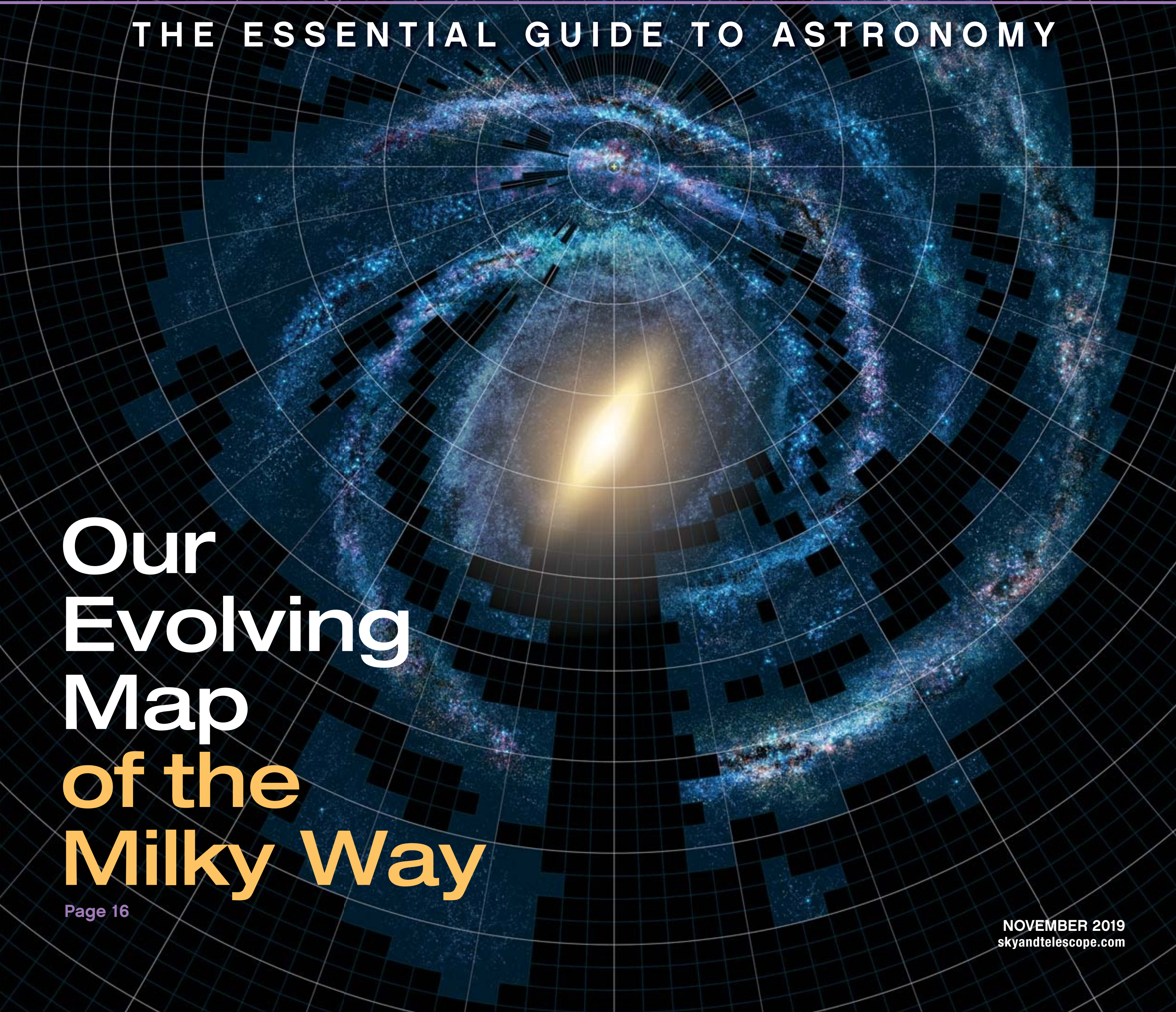

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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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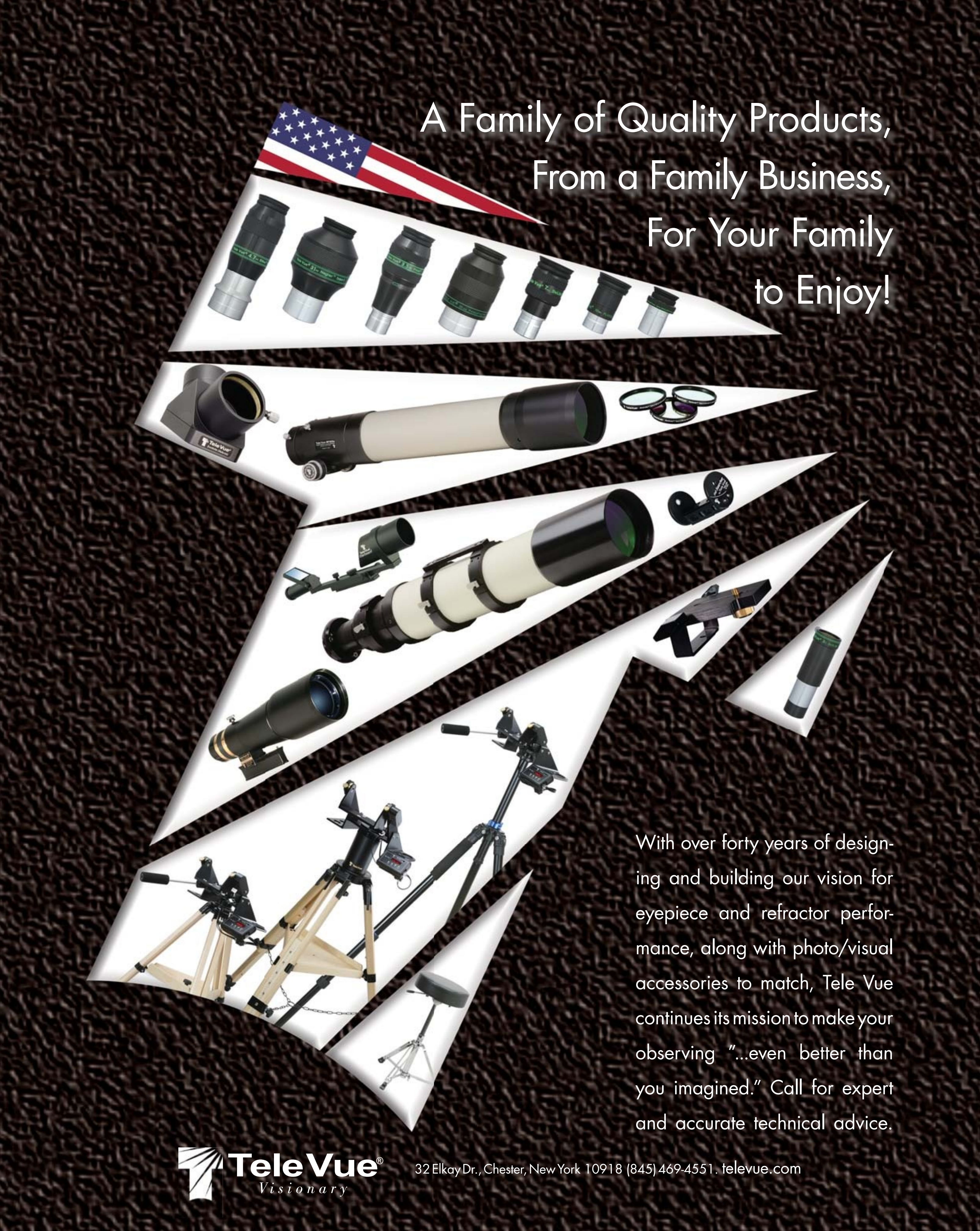
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ON THE COVER

Artist's concept of our Milky Way map under construction

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Mapping the Milky Way

IMAGINE YOU'RE IN THE MIDST of a large crowd in a field. You're all circling the center, angling for a glimpse of a famous person, say. From where you're standing, midway between the throng's core and edge, you can't see the center, much less what's beyond it — too many people in the way. Now and then, through fleeting gaps, you get a sense of just how big the mob is. But all you can really see is that it gets thicker toward the center and thins out behind you toward the periphery.

Now, imagine you've been tasked to depict that crowd as if you were floating above it in a balloon. From overhead you could see the whole aggregation at a pop, allowing you to clearly limn all its distinctive characteristics.

But, alas, you don't have that luxury. You're stuck deep in the middle. How are you going to create that plan view?

This is the challenge facing those who strive to map our home galaxy, as Ken Croswell explains in our cover story on page 16. We know the Milky Way is a barred spiral, not unlike the galaxy seen at left. But how do we gather the details of its spiral arms, especially those segments on the farside of the galaxy from where we live?

Our galaxy resembles the barred spiral UGC 12158.

ESA / HUBBLE & NASA

Star-forming complexes and giant molecular clouds can help us delineate such distant arms. But because Earth lies near the midline of our galactic plane — in other words, you're of average height and you can't see over or beneath those around you — many of those structures are superposed on the sky. This aspect is particularly noticeable when we look towards the galactic center.

We know that these entities lie at vastly different distances from us, perhaps even in different arms, but how can we distinguish their respective distances when they're all mashed together in our line of sight? Adding to the difficulty is our inability to observe many of these structures in visible light — intervening clouds of interstellar dust absorb optical wavelengths. What to do?

Such handicaps only spur on galactic cartographers. Can't see in the optical? Observe in radio or infrared wavelengths, which pass right through that visibly opaque dust. Need a better fix on an object's distance? Measure its velocity and fit that to a rotating model of the galaxy. Or pick up signals from astrophysical *masers* — naturally occurring sources of laserlike radiation, typically in microwave wavelengths, that arise in active star-forming regions.

With such techniques, it'd be as if you had friends seeded around that crowd, texting you particulars of the horde around them. Receive enough of these texts and you might just be able to assemble that plan view after all. That's the hope of these intrepid mappers of the Milky Way.

Peter

Editor in Chief

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To Observe and Protect

After reading Dennis Kelly's "Encounters with Police" (*S&T:* Aug. 2019, p. 84), in addition to climate change, environmental toxins, nuclear devastation, and the zombie apocalypse, I now fear being gunned down by law-enforcement officials while stargazing.

According to Mr. Kelly, my Schmidt-Cassegrain could be mistaken for a mortar, and that 20-inch Dob I've been eyeing for purchase could be misinterpreted as an ICBM. Yet somehow I've survived more than 50 years of celestial sightseeing without having to put reflective tape on telescope tubes or mounts, or having a single incident involving local law enforcement.

Law-enforcement professionals are obligated to implement investigative procedures bound by the restrictions of reasonable suspicion and probable cause before questioning a private citizen, let alone resorting to the use of deadly force. By contrast, in our constitutional democracy it's not incumbent upon stargazers to prove innocent participation in a harmless pastime. It's saddening and alarming to learn that the civil rights of private citizens may have been eroded and constitutionally based evidentiary burdens perverted to a point at which even stargazing has been recast as inherently suspect criminal activity.

Raymond G. Gregory
Gaylord, Michigan

Like Dennis Kelly, I too have had several astronomical encounters with police.

One day the police knocked on my front door. "We have a report of an anti-aircraft gun in your backyard. Could we please take a look?"

Then, in 1970, a building blocked my view of Comet Bennett. So at 4 a.m. I carried my 15-cm Newtonian down the predawn street to my local schoolyard. A police car stopped me, and the officer asked, "Whose backyard did you steal this from?" Fortunately, Comet Bennett was of naked-eye visibility from the street, so I pointed it out. "Well, I'll be!" came the officer's reply. I walked away with Comet Bennett as my alibi.

Not every contact with law enforcement needs to be a confrontation.

Today my astronomy is with a 20-cm SCT from my 9th-floor balcony. I set up only when it has gotten dark, and I never speak of it to other tenants.

Ken Pilon
Toronto, Ontario

About 30 years ago I also had an encounter with police. I was in a parking area on the north end of Fort Lauderdale Beach happily checking out the Moon, nebulae, and a few double stars when I noticed a cloud bank moving in, so I started to break things down. Two police cars pulled in shortly after I opened my trunk. I figured I was in trouble as this area closed at 9 p.m., and here it was around 1 a.m.

After the officers questioned me about my scope, I asked them if they had ever seen a crater on the Moon up close and personal. They hadn't, and the end result was that they kept me out there a lot longer, then told me there was no need to leave on their account. To this day I have no idea how they explained where they were that night.

Ken Cottrell
Friendship, New York

The solution is simple: Call your local or state police in advance. The dispatcher will inform whoever covers that area of what you intend to do. Or, better yet, invite the officers to drop by for a peek through the telescope. If you're a club, you might pick up a new member!

Allison McCullough
Lagrange, Maine

Well-Rewarded

I was informed in April that I was selected for the Astronomical League's Leslie Peltier Award for 2019, and I'd like to thank the editors of *S&T* for their part in my receiving this honor. It's something I never really thought about achieving, and it's amazing to me that one can be honored for doing something so enjoyable. Observing the night sky is what provides the necessary balance in my life, especially when I need it the most. I'm rewarded every time I look through an eyepiece at a celestial wonder.

Tom Reiland
Glenshaw, Pennsylvania

Note from the Editors: *The Astronomical League (**astroleague.org**) presents its annual Leslie C. Peltier award to an amateur astronomer who has contributed to astronomy observations of lasting significance. Named in honor of amateur astronomer Leslie Peltier, the award was created in 1980 and first presented in 1981. Tom Reiland penned the article "The Herschel Hustle," which appeared in the March 2019 issue (p. 30).*

1, 2, 3, Red Light

Dr. Ken Wishaw's article on the effects of different color low-light-level illumination on the human eye's ability to see faint stars (*S&T:* July 2019, p. 34) was fascinating. I was reminded of one other way to increase your eye's limiting magnitude: breathe 100% oxygen.

I used to work for an observatory at an elevation of 3,200 meters (10,500 feet). A few of us would have symptoms of hypoxia on our first day at the summit, so the observatory always had medical oxygen tanks on hand. One night I did a test, spending 5 or 10 minutes outside looking at the sky, then breathed O_2 for 5 minutes and went back out. The difference was dramatic. Even without a long period of dark adaptation, my fully oxygenated eyes could see twice as many stars!

To be fair, my pulse-ox level up there was usually in the low 90s to

VICTOR MOUSSA / SHUTTERSTOCK.COM

start with, which would reduce sensitivity. (Normal is about 98% for most people.) I don't know if the effect of oxygen on me would be as great if I were at sea level, although other observatory staff members did report the same effect. There's probably a lot of individual variation.

Tom Sargent
Tucson, Arizona

Legacy Observatories

I was very happy recently to get a call from Sam Hale, CEO of Mount Wilson Institute. Sam is the grandson of George Ellery Hale (1868–1938), founder of Kenwood, Yerkes, and Mount Wilson Observatories, and a key figure in the creation of Palomar Observatory. Sam asked me to join a small and informal weekend meeting bringing together people concerned with "legacy observatories." The proposal was to consider a new organization that would serve the needs of such institutions.

The meeting took advantage of initial considerations written down by a small group of senior astronomers who had gathered informally at a prior meeting of the American Astronomical Society (AAS). As resolved that weekend, the working name for the new organization is Alliance of Historic Observatories. Three participants agreed to lead an effort to refine a draft mission statement and other key wording, and the group plans to reconvene this fall at an event hosted by Palomar Observatory.

Of many extremely interesting points raised, it's notable that the intangible spirit of astronomical observatories, and of their grand historic instruments, was not overlooked. The group recognized the power of this for education.

All of us interested in preserving astronomical heritage and exploiting it for education and engagement can be pleased that development of the Alliance of Historic Observatories will certainly continue.

John W. Briggs
President, Antique Telescope Society
Magdalena, New Mexico

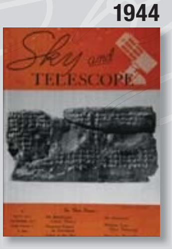
FOR THE RECORD

- In "The Moon Three Ways" (*S&T:* July 2019, p. 22), the Moon in the composite photograph that opens the article is waxing, not waning.
- Several alert readers reminded us that Earth's distance from the Sun at aphelion (*S&T:* July 2019, p. 47) is 1.0168 astronomical units, not 1.1068 a.u. Nostra culpa.
- In "Action at Jupiter" (*S&T:* Aug. 2019, p. 50), the second sentence should read in part ". . . and diminishes to a still-luminous -2.2 by the end of the month."

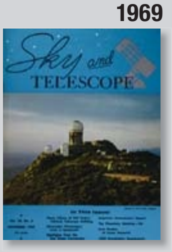
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1944



1969



1994

◖ November 1944

Faraway Suns "Dr. C. K. Seyfert and Prof. J. J. Nassau, of the Warner and Swasey Observatory, find that there are around 2,500 supergiant stars in the Andromeda system [Messier 31], each of which is at least 1,000 times as bright as our sun. The investigation was made on photographs obtained with the new 24-inch Schmidt telescope at Cleveland. We thus actually have a far more complete census of the supergiants in this distant system than in our own galaxy."

Because we see the Milky Way edge on, many of its more distant stars are obscured from our view by interstellar dust.

◖ November 1969

Meteor Up Close "The unusual experience of seeing a 1st-magnitude meteor pass through the field of view of a 30-inch refractor at 600× is described by W. A. Feibelman. [He] was photographing the planetary nebula NGC 7009 on September 2, 1968, with the Thaw refractor at Allegheny Observatory in Pittsburgh. The guiding eyepiece into which he was looking received part of the beam of the 30-inch f/18.5 objective, and had a field of one minute of arc.

"The very swift passage of the meteor left a yellow trail about seven to 10 seconds of arc in width. After the observer recovered from the momentary dazzle, he saw the field filled with tiny luminous centers moving with the same velocity and direction as the meteor, except along the original trail, which was now empty. Quickly this smooth motion changed to a turbulent one, with twisting filaments and eddies, until the whole phenomenon faded from view. The entire sequence of events lasted only about four seconds."

◖ November 1994

Brand New Neighbor "An international team of astronomers has found a large spiral galaxy in our cosmic backyard. The object, located in Cassiopeia . . . was announced at the 22nd General Assembly of the International Astronomical Union. . . .

"Dubbed Dwingeloo 1, the galaxy was detected with the 25-meter radio telescope in Dwingeloo, the Netherlands, one of the oldest radio telescopes in the world. Renée Kraan-Korteweg . . . and Andrew J. Loan [and colleagues] found the galaxy [during] a search for hitherto unknown galaxies in the Zone of Avoidance, the part of the sky that is largely hidden from view by dust in the plane of our galaxy. . . . According to team member W. Butler Burton (Leiden Observatory), it is probably 10 million light-years away [or] just outside the Local Group."

In 1996, Loan and his team identified Dwingeloo 1 as a dim and extended glow of total visual magnitude 14 using the 2.5-meter Isaac Newton Telescope (Canary Islands), among others. It turns out to be a barred-spiral galaxy.

◀ An artist's conception shows the Vikram lander deploying the Pragyan rover on the surface of the Moon.

SPACE

Chandrayaan 2 Heads to the Moon

ON JULY 22ND, INDIA'S ambitious Chandrayaan 2 — an all-in-one mission that includes an orbiter, lander, and rover — lifted off for the Moon.

The spacecraft follows in the footsteps of the successful Chandrayaan 1 orbiter, which launched in October 2008 and orbited the Moon for nearly a year. That mission deployed an impact probe to the lunar south pole and found direct evidence of water ice.

Chandrayaan 2 (Hindi for "mooncraft") is due to return to the south pole, this time with a soft landing on a plain between the Simpelius N and Manzinus C craters. China's Chang'e 4 also landed in the south polar region but on the farside.

As of early August, the Indian Space Research Organisation (ISRO) reports that the spacecraft has completed five maneuvers to successively raise its orbit around Earth. On August 14th, it left orbit around our planet and headed for the Moon. Lunar capture is expected in late August. Chandrayaan 2 will eventually attain an orbit that takes it 100 kilometers (60 miles) above the lunar surface. Using a high-resolution camera, it will map the proposed landing site and other specific areas of interest. Other instruments aboard the orbiter will characterize the composition, temperature, and other properties of the lunar surface.

The Vikram (Sanskrit for "valor") lander will detach from the orbiter and head toward the lunar surface for a September 7th landing. If all goes well, engineers will instruct Vikram to deploy a small rover named Pragyan (Sanskrit for "wisdom"). The solar-powered lander and rover will arrive near lunar sunrