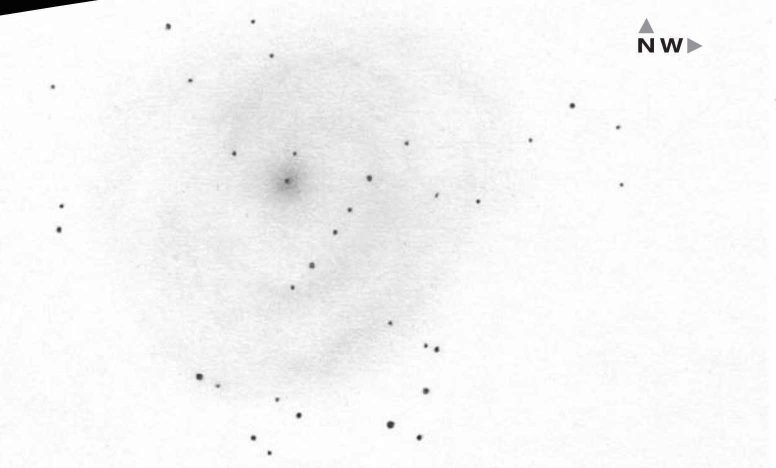
The discoverer of M45 was probably Urg, or somebody with a similar caveman-like appellation, since its brightest stars are quite noticeable to the unaided eye. It's a sad commentary on wasted light that this is no longer true everywhere. Although the Pleiades are commonly called the Seven Sisters, I could routinely see nine Pleiads on an average night when I moved to my upstate New York home 34 years ago. Now the norm is six stars.

In far northern Taurus, lesser-known **NGC 1514** is a remarkable planetary nebula. William Herschel discovered it in 1790, and his journal reads: "A most singular phenomenon. A star about 8m, with a faint luminous atmosphere of a circular form."

NGC 1514's 9th-magnitude, central binary star is handily located between two 8th-magnitude stars 17′ apart, and through the 130-mm scope at 23×, a very faint, sizable glow surrounds it. At 48× the nebula becomes prominent and dimmer in the center, leaving a wide annulus that's unevenly bright with the most luminous portions northwest and southeast. At 102× I can see that it fades in the northeast and south-southwest. A narrowband filter nicely increases contrast, and an O III filter helps even more.

The view is wonderfully complex through my 15-inch reflector at 216× with a narrowband filter. A fainter fringe coats the nebula, more than 2′ across and most prominent where it caps northwest and southeast bright patches. A fainter part of the fringe bulges outward from the south-southwestern dim area. This tantalizingly irregular cloudiness is the source of NGC 1514's popular name, the Crystal Ball Nebula. Look for your cosmic fortunes within.

■ Contributing Editor **SUE FRENCH** welcomes your comments at **scfrench@nycap.rr.com**.



In a 10-inch scope at 88×, IC 342 reveals a dusty suggestion of spiral arms. Look for the brighter galactic core and the distinctive line of stars running southeast-northwest across the galaxy's southwest quadrant.

▲ Sometimes called the "Hidden Galaxy," IC 342 lies in a dusty region near the galactic equator.

▼ The delicate nebulosity lit up by the Pleiades isn't physically associated with the open cluster. Rather, the dust cloud is following a trajectory that just happened to intersect with that of the star cluster.

Objects on High

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 869	Open cluster	3.6	29′	$2^h\ 19.1^m$	+57° 08′
NGC 884	Open cluster	3.7	29′	$2^h\ 22.3^m$	+57° 08′
Messier 34	Open cluster	5.2	35′	$2^h\ 42.1^m$	+42° 45′
IC 342	Spiral galaxy	8.4	21.4′ × 20.9′	$3^h\ 46.8^m$	+68° 06′
Pleiades	Open cluster	1.2	2°	$3^h\ 47.5^m$	+24° 06′
South 437	Double star	7.8, 7.7	39.5″	$3^h\ 46.3^m$	+24° 11′
NGC 1514	Planetary nebula	10.9	2.2′	$4^h\ 09.3^m$	+30° 47′

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.

PLEIADES: THOMAS JÄGER / CC BY-SA 4.0; SKETCH: SUE FRENCH; IC 342: T. A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE) / H. SCHWEIKER (WIYN) / NOAO / AURA / NSF

Fleming’s Semicircular Indentation

Can you see the Horsehead Nebula? It’s all about contrast and scale.

▲ **ICONIC NEBULA** The Horsehead Nebula is silhouetted against the brightest part of the emission nebula IC 434, which stretches horizontally (south) through the center of the photo from the bright star Alnitak (Zeta Orionis, left center), the easternmost star of Orion’s Belt. The naked-eye star Sigma Orionis is just out of view at top. The Flame Nebula, NGC 2024, is east of (below) Alnitak, and the much smaller NGC 2023 is due south (right) of the Flame and northeast (below and left) of the Horsehead.

MASIL IMAGING TEAM

I got pretty excited the first time I saw the Horsehead Nebula:

! Horsehead —

. . . I carefully pinpointed its exact location with Uranometria and at 53× centered the field in the eyepiece. Then with the 16-mm at 182× and the O III filter I looked — nothing. Rats. Let’s try the UHC — I looked — wait a minute, wait a minute — a little more averted vision, then after all these 23 years I saw it with my own eyes . . .

It was quite a bit larger (and fainter) than I expected (which is what most people say, I hear). It was more like a darker notch taken out of the sky rather than a silhouette against a bright nebula. Although that may sound rather contradictory, that was my impression. After looking at it in Chuck Dethloff’s 24-inch and an h-beta filter (which showed it very clearly) he loaned me the filter (which was a 2-inch) and I tried it on my 55-mm Plossl at 53× — wow! Very obvious now with the filter and the wider field of view.

This was the most satisfying view of anything I’ve ever looked at. This was magical.

These are my notes from the early morning of October 13, 1991, which was also the first night I had my then-new 20-inch f/5 Obsession Dobsonian under a dark and transparent sky. I was with a small group of observers at Indian Trail Spring in central Oregon, which the following year became the site of the Oregon Star Party. The entire night was astounding, but seeing the Horsehead for the first time positively blew me away.

Little did I know I didn’t need a 20-inch telescope to see the Horsehead Nebula, and that I could have seen it with my 8-inch scope decades earlier if I’d been under a good enough sky. But as a kid I didn’t even know the Horsehead was possible to see visually.

Today it’s one of the most famous deep-sky objects and after M42 probably the second most sought-after object in Orion. However, the Horsehead is nearly impossible to see from even mildly light-polluted skies, frustrating far too many observers for far too long. But it's surprisingly easy to see under truly dark and transparent conditions — and with a smaller telescope than you may imagine.

Discovery

Photographed in 1888 with an 8-inch astrograph at the Harvard College Observatory (HCO) in Cambridge, Massachusetts, the discovery plate, B2312, was examined by Williamina Fleming of the HCO, who published her description of the photo in 1890. In Volume 18 of the *Annals of the Harvard College Observatory*, she mentioned a "semicircular indentation" that we now call the Horsehead Nebula:

> *A large nebulosity extending nearly south from ζ Orionis for about 60′. More intense and well marked on the following side, with a semicircular indentation 5′ in diameter 30′ of ζ.*

Although the discovery was initially credited to the HCO's Director Edward Pickering in the 1895 edition of the *Index Catalog* (IC), in Volume 60 of its *Annals* in 1908 the HCO correctly listed Fleming as discoverer of the Horsehead Nebula. The nebula was cataloged as **B33** by E. E. Barnard in 1919. The "large nebulosity," now known as **IC 434**, was originally discovered by William Herschel in 1786.

Visual Detection

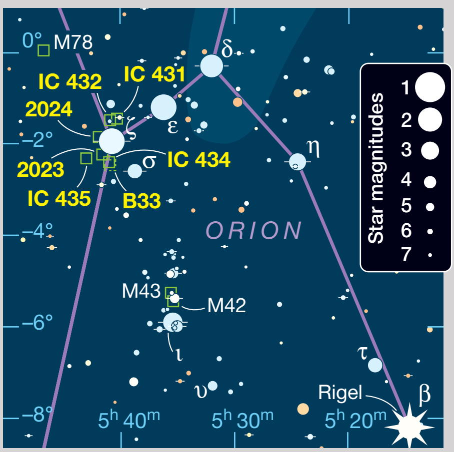
IC 434 provides the slightly brighter background against which the Horsehead is silhouetted. Without this background the Horsehead would be invisible to visual observers, so it's IC 434 that's crucial to detect — if you can't see IC 434 you won't see the Horsehead.

An important tool for visually observing IC 434 is a hydrogen-beta nebula filter. Sometimes referred to as the "Horsehead Filter," it increases the contrast between IC 434, the background sky, and the Horsehead. If you have one, use it. If you don't, get one. It's useful on more than just the Horsehead, of course, but its nickname is deserved because it can make this famously difficult object a lot easier to see.

Although I was able to detect the Horsehead using an Ultra-High Contrast filter with my 20-inch, borrowing Chuck's hydrogen-beta filter increased contrast immensely and produced a *much* more satisfying image. On the other hand, if you're ever under a pristine dark sky with Orion near the meridian, try to see the Horsehead without a filter and you may be pleasantly surprised. On these rare nights I've thought it looked like a knight, the chess piece.

If you've never seen the Horsehead visually, there are two confounding factors to overcome. The first is to get yourself under a truly dark and transparent sky. Without a quality dark sky you have almost no chance to see the Horsehead visually no matter how large or fine a telescope you're looking through. Even the hydrogen-beta filter won't help much.

The second factor is expectation, and being aware of this is just as important as the observing conditions. We've all seen wide-field photographs of the Horsehead and its environs (like those in this article) showing the Horsehead as a rather small object in relation to its spectacular surroundings. Because of photos like these, there's a good chance you'll expect the Horsehead to appear smaller in your eyepiece than it actually appears, and to have more contrast with its background. If so, your eye might skip over its much larger apparent size and subtle contrast.



CENTER FOR ASTROPHYSICS / HARVARD & SMITHSONIAN

▲**THE HORSE'S HEAD APPEARS** A cropped scan of plate B2312, the discovery image of the Horsehead Nebula (at center) from the Harvard College Observatory, has also had the colors reversed for better contrast. Taken with the 8-inch Bache doublet refractor in 1888, this plate was examined by Williamina Fleming in 1890 when she discovered the Horsehead Nebula. The Horsehead is included in E. E. Barnard's 1919 catalog of dark nebulae as B33. We now know the Horsehead is the closest nebula pillar sculpted by photoionization, and that protostars are forming within it.

To calibrate your expectations, the Horsehead is approximately the same apparent size as M27, the Dumbbell Nebula, and has even less contrast than the Pillars of Creation in M16.

A big telescope isn't required to see the Horsehead. I've been able to see it quite well in scopes down to a 4.25-inch Newtonian from the unspoiled skies of Steens Mountain in southeast Oregon, illustrating that a top-notch sky is more important than the size of the telescope.

Details

In her plate notes, Williamina Fleming mentioned that IC 434 is "more intense and well marked on the following (east) side," but visually it doesn't have a sharp eastern edge, even though it does fade more gradually westward. The sharpest boundary is created by the Horsehead Nebula itself, which helps tremendously with its detectability. Even so, on most nights the Horsehead will appear as a dark, fuzzy-edged scoop into IC 434 that's only slightly darker than its surroundings. IC 434 is quite faint even with the help of a hydrogen-beta filter.

◀ THE HORSE'S HEAD SKETCHED The author's drawing of the Horsehead Nebula and its surroundings combined many fields of view to produce this composite sketch. A little more than 4.5 hours of sketching time over several nights using a 28-inch f/4 Newtonian went into this drawing, which is based on views using magnifications of 131× to 253× and a 1990s-era Lumicon hydrogen-beta filter. Note how the top edges of the Horsehead's profile have the greatest contrast. One of the more spectacular objects in this 3°-wide field of view, and certainly the brightest, is the double star Alnitak, Zeta Orionis, the easternmost star of Orion's Belt — note that its double nature is not at all evident in the previous photos. The A component is the brightest *O* star in the sky.

We see IC 434 because of the O-type star Sigma (σ) Orionis. Its intense ultraviolet light causes IC 434 to glow by a process called photoionization, which produces its characteristic red glow seen in color photos. We see the Horsehead as a dark nebula, but on its opposite side it's also photoionized by Sigma. We see a tiny bit of that glow around the top edge of the Horsehead's silhouette, which enhances its contrast. Seeing this thin bright edge is a challenge, but it is possible. On the best nights you might be able to see the faintly glowing equine outline of the horse's mane, head, and brow, as well as the top of the muzzle. It's an exciting observation and demonstrates that the Horsehead is an extension of IC 434 that's silhouetted against itself.

More difficult to see is the bottom (eastern) edge of the Horsehead's muzzle. It's much less distinct than the top, and whether you can see any contrast between IC 434 and the bottom of the muzzle will determine if you see a dark nebula shaped like a horse's head in profile or something more like Fleming's "semicircular indentation."

Even more challenging is a very slightly lighter area in the neck that extends east-west and highlights the Horsehead's mane. Detecting this area requires a pristine sky and superior observing skills. I have yet to identify it unambiguously, but it's been seen by other observers.

Tracing the full extent of IC 434 is a challenge because it blends ever so gently into the sky background in all directions. It takes careful examination of the field of view to determine where it disappears, and I've been surprised how far I've been able to trace it. Subtle east-west striations in the area west of the Horsehead can also be detected.

Spectacular Surroundings

Just northeast of the Horsehead Nebula is **NGC 2023**, a compact reflection nebula surrounding the 7.8-magnitude star HD 37903. Discovered by William Herschel in 1785, on the best nights you may be able to see a fairly sharp edge on NGC 2023's northwestern edge, which highlights how far off HD 37903 lies from the true center of the nebula.

If NGC 2023 is an obvious glow without a nebula filter, you have a good chance of seeing the Horsehead. If you can't see NGC 2023, then you'll need to wait for a darker and/or a more transparent night.

By far the most obvious bright nebula in the area is **NGC 2024**, the Flame Nebula. Also discovered by Herschel, it's just east of brilliant Alnitak, or Zeta (ζ) Orionis, the easternmost star of Orion's Belt. The Flame can be washed out by the glare of Alnitak so place the star just outside the field of view. The Flame is an H II star-forming region, energized by nearby Alnitak. Streaks of dark nebulosity divide it into three distinct parts that create its flamelike shape.

The Horsehead and Its Nebulae

Object	Type of Nebula	Size	RA	Dec.
B33	Dark	6′ × 4′	$05^h\ 40.9^m$	−02° 28′
IC 434	Emission	60′ × 10′	$05^h\ 41.0^m$	−02° 24′
NGC 2023	Emission + Reflection	10′ × 10′	$05^h\ 41.6^m$	−02° 16′
NGC 2024	Emission	30′ × 30′	$05^h\ 41.9^m$	−01° 51′
IC 431	Reflection	5′ × 3′	$05^h\ 40.3^m$	−01° 27′
IC 432	Reflection	8′ × 4′	$05^h\ 40.9^m$	−01° 29′
IC 435	Reflection	4′ × 3′	$05^h\ 43.0^m$	−02° 19′

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.

HOWARD BANICH

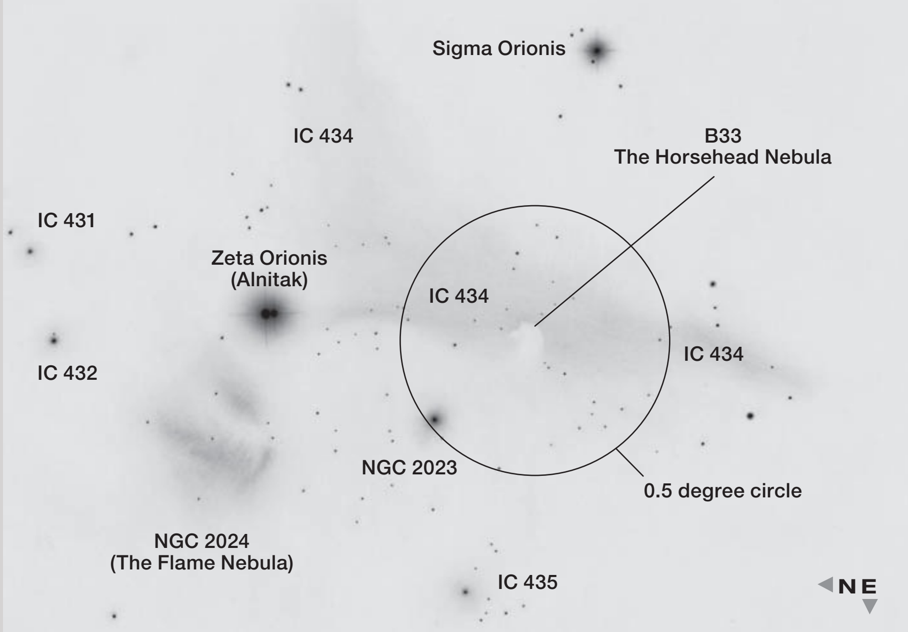
Although it shows well without a nebula filter, I prefer the view using a DGM Optics Narrow Pass Band filter because it gives a nice balance of nebular detail and stars.

The Flame hides a star cluster made up of some 800 newly formed stars and protostars, ages 0.2 to 1.5 million years old, with the newest clustering toward its center. Discovered by near-infrared observations, the vast majority of these stars seem to have circumstellar discs. We can't see this cluster in visual wavelengths, but it's fascinating to know it's in there.

The Flame is approximately the same distance away as IC 434, the Horsehead, M42, and all the other nebulae in this region — about 1,400 light-years — because they're all part of the Orion Molecular Cloud. We can think of them as being the brightest parts of the same nebula. The main difference is that their illuminating stars energize them to different degrees and from different angles.

IC 431, **IC 432**, and **IC 435** are smaller, fainter versions of NGC 2023 — stars surrounded by faint reflection nebulosity — and bracket the Flame Nebula to its southeast and northwest. They're fun to track down if you can tear yourself away from the more famous and obvious sights in the area.

The multiple star Sigma Orionis that's energizing IC 434 shines at magnitude 3.8 and is surrounded by a loose cluster of low mass and brown dwarf stars. It's also part of the Orion OB 1 b stellar association, which includes all three of the Orion's Belt stars.



▲**THE HORSEHEAD AND COMPANIONS** This labeled version of the author's sketch helps set the scale of the Horsehead with its surroundings. The ½° circle centered on the Horsehead is about the same apparent size as the full Moon, and the Horsehead itself is nearly the same apparent size as the Dumbbell Nebula. The hydrogen-beta filter tends to produce its highest contrast views when used with an eyepiece that gives a 4-mm to 7-mm exit pupil, so try to use eyepieces that fall in this range.

Of course, by far the most obvious and spectacular object in this area is Alnitak. At magnitude 1.8, it's actually a close visual double star, with its A and B components shining at magnitude 1.9 and 3.7, respectively, and separated by about 3″. They're a beautiful sight when the seeing is steady enough to split them cleanly. A third, unseen star was discovered spectroscopically. The A component is the brightest O star in the sky, with the other two stars belonging to spectral type *B*.

All this starry brilliance should be placed outside the field of view when trying to observe the Horsehead in a wide-field instrument. Even so, it's possible to see both at the same time if you keep the Horsehead Nebula in the sweet spot of your averted vision, then move Alnitak into the field of view.

This corner of Orion would be irresistible even without the Horsehead Nebula, but there's no doubt this most famous of the dark nebulae is the main attraction. Its shape really can look like the profile of a horse's head, and even though I sometimes think of the chess piece, there's no more aptly named object in the sky.

▶**THE HORSE'S HEAD UP CLOSE** This European Southern Observatory image of the Horsehead Nebula was obtained with the 8.2-meter Kueyen telescope, one of the four Very Large Telescope units at Cerro Paranal in the Atacama Desert, Chile. Note the bright edge along the top of the horse's mane, head, brow, and muzzle, all of which can be detected by visual observers. The more diffuse area along the bottom of the muzzle can also be seen but is much more difficult because of lower contrast. The most challenging area is the ever so slightly less dark area interior to the mane. The orientation is the same as in the other images.

SKETCH: HOWARD BANICH; CLOSE UP: ESO

■ Contributing Editor **HOWARD BANICH** and Chuck Dethloff, co-founder of the Oregon Star Party and a great friend of the author's since 1991, still get excited about a great view of the Horsehead Nebula. Howard can be reached at **hbanich@gmail.com**.

Suburban Stargazing: The Wintry North

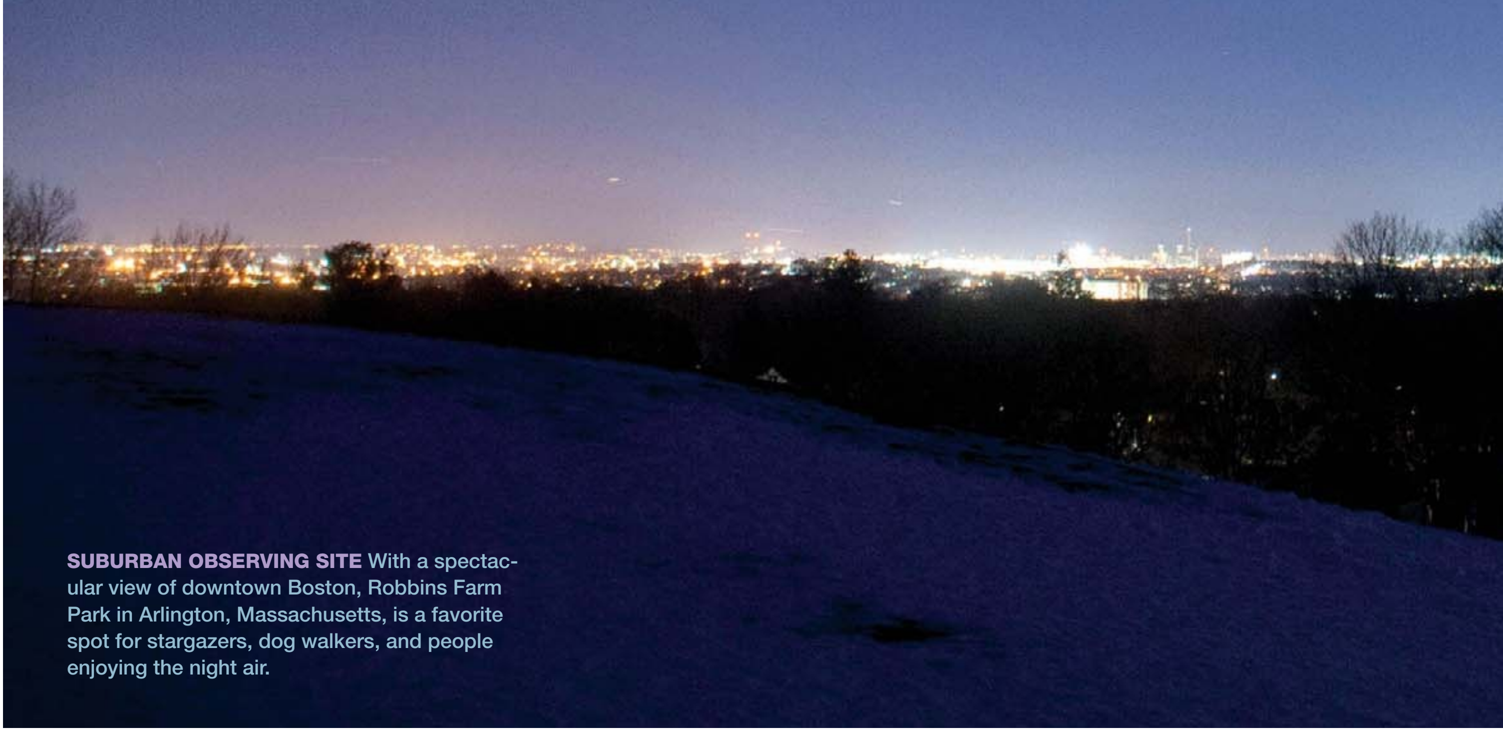
Cassiopeia and southwestern Camelopardalis are treasure troves for bright-sky observers.

I am a creature of two worlds. For most of my childhood I lived in Manhattan during the school year and spent summers at my family's country home in upstate New York. As long as I can remember, I have felt equally comfortable exploring the sidewalks of a giant city and wandering through the woods miles from the nearest road.

Likewise, I have been fortunate enough to pursue astronomy under some of the darkest and clearest skies on our planet. Yet I still enjoy observing near my current city home in Cambridge, Massachusetts, one of the most densely populated cities in the United States. It's amazing how much you can see from a city or suburb if you know what to look for.

Like most Cambridge residents I have no backyard, so I do my local observing in city parks. My current favorite is Robbins Farm Park in Arlington, the next town out from Cambridge. Consisting mostly of single-family homes separated only by driveways, Arlington is typical of the inner suburbs of any major city in the northeastern U.S. On a good night averted vision shows stars down to magnitude 5.0 near the zenith, and my Sky Quality Meter reads anywhere from magnitude 18.2 to 18.7 per square arcsecond. I can glimpse the Andromeda Galaxy without optical aid, but the Milky Way is invisible.

For tonight's tour we'll be observing stars and star clusters, the objects most resistant to light pollution. Skyglow reduces any given telescope's ability to resolve faint stars, but that can be counteracted by using bigger scopes and/or higher magnifications. I observed all the deep-sky objects in this article with a 130-mm reflector,



SUBURBAN OBSERVING SITE With a spectacular view of downtown Boston, Robbins Farm Park in Arlington, Massachusetts, is a favorite spot for stargazers, dog walkers, and people enjoying the night air.

TONY FLANDERS

which at Robbins Farm resolves clusters about as well as a 60-mm refractor does under dark skies. An 8- or 10-inch scope would give even more impressive views of almost all the objects.

Cassiopeia

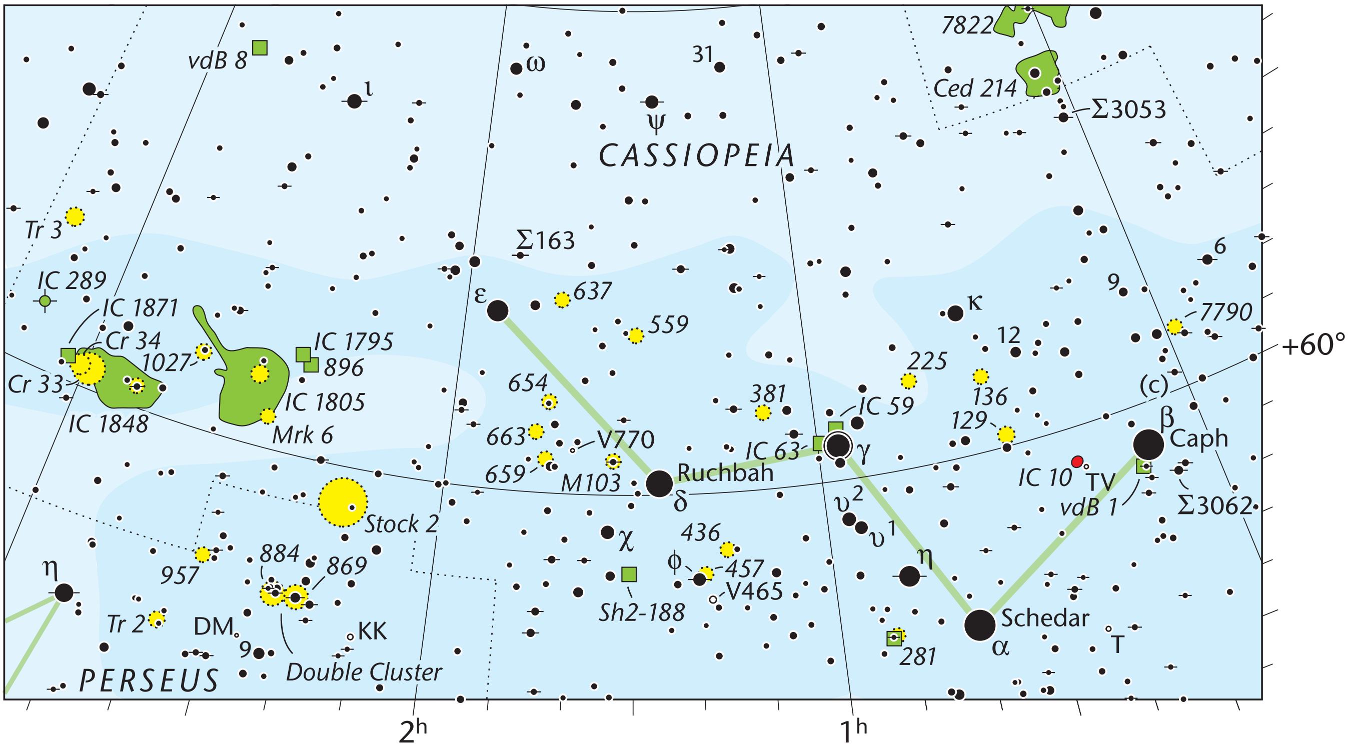
Tonight we will explore the bottoms of pages 1 and 11 in *Sky & Telescope's Pocket Sky Atlas*, starting in Cassiopeia, dipping briefly into Perseus, and ending in Camelopardalis. This is the region where the cluster-rich galactic plane passes farthest north, so it remains high for a very long time for observers at mid-northern latitudes. U.S. observers will find all these objects well-placed in the evening sky from October to early March.

The beginning of our tour is extraordinarily easy to navigate because it traces along one of the most prominent patterns in the night sky: the W of Cassiopeia. We'll start with the startlingly red star **WZ Cassiopeiae** 1.5° northwest of Beta (β) Cas, the westernmost star of the W. The variable-star designation WZ is omitted in the *Pocket Sky Atlas*, but the star has the label (c) to mark it as a carbon star. It's also marked as a double, though its companion, about 1′ to the east, is physically unrelated.

Carbon stars are red giants with an excess of carbon in their outer regions. The carbon forms molecules that filter out almost all the blue light, giving these stars a very distinctive appearance. Normal red giants and supergiants such as Betelgeuse have a reddish tint, like incandescent light bulbs. Carbon stars come in various hues of deep, saturated red, more like Christmas-tree lights. In the case of WZ Cas, the color is further enhanced by the contrast with its blue-white companion. Like all carbon stars, WZ is a variable. It's usually significantly brighter than its companion, but they're near-twins in brightness when WZ is at the bottom of its cycle.

Carbon stars make great targets for bright-sky observers, because skyglow does not reduce the perception of color, and might even enhance it. The Astronomical League has an excellent list of carbon stars at **https://is.gd/al_carbon_stars**. But beware of the magnitudes; many of the stars come nowhere near the bottoms of the ranges listed in that table.

Tracing eastward along the W, our next stop is the wonderful double star **Eta (η) Cassiopeiae**. I can split it with some effort at 30×, but it looks much better at 50× to 90×, with a brilliant yellow-white primary widely separated from the much fainter reddish secondary. Like carbon stars, colorful doubles are ideal bright-sky targets. Sissy Haas's *Double Stars for Small Telescopes* is a great resource for double-star fans, as is the online database **https://is.gd/haas_project**.



▲ **TAKE THE ATLAS WITH YOU** All the objects described in this article are plotted and labeled in *Sky & Telescope's Pocket Sky Atlas*. Because it shows only the brightest deep-sky objects, the *Pocket Sky Atlas* is ideal for stargazers whose views are impaired by light pollution.

ROGER SINNOTT / S&T'S POCKET SKY ATLAS

If you sweep from Epsilon (ε) at the easternmost end of Cassiopeia's W through Delta (δ) and continue half again as far, bending slightly to the south, you land atop 5.0-magnitude Phi (φ) Cassiopeiae. It's the brightest star that appears within the open cluster **NGC 457**, though it's probably an unrelated foreground star.

Many people consider this the most attractive cluster in the constellation because its stars form a striking stick figure, with Phi and 7.0-magnitude HD 7902 as the much brighter eyes. The figure has many popular names, including the Owl, the E.T. (after Steven Spielberg's film of the same name), and the Kachina Doll Cluster. I can see all the important stars in my 130-mm scope at 27×, but you might need more magnification if you have a smaller telescope.

A remarkable field containing the open clusters **M103**, **NGC 663**, **NGC 659**, and **NGC 654** lies east and northeast of Delta Cas. Under dark skies, my 130-mm reflector shows all four of these in the same field of view at 22×. But from the suburbs, NGC 654 and NGC 659 disappear completely at such low magnifications, and M103 becomes a shadow of its true self. Sadly, the high magnifications necessary to combat skyglow preclude the rich wide-field views that make dark-sky observing so enticing.

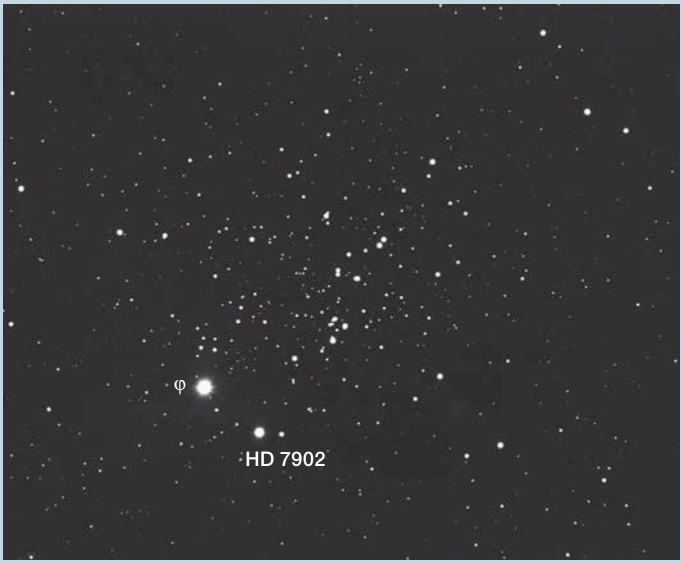
At low power M103 appears to be just four medium-bright stars in a very tight formation reminiscent of a lower-case Greek lambda (λ). The southernmost and second-brightest of those, 8.2-magnitude HD 9365, is actually a foreground star. But when I use 81× in my 130-mm scope, I pick up another eight stars in the northern half of the cluster. Bigger scopes and darker skies show even more, revealing M103 to be a fairly rich, densely packed cluster.

NGC 663 is by far the biggest and brightest of the four clusters, revealing a dozen stars at 22×, and at least twice as many at 81×. But for all its brightness, NGC 663 is somewhat lacking in charm due to the fact that its stars are fairly loosely packed and don't make any eye-catching patterns.

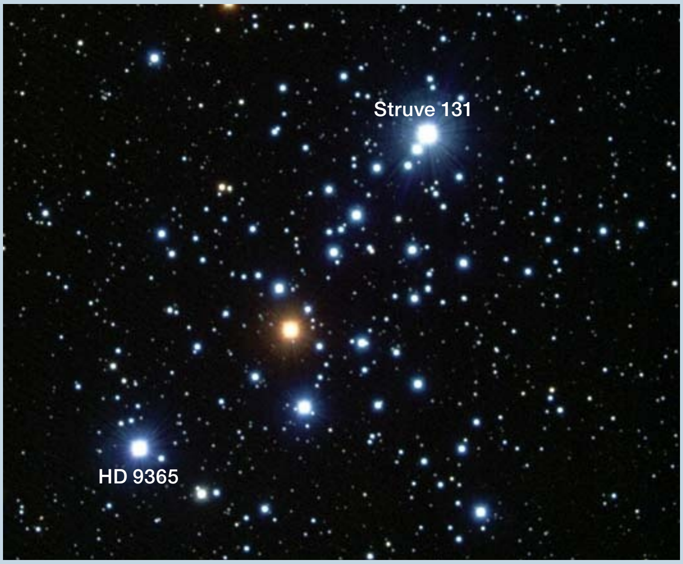
Using averted vision at 27× I can just make out NGC 659 as a faint, unresolved blur ½° south-southwest of NGC 663, just off the tip of a prominent star triangle. Three or four stars twinkle intermittently through the haze when I raise the magnification to 81×.

The prominent reddish 7.3-magnitude star HD 10494 lies ¾° north-northwest of NGC 663, with NGC 654 just beyond. I find this cluster somewhat harder to make out at 27× than NGC 659, presumably because it's camouflaged by the glare of HD 10494. But at 81× NGC 654 becomes more prominent than NGC 659. Averted vision reveals a half dozen 11th-magnitude stars.

Surprisingly, HD 10494 probably is a member of this cluster, despite the fact that it outshines the second-brightest star by a factor of 20. Such a big brightness gap implies that the star must be something special, and indeed spectroscopy shows that it's a rare *F*-type supergiant. Supergiants are short-lived, so this in turn proves that NGC 654 must be quite young. Indeed, NGC 654 is about 14 million years old, compared to roughly 120 million years for the mature



▲ **QUIRKY CLUSTER** Nestled around Phi Cassiopeiae, the open cluster NGC 457's nicknames include the Owl, E.T., and Kachina Doll. Which do you see?

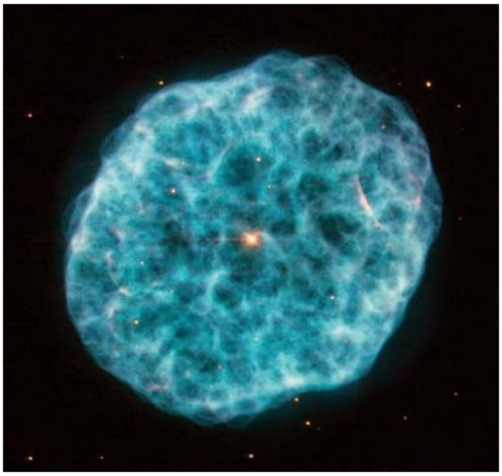


▲ **FARAWAY SPARKLES** M103, also known as NGC 581, is an open cluster situated some 7,200 light-years from us. The star HD 9365 is in the foreground and not a cluster member.

▲ **DELIGHTFUL ASTERISM** Kemble's Cascade, named after the Canadian amateur astronomer who identified it, consists of 7th- to 9th-magnitude stars and is 2.5° long. Note the open cluster NGC 1502 at the bottom-left of the trickle of stars.

NGC 457: NOAO / AURA / NSF; M103: HILLARY MATHIS / N. A. SHARP / NOAO / AURA / NSF; KEMBLE'S CASCADE: GREG PARKER / NEW FOREST OBSERVATORY

Pleaides (M45) or 600 million for the late-middle-aged Beehive (M44).



◀ **COMPLEX NEBULA** Situated in Camelopardalis, the Giraffe, the planetary nebula NGC 1501 lies around 4,000 light-years away. The bright central star that can be seen in this image earned this object its nickname, the Oyster Nebula. Remember, you will not see this intricate nebula in all its finest detail (and the colors here are arbitrary), but as you peek through your scope on a cold winter's night, bear this image in mind as you remind yourself that you are in fact seeing the last gasps of a star across the vast distances of space.

A Dip into Perseus

If you proceed from Delta Cas to Epsilon and then double back to form an imaginary fifth leg to Cassiopeia's W, you land atop the huge, loose open cluster **Stock 2**, which straddles the Cassiopeia-Perseus border. Measuring roughly 1° across and dominated by two dozen 8th- and 9th-magnitude stars, it's best observed at the lowest magnification that your telescope can achieve. The cluster's apparent size indicates that it must be nearby, and indeed it lies just 1,000 light-years away.

At an estimated age of 170 million years, Stock 2 is also by far the oldest cluster in our tour. You might guess that by the fact that so many of its stars are almost identical in brightness. In older clusters, all the brightest, most massive stars have already burned out.

Many people see Stock 2's stars as the figure of a giant. One hand grasps a chain of 6th- and 7th-magnitude stars that stretches 2° south to the peerless **Double Cluster**.

The apparent proximity of Stock 2 to the Double Cluster is an illusion. Stock 2 lies in our galaxy's Orion-Cygnus Arm (also called the Local Arm and many other names), the same arm that hosts our own solar system. All the other clusters we've discussed so far are much farther away, in a particularly active star-forming region of the neighboring Perseus Arm. The superposition of nearby Orion-Arm clusters with luminous young Perseus-Arm clusters is what makes this region so rewarding to explore.

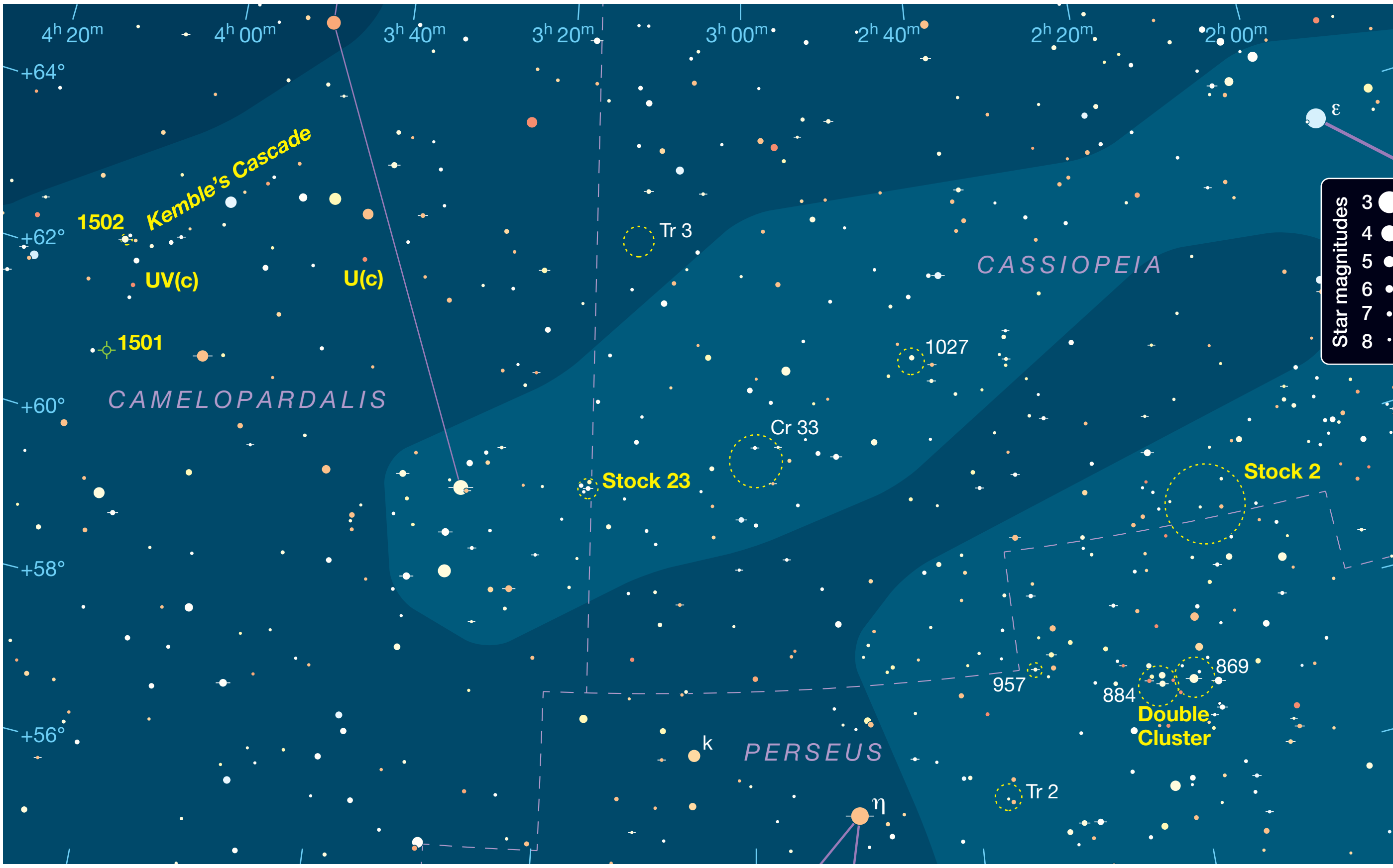
I never tire of viewing the Double Cluster through any instrument at any magnification under any conditions. Its components are among the most luminous open clusters known; each appears as bright as the Beehive Cluster despite being 14 times more distant. If the Double Cluster were at the same distance as the Beehive, it would appear as bright as Jupiter and bigger than Cassiopeia's W. For more information on this amazing cluster pair, see Sue French's discussion on page 54.

Jewels of the Wintry North

Object	Type	Mag(v)	Size/Sep	RA	Dec.
WZ Cassiopeiae	Carbon star	6.9–8.5	—	$0^h\ 01.3^m$	+60° 21′
Eta Cassiopeiae	Double star	3.4, 7.5	13″	$0^h\ 49.1^m$	+57° 49′
NGC 457	Open cluster	6.4	13′	$1^h\ 19.5^m$	+58° 17′
M103	Open cluster	7.4	6′	$1^h\ 33.4^m$	+60° 39′
NGC 663	Open cluster	7.1	15′	$1^h\ 46.3^m$	+61° 13′
NGC 659	Open cluster	7.9	6′	$1^h\ 44.4^m$	+60° 40′
NGC 654	Open cluster	6.5	6′	$1^h\ 44.0^m$	+61° 53′
Stock 2	Open cluster	4.4	60′	$2^h\ 15.6^m$	+59° 32′
Double Cluster	Cluster pair	2.9	45′ × 30′	$2^h\ 20.7^m$	+57° 08′
Stock 23	Open cluster	5.6	14′	$3^h\ 16.3^m$	+60° 02′
U Camelopardalis	Carbon star	7.0–8.0	—	$3^h\ 41.8^m$	+62° 39′
Kemble's Cascade	Asterism	—	150′	$3^h\ 57.4^m$	+63° 04′
NGC 1502	Open cluster	5.7	7′	$4^h\ 07.8^m$	+62° 20′
UV Camelopardalis	Carbon star	7.5–8.5	—	$4^h\ 05.9^m$	+61° 48′
NGC 1501	Planetary nebula	11.5	52″	$4^h\ 07.0^m$	+60° 55′

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.

ESA / HUBBLE / NASA / MARC CANALE



▲ **CHARTS ARE USEFUL** Many of the clusters in tonight's tour are rich in stars brighter than magnitude 8.5, the limit for this chart. That makes them impressive from urban and suburban skies even through very small telescopes.

Camelopardalis

From Stock 2's center, sweep 7.8° east and 0.8° north to the charming open cluster **Stock 23** on the Cassiopeia-Camelopardalis border. At 22× I see a skewed four-star diamond. Slightly higher magnification reveals a fifth star, making a shape like the Head of Hydra. A dozen additional stars appear at 81×, and Σ362, the central star on the western edge, resolves into a delightful tight double.

A prominent 1.7°-long arc of four stars, magnitudes 4.8 to 5.8, lies 5° northeast of Stock 23. The 7th-magnitude carbon star **U Camelopardalis** floats 0.6° south of the arc's western end. I find it very deep red, much more so than WZ Cas.

A delightful line of 7th- to 9th-magnitude stars some 2.5° long intersects the eastern end of our bright arc. This asterism is known as **Kemble's Cascade**, after the noted Canadian amateur astronomer Father Lucian Kemble. The line ends at the lovely open cluster **NGC 1502**, which, like Stock 23, consists of a tight group of bright stars with a wide double at its center. But NGC 1502's members are more densely packed than Stock 23's, and the central double is wider and brighter, with more evenly matched components. NGC 1502 is both young (11 million years) and fairly nearby (3,300 light-years).

Yet another carbon star, **UV Camelopardalis**, lies 0.6° south-southwest of NGC 1502's center. It's worth a look while you're in the neighborhood, though it's not nearly as deep red as U Cam. The contrast between these two stars, just 3° apart, shows how varied carbon stars can be.

We'll finish 1.4° south of NGC 1502 with the planetary nebula **NGC 1501**. It's a little challenging with my 130-mm scope from Robbins Farm, but I can detect it with averted vision at 81×, and once detected, I can hold it with direct vision. It appears as a faint but substantial circular patch of light. A narrowband nebula filter improves NGC 1501's visibility considerably.

NGC 1501 is not as spectacular as the stars and star clusters that we've visited, but it's pleasant to end our tour with something completely different: the gaseous envelope thrown off by a star before fading to a white dwarf. Planetary nebulae remind us that for all their seeming permanence, stars are born, live, and die just as we do — though on much larger scales of space and time.

■ Contributing Editor **TONY FLANDERS** was a *Sky & Telescope* editor from 2003 to 2014. His first article described observing all the Messier objects from a local city park.

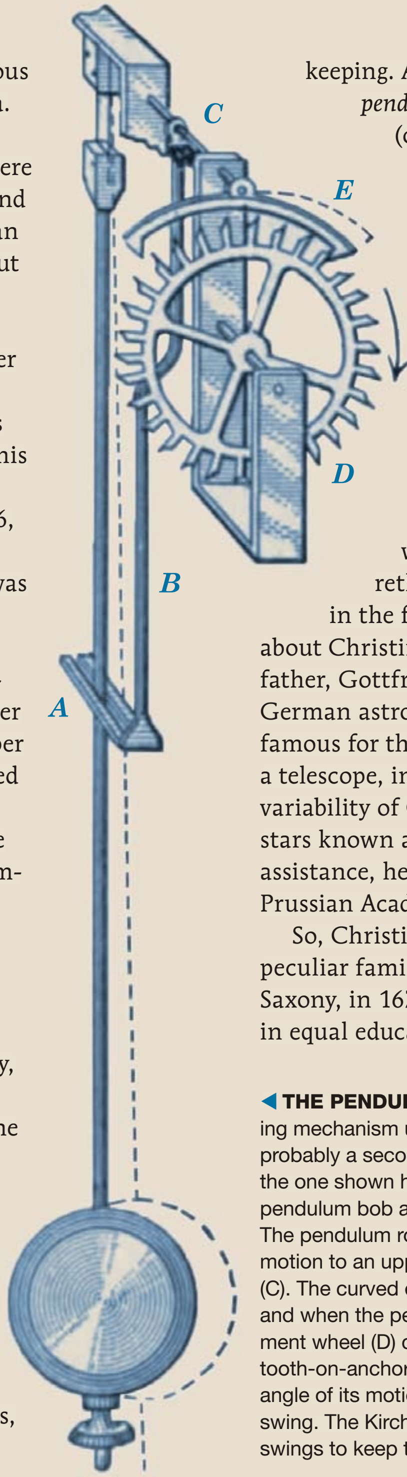
400 Thalers *or* 50 Pounds

Who was the first professional woman astronomer?

Caroline Herschel is probably the most famous female astronomer of the early modern era. In 1772, her celebrated brother William, discoverer of Uranus, brought her to England, where she helped him in his activities, first as a singer and then as an astronomer. Although this little woman (a disease in her youth limited her growth to about 4 feet 3 inches) had to work under the supervision of her renowned brother, she was gradually able to pursue an independent astronomical career sprinkled with several important successes. She discovered 14 deep-sky objects, including galaxies and open clusters that William later included in his catalog, as well as eight comets; the first of these comets, discovered on the night of August 1, 1786, is now designated C/1786 P1 Herschel.

In the Herschel era, the discovery of a comet was reputed to be so important that it led to another historical milestone. In the year following Caroline's first comet discovery, King George III recognized her astronomical work (as an assistant to her brother) and assigned her a salary of 50 pounds per year. This made Caroline Herschel the first salaried woman astronomer, at least in modern history. Almost 50 years later, near the end of her life, she and Mary Somerville became the first female members of the Royal Astronomical Society.

Given the enormous difficulties that women faced at the time, Herschel built an impressive career, and her importance should not be underestimated, even if it turns out that she was not the first professional woman astronomer. Actually, primacy should be awarded to another European astronomer. In 1787 Caroline Herschel became the first woman in the United Kingdom to be paid as an astronomer, but the second in the world. The honor of first had already been earned by a German observer named Christine Kirch.



The Family Tree

Anecdotal evidence tells us that in her childhood, Christine used to mark the time, or time intervals, with a pendulum. From Galileo onwards, the pendulum had been used in Europe for timekeeping. Astronomers usually used a *seconds pendulum*, which had a period of two seconds (one second per swing). While tracking the pendulum's motion was probably a game for Christine, it was actually a help to her family. She was the first daughter of two astronomers, and at the age of 10 she, together with her brother and sister, was instructed in the family business.

Christine's mother, Maria Margarethe Winkelmann, gave birth to her in 1696 in Guben, Germany. Christine had been preceded by a brother, Christfried, in 1694, and would be followed by a sister, Margaretha, in 1703. (There were seven children in the family, but we only have information about Christine, Christfried, and Margaretha.) Their father, Gottfried Kirch, was one of the most famous German astronomers of the 18th century. He was famous for the first discovery of a comet made with a telescope, in 1680, and for the detection of the variability of Chi (χ) Cygni, one of three variable stars known at the time. And with Winkelmann's assistance, he managed the Observatory of the Royal Prussian Academy of Sciences in Berlin.

So, Christine belonged to a notable yet somewhat peculiar family. Her mother was born in Panitzsch, Saxony, in 1670 to a Lutheran pastor who believed in equal education for both sexes and who made a

◀ **THE PENDULUM GAME** Little is known about the exact timing mechanism used in the Kirch household, but the clock was probably a seconds pendulum with an escapement anchor, like the one shown here (E). A thread and nut on the bottom of the pendulum bob allowed the user to adjust the rate of the clock. The pendulum rod passed through a fork (A) and transferred its motion to an upper rod (B), which turned on a horizontal axis (C). The curved escapement anchor was attached to the axis, and when the pendulum was in motion, the teeth of the escapement wheel (D) connected with the anchor's limbs. This press of tooth-on-anchor was transmitted to the pendulum to reduce the angle of its motion, which meant that it required less energy to swing. The Kirch children made a game of counting pendulum swings to keep track of time while observing.

SILAS ELLSWORTH COLEMAN, *THE ELEMENTS OF PHYSICS* (1906) / PUBLIC DOMAIN personal effort to make sure his daughter received comprehensive instruction. He encouraged her interest in astronomy from a very young age, and later she had the opportunity to study with and, finally, become an assistant to, the peasant astronomer Christoph Arnold of Sommerfeld. Arnold worked in Leipzig, where he observed the Great Comet of 1686 with Gottfried Kirch. Winkelmann met Kirch, who would soon become her husband, while she was acting as Arnold's observing assistant.

Gottfried Kirch was born during the Thirty Years' War, the son of a tailor. He lived a quite restless childhood and probably didn't get a degree, but he had good academic contacts. For example, Erhard Weigel, professor of mathematics at the University of Jena from 1653 to 1699, recommended him to the Polish astronomer Johannes Hevelius. Thanks to this endorsement, Kirch worked in Danzig, at Hevelius's well-equipped private observatory, for a short time in 1674. Before reaching tenure as full astronomer in Berlin in 1700, Kirch supported himself with teaching and the production of books of observations and calculations, but also through the preparation of calendars. The latter is a key point in this story.

Kalenderpatent

Calendar production was a major responsibility for astronomers in the late 17th to early 18th century. In addition to including information about feast days (religious holidays), calendars were replete with information on celestial objects, including lunar phases and positions of major stars and planets. Gottfried Kirch was the widest-read calendar maker of his generation, publishing up to 13 calendars at a time, including eventually the official state calendar.

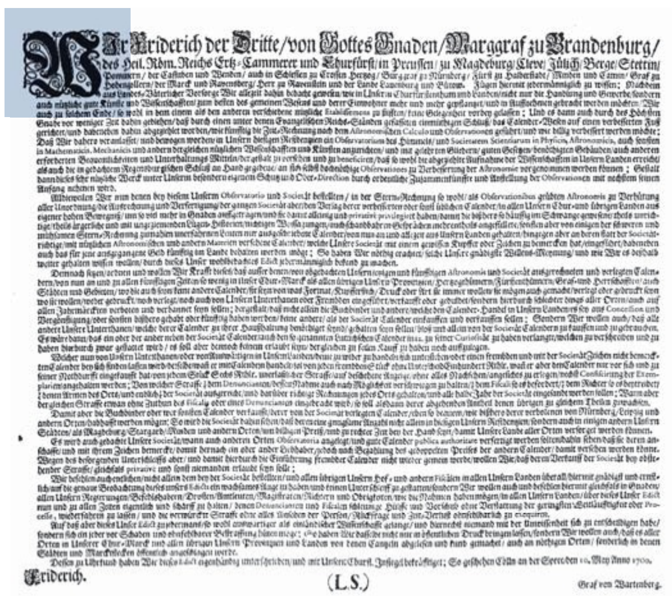
The task of producing the state calendar was tied to an appointment called a *Kalenderpatent*, a position that had been expressly created by Frederick III, Prince-elector of Brandenburg, with an edict issued on May 10, 1700. The act followed the decision of German Protestant states to introduce a new and improved calendar beginning in 1700; the calendar, which was to be calculated by qualified astronomers, would be identical in practice to the Catholic Gregorian calendar, with the exception of the date of Easter. This edict thus introduced a monopoly for calendar production in the Electorate of Brandenburg, and later in Prussia, and allowed for the imposition of a "calendar tax," the proceeds of which were used to pay the astronomers and other members the Royal Prussian Academy of Sciences in Berlin, which was founded on July 11th of the same year. Not coincidentally, Frederick III also promised the creation of an observatory in Berlin, which was then inaugurated on January 19, 1711.

Gottfried Kirch was awarded the important appointment of *Kalenderpatent* eight years after his marriage to Winkelmann, his second wife. Despite the difference in age (Winkelmann was the younger by 30 years), their shared passion for astronomy nurtured family activity in this field. It was common at the time for women trained in the sciences to marry a scientist in order to continue her own work. After the wedding, Gottfried directed Winkelmann-Kirch's studies much as he had done for his three sisters. Between 1700 and 1710, the year of Gottfried's death, their household, including apprentices, domestic help, friends, and eventually children, held the monopoly on Prussian calendars.

After Gottfried's death, Winkelmann-Kirch carried on with her observations in spite of various obstacles. Despite the fact her husband held the position of *Kalenderpatent*, she had always taken care of the preparation of the calendar. However, the Academy of Sciences denied her request when she asked that she and her son be appointed assistant astronomers in charge of producing calendars. Despite the open support of its president, the physicist and philosopher Gottfried Leibniz, the Academy wished to avoid the precedent of a woman at a public institution, and rejected her application. Ironically, it was nonetheless necessary to ask her to continue the same work in an unofficial capacity.

In October 1712 Winkelmann-Kirch was admitted as an astronomer to the private observatory of Baron Bernhard Friedrich von Krosigk in Berlin, where she and Gottfried had worked while the Academy observatory was under construction. Here, she observed daily as "master" astronomer and trained Christine and Christfried as assistants. She published planetary and lunar ephemerides under her own name and continued her work on the preparation of calendars for the cities of Wrocław (the German Breslau), Nuremberg, and Dresden, as well as for Hungary. When the Baron died in 1714, she moved to Danzig to reorganize and use the observatory of the well-known (but deceased) astronomer Johannes Hevelius.

▼ **ROYAL COMMAND** Frederick III, Prince-elector of Brandenburg, created the official post of *Kalenderpatent* with this edict, issued on May 10, 1700. The edict, which served as the founding charter for the Electoral Brandenburg Society of Sciences (soon to be renamed the Royal Prussian Academy of Sciences), also called for the construction of an astronomical observatory.

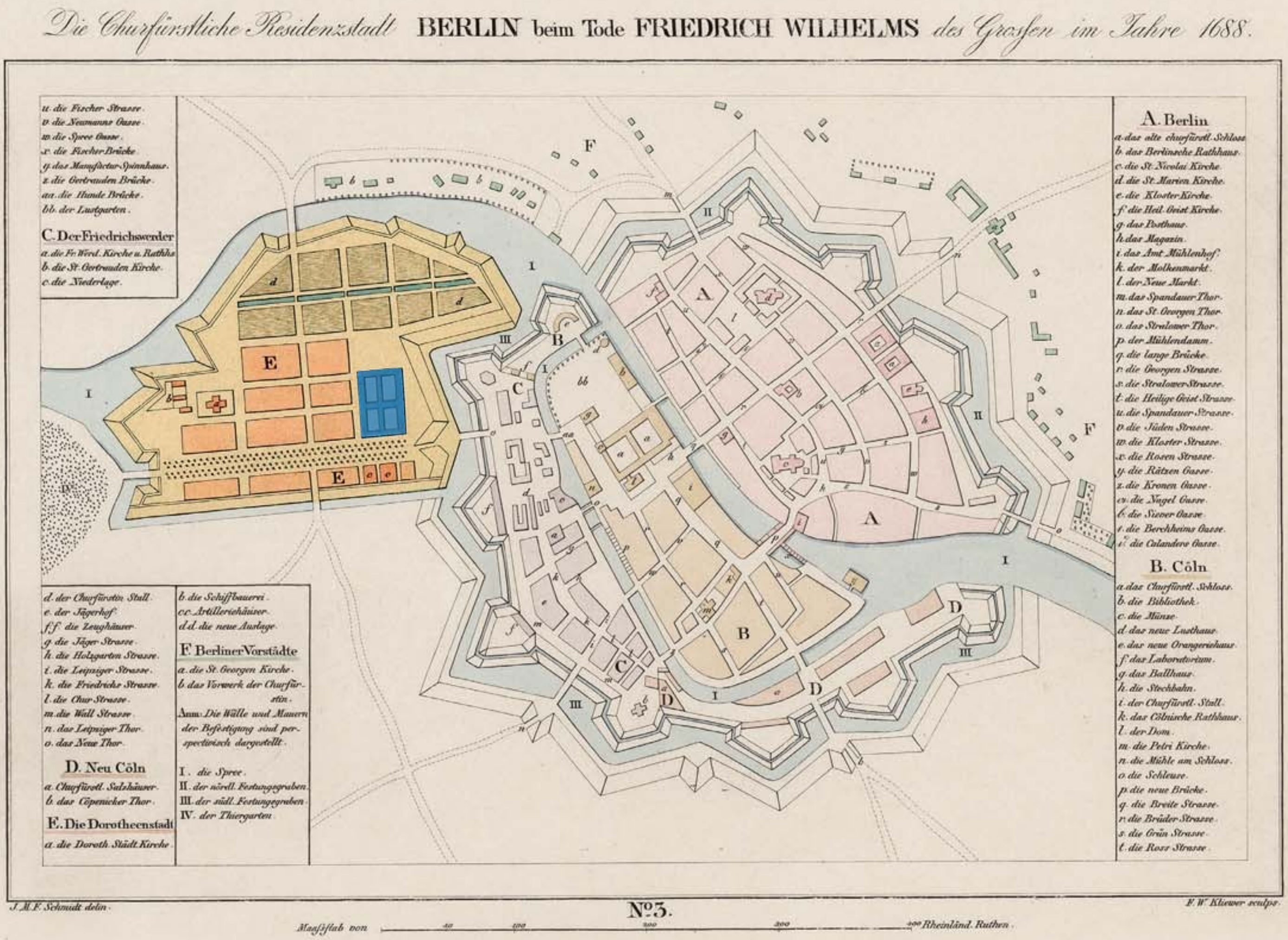

Wir Friderich der Dritte/von Gottes Gnaden/Marggraf zu Brandenburg/
des Heil. Röm. Reichs Ertz-Cammerer und Churfürst/in Preussen/ zu Magdeburg/Cleve/ Jülich/ Berge/Stettin/

Friderich.

(L.S.)

The "Kirchin," however, in spite of several decades' unceasing work as assistants, continued to miss official recognition until Christine, near the end of her career, finally received some much-deserved credit.

▲ **OBSERVING ON HIGH** Designed by architect Martin Grünberg, the five-story tower of the Berlin Observatory was erected over the north wing of the royal stables. The second floor of the tower was used by the Royal Prussian Academy of Sciences for its meetings, while the third floor was reserved for observing activities. Gottfried Kirch never had a chance to work at the new observatory, as he died six months before its formal dedication.



▲ **OUTSIDE THE WALLS** The Berlin Observatory was constructed at the very edge of the city on what is known today as Dorotheenstrasse in the Mitte district. Marked here in orange, the region was colloquially referred to as "the farmyard" (*Am Bauhof*) or "the back alley" (*Hinter Gasse*) in the early 1700s. The observatory was added to the block of royal stables, highlighted here in blue, which had been built between 1677 and 1688.

DRAWING: JOHANN GABRIEL DOPPELMAYR, *ATLAS COELESTIS* (1742) / PUBLIC DOMAIN;
MAP: J. M. F. SCHMIDT, *HISTORISCHER ATLAS VON BERLIN* (1835) / PUBLIC DOMAIN

In 1716 Winkelmann-Kirch was invited to become the astronomer at the court of the Tsar of Russia, Peter the Great, but she declined the offer so she could return to the Berlin Observatory, where Christfried had been appointed observer. Since the Academy was concerned about Christfried's qualifications (he was allegedly weak in astronomical theory), having Winkelmann-Kirch return to the observatory as an unofficial assistant was a necessity. However, when guests visited the observatory, Winkelmann-Kirch was to make herself scarce (in fact, she was reprimanded by the Academy for engaging with visitors and being too visible on public occasions). So, as precious as she was to Christfried's work, she was required to fade into the background.

Winkelmann-Kirch was forced out of the observatory (though she was expected to continue to provide her son meals) in 1717, and died in 1720 at the age of 50. It was then her daughters Christine and Margaretha, or the "Kirchin," began to serve as shadow assistants to their brother. For years, they helped with observations, doing the astronomical calculations for planetary ephemerides, and compiling the annual calendars issued by the Academy.

During this period, the structure of the work at the Observatory remained essentially the same as it had been under Gottfried Kirch. In addition to the preparation of the calendar, celestial objects were tracked for scientific and astrological purposes, with observations recorded in both communal and personal diaries. Observing in shifts, the family ensured that the night sky was under continual study. The house logs include notes on observations made during the transit of Mercury in November 1723, for instance, as well as those made during the total solar eclipse of May 1733. And, following a technique first suggested by Galileo a century before and put in practice by Giovanni Domenico Cassini in France, the differences in longitude between Berlin, Paris, and St. Petersburg were determined using the eclipses of Jupiter's satellites and then inscribed in the family diary.

Christfried was admitted as a foreign member to the French Academy of Sciences in 1723 and promoted from the position of observer to that of regular astronomer at the Berlin Observatory in 1728. After his death he was elected to the Royal Society of London. The "Kirchin," however, in spite of several decades' unceasing work as assistants, like their mother, continued to miss official recognition until Christine, near the end of her career, finally received some much-deserved credit.

Coming Into Her Own

From a very young age and for most of her life, Christine worked in the shadow of her father, mother, and then older brother and other assistants. Her training and education started in childhood, when she helped her family with the "pendulum game"; later she was introduced to the production of calendars. She began by helping Winkelmann-Kirch, and then Christfried, making observations and doing calculations for planetary ephemerides, despite not receiving a regular salary. (Margarethe also worked at the observatory throughout her life, recording observations of Comet 1743 C1, for example; however, less is known about her.) But in 1740 the tide began to turn. Christine started receiving occasional (and small) donations from the Academy. But why? Simply because Christfried had died of a heart attack on March 9th of that year. With Winkelmann-Kirch 20 years gone, and the Academy deprived of its main astronomer, the state became more dependent on the professional help of Christine for producing calendars.

▲ **FURTHER DEVELOPMENTS** The Berlin Observatory was renovated under Johann Bode. The top two stories of the tower were combined and given over to observing. The observatory remained in use until the new Berlin Observatory was constructed in the 1830s.

LEOPOLD LUDWIG MÜLLER (1824) / PUBLIC DOMAIN

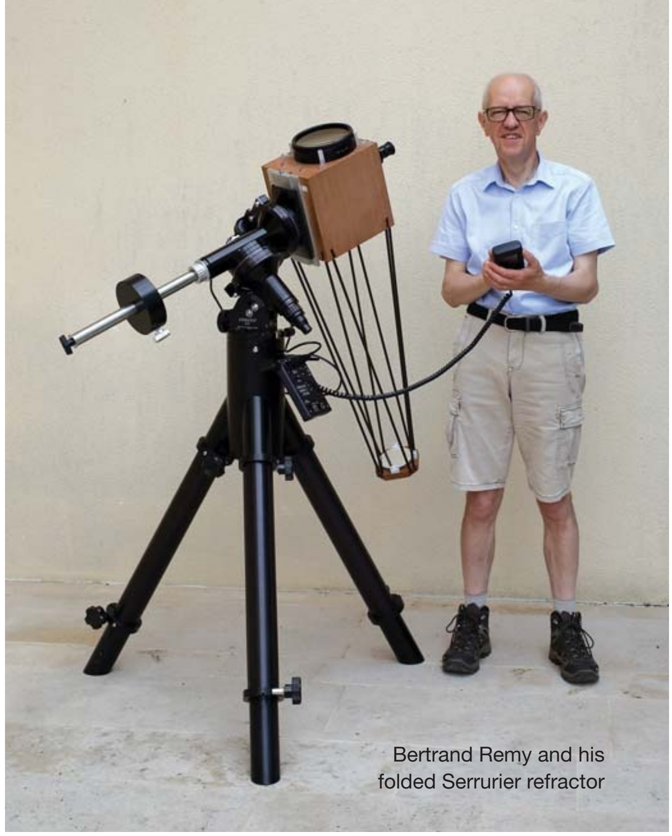
And the production of calendars was more important than ever. Between 1740 and 1742, Frederick the Great, King of Prussia, conquered the populous province of Silesia, a region of Central Europe that today belongs almost entirely to Poland. This was good news for the Academy in Berlin: It could significantly increase its income, which depended on its monopoly on the calendars of Prussia. This should have been good news for Christine as well, as she became responsible for preparation of the Silesian calendar. However, her work apparently wasn't deemed important enough to grant her more than "pocket money" from the prestigious institution.

Eventually, her hard work paid off, however. At the age of 77, she was given an honor equivalent to "Emeritus" by the Academy, which expressed its explicit gratitude for her calendar work in a letter. Around this same time, she introduced the astronomer Johann Bode both to calendar making and to the scientific community of Berlin. The first edition of the almanac *Berliner Astronomische Jahrbuch*, produced by Bode with Christine's help, appeared in 1774 (with data for 1776). In 1776 the Academy finally assigned Christine a salary of 400 thalers (the German silver coin). The salary came without a binding obligation to produce calendars or observe; rather, it was recompense — an obvious back payment — for her many years of hard work. In this way, Christine Kirch preceded by 11 years the record of her colleague Caroline Herschel as the first female professional astronomer.

■ **GABRIELLA BERNARDI** holds degrees in Physics and Scientific Communication. After working on the Rosetta mission at Alenia Spazio in Turin, she decided to devote her energies to science, and especially astronomy. She is currently a freelance journalist and science writer, with two books to her credit, one about women astronomers of the past and one on Giovanni Domenico Cassini.

A Folded Serrurier Refractor

Here's a practical solution to long-focal-length refractors.



Bertrand Remy and his folded Serrurier refractor

REFRACTING TELESCOPES HAVE faced a fundamental design challenge since the beginning: The longer the focal ratio the less chromatic aberration, but the more unwieldy the telescope becomes. Early refractors reached a ridiculous extreme with scopes like Johannes Hevelius's 46-meter (150-foot) monster of the 1640s.

Triplet lens designs that correct for color fringing have largely solved that problem, but triplets are expensive. Doublets do okay and are relatively inexpensive, but they still function better at longer focal ratios.

French amateur Bertrand Remy has come up with an excellent solution that neatly bypasses the length compromise. Inspired by articles in the December 1984 and March 2001 issues of *Sky & Telescope*, he designed a combination refractor/reflector that folds a long-focal-ratio (f/15) light cone into an easily manageable package.

▼ The objective lens, tertiary mirror, and focuser all nestle into the front box.

He started with a two-element, air-spaced 150-mm (6-inch) f/15 Clavé achromat. A little less than halfway down its light cone he positioned a 4-inch Edmund Optics 1/20-wave silica mirror, which bounces the light back toward the objective, but off to the side where a 66-mm (2.6 inch) 1/30-wave Antares diagonal mirror reflects the light through a Moonlite focuser to the eyepiece.

To support the secondary, he chose an eight-truss Serrurier design that holds the secondary perpendicular to the light path even if the trusses sag a bit under its weight. This little bit of magic is achieved by using eight trusses instead of six. There's a triangle on each side, making it very stiff in all directions, but even if the trusses do flex a little, their length won't change. The entire structure acts as a parallelogram, and we all remember from basic geometry (right?) that when you flex a parallelogram, the opposite sides remain parallel to one another.

In Bertrand's case, the objective lens, the tertiary mirror, and their mounting box make up one end of the parallelogram, while the secondary mirror makes up the other. If the secondary end of the telescope sags a bit, it's still held parallel to the objective. And since the secondary is flat, flexure-induced collimation change is not an issue.

The result is a dramatic reduction in the scope's overall length while actually reducing the worry of tube flexure affecting the collimation. The finished scope folds a 2,250-mm (7.4-ft) focal length into an impressively short 1,090-mm (3.6-ft) package.

This design has several additional advantages:

It's light. The whole works weighs only 8 kilos (18 lbs) including the dovetail plate.

The scope is compact, so it's easy to transport and easy to place on its Losmandy G-11 mount.

The damping time is only half a second. This extremely low figure is undoubtedly due to the Serrurier trusses.

The image is sharp, even at magnifications above 300×. Bertrand reports that color fringing is minimal, even on the bright Moon.

It's easy to collimate. Bertrand says, "Thanks to the large coma-free field of the objective, collimation is very forgiving. I only had to do it once to get crisp images, simply viewing

▶ The secondary is actually the first mirror in the light path but the second optical element.

and centering the mirrors with unaided eyes looking through the focuser."

Also, the two mirrors re-reverse the image inversion common to refractors, so the image is correctly oriented.

Additionally, the center of gravity is near the middle of the wooden box that houses the objective, focuser, and tertiary mirror, so the eyepiece remains at nearly the same height regardless of where the telescope is pointed.

You might wonder, as I did, why Bertrand chose to put his tertiary mirror across the box from the focuser rather than right next to it (and thereby allowing for a smaller tertiary). Bertrand explains: "First, putting a small tertiary mirror next to the focuser would have led to a 100-mm increase of the overall length of the refractor. And second, I already owned a very good 66-mm diagonal and did not want to buy another one." Excellent reasons, both!

To cut down on stray light decreasing image contrast, Bertrand uses a shroud around the bottom end of the scope and a dew shield when observing.

How does the scope perform under the stars? "I love observing the Moon with my refractor and a 7-mm Nagler eyepiece, which provides a 'spacewalk experience.' This reminds me of my childhood, when I watched the live coverage of Apollo 11's lunar landing," says Bertrand with nostalgia.

For more information, contact Bertrand at **bertrand_remy@yahoo.fr**.

■ Contributing Editor **JERRY OLTION** is a big fan of short telescopes. Contact him at **j.oltion@gmail.com**.


The shroud and front shield protect against stray light and dew.

BERTRAND REMY (4)

COMETARY VISITOR
Gerald Rhemann
Comet 21P/Giacobini-Zinner sports a long tail as it passes several emission nebulae in Auriga, including Sh2-235, Sh2-232, and Sh2-231, seen left to right, respectively. South is up in this photo.
DETAILS: *ASA 12-inch f/3.8 Newtonian astrograph with an FLI ML 16200 CCD camera. Total exposure: 58 minutes through LRGB filters.*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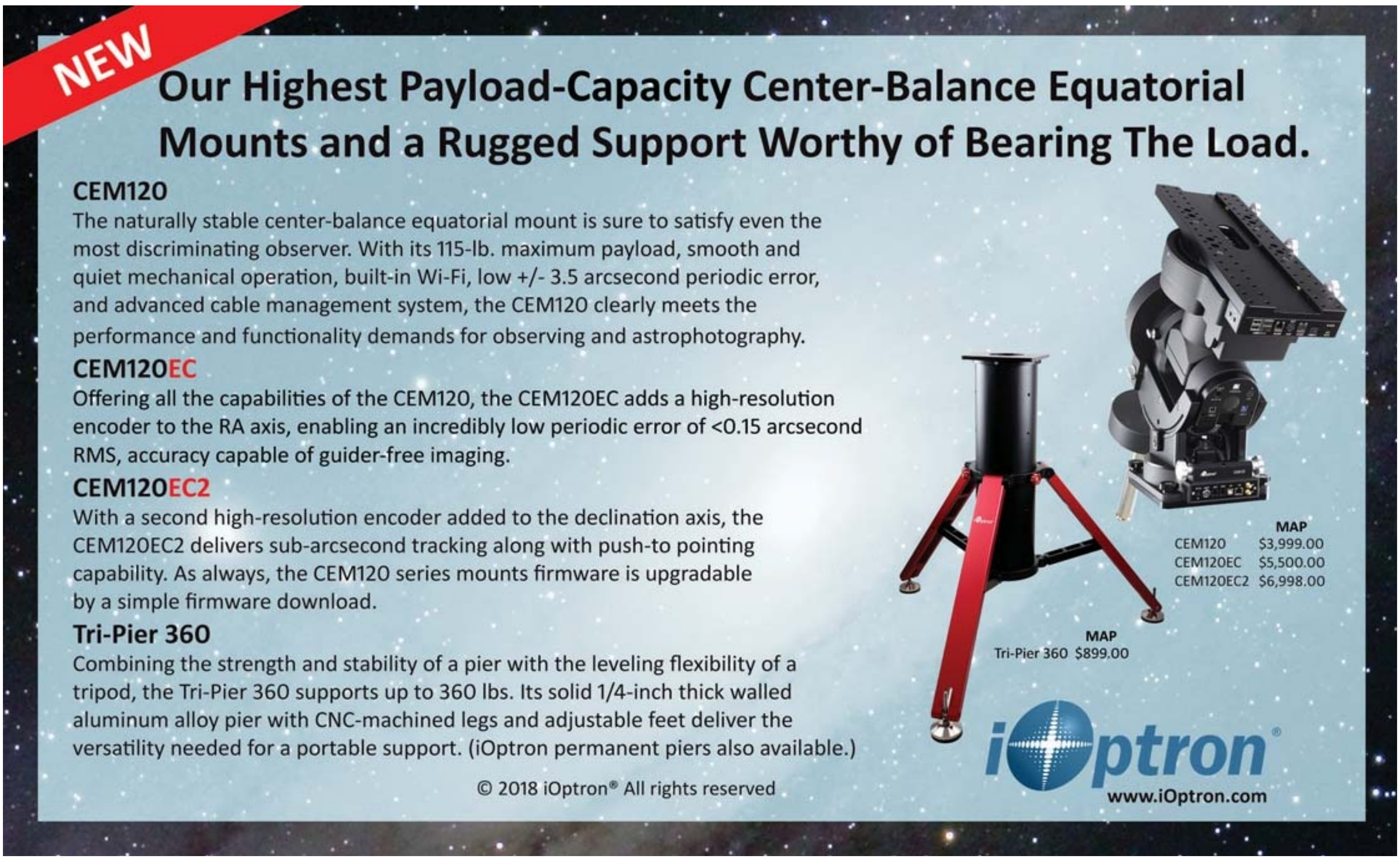
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▷ ECLIPSE RISE

Paolo Lazarotti

On the night of July 27, 2018, the Moon entered the longest lunar eclipse of the 21st century. Here it is seen with Mars rising over the village of Tellaro, Italy, and the Gulf of La Spezia, also known as the Gulf of Poets.

DETAILS: *Canon EOS 500D with 18-to-35-mm zoom lens at 24 mm. Composite of 52 images, each exposed for 2 seconds at ISO 100, f/5.6.*

NEBULOUS NEIGHBOR

Douglas Struble

The intricate yet obscure supernova remnant CTB-1 in Cassiopeia is roughly 10,000 light-years from Earth and about 36 arcseconds in diameter.

DETAILS: *Stellarvue SV70T refractor with ZWO ASI1600MM-Pro CMOS camera. Total exposure: 50.4 hours through Astrodon color and narrowband filters.*

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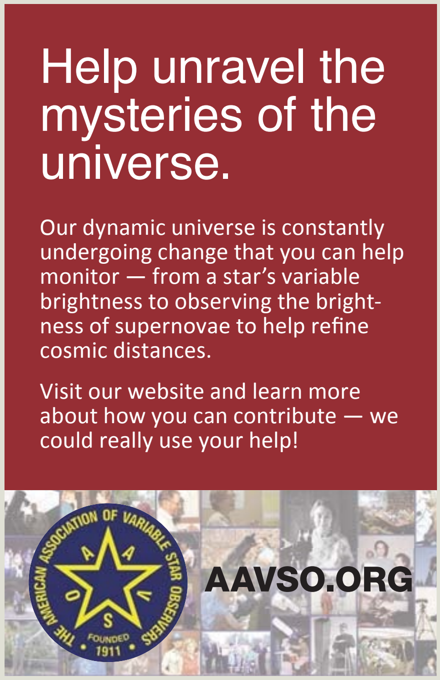

TELESCOPES

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

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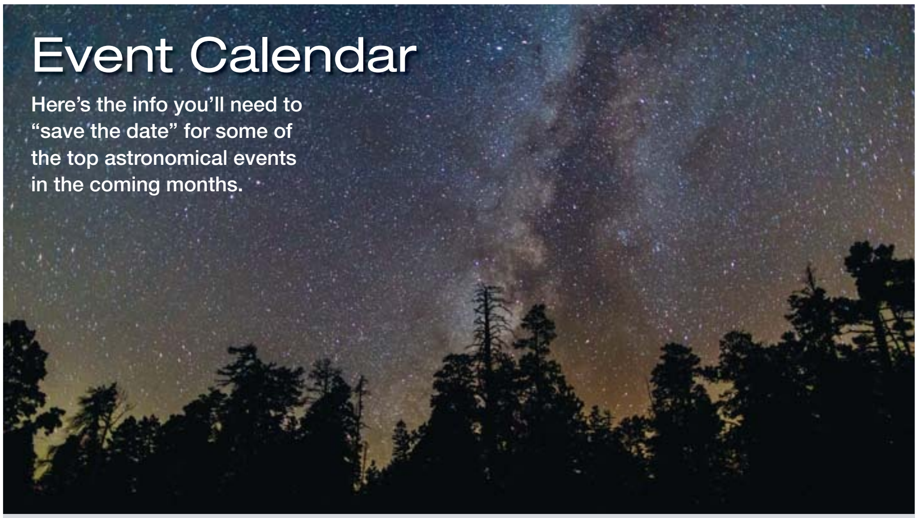

Event Calendar

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

February 4–10
WINTER STAR PARTY
Scout Key, FL
scas.org/home/winterstarparty

April 3–6
MIDSOUTH STARGAZE
French Camp, MS
rainwaterobservatory.org/events

April 6–7
NORTHEAST ASTRONOMY FORUM
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May 11
ASTRONOMY DAY
Events across the continent
https://is.gd/AstronomyDay

April 28–May 5
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

May 30–June 2
CHERRY SPRINGS STAR PARTY
Coudersport, PA
astrohbg.org/CSSP

June 22–29
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCSP2019

June 26–30
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

July 26–August 4
SUMMER STAR PARTY
Plainfield, MA
rocklandastronomy.com/ssp.html

July 30–August 3
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

July 30–August 4
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

August 1–4
STELLAFANE CONVENTION
Springfield, VT
stellafane.org/convention

September 19–22
RTMC ASTRONOMY EXPO
Big Bear City, CA
rtmcastronomyexpo.org

October 5
ASTRONOMY DAY
Events across the continent
https://is.gd/AstronomyDay

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

Sight Unseen

On a fine observing night with friends, an amateur astronomer gets an alarming surprise.

OUR LOCAL ASTRONOMY CLUB, Astrolabe of Wheeling, West Virginia, hosts a monthly starwatch every third Friday. Since it was finally a clear evening, I traveled to the site to get ready for what I hoped would be a great evening observing a crescent Moon and lots of deep-sky objects. I was especially looking forward to my last peek of the season at M42, the Orion Nebula.

When I arrived, the Sun was still up but low on the horizon, and the Moon was high in the western sky. I took advantage of the sunlight to set up my scope and start viewing the Moon — it was magnificent in my Unitron. As the evening wore on, the sky darkened nicely, and the stars began popping out.

That's when I started to notice that something was not right. I'm almost always the first of the group to find objects and usually the one to point them out to my compatriots. As Venus appeared, I kept losing it when trying to aim my scope at it, while my buddies seemed to have no problem keeping a lock on our sister planet. *Oh well*, I thought, *I must be a little off my game tonight*. Later, one of the group was trying to get me to M42, and I was having trouble locating the Belt stars to indicate the way to the Sword. Again, I thought I was just a bit off.

Later still, one of the folks found M51, the Whirlpool Galaxy in Canes Venatici. When I put my eye to the eyepiece of his 10-inch reflector, I was barely able to make out the "main" galaxy and certainly couldn't see the companion. *Bad night indeed*, I thought. Then one of the inexperienced visitors peered in and saw both galaxies with no problem.

What was happening? Was I losing my sight?

The night continued in the same vein for a while, and I contented myself with observing the Moon. It really *was* outstanding, so the night wasn't a total disappointment. But I left the site with a real worry nagging at me. Were my eyes finally succumbing to old age? I'm only 63, after all!

On my drive home, my headlights didn't seem to be working as well as usual, and as I pulled into my driveway I checked to see if both headlights were functional. (They were.) Okay, now I was *really* worried. Can sudden loss of vision happen? Anticipating an emergency visit to an ophthalmologist in the morning, I morosely started dragging my stuff inside. As I entered the house, everything seemed dim as well. Not good.

Then, feeling like a complete idiot, I noticed that I still had my sunglasses on! They're the same prescription as my regular glasses, including being bifocals. It'd been sunny when I arrived at the stargazing site, and I'd simply forgotten to remove them.

Moral: It's never too dark to be cool, but if you see someone in your group wearing sunglasses after dark, you *might* want to mention it.

LEAH TISCIONE / *S&T*

■ **PAT PLUNKETT** spent 20-plus years in the U.S. Air Force, retiring at the rank of Lieutenant Colonel, after which he taught computer science at Wheeling Jesuit University for another 20-plus years. He retired as an associate professor in May of last year.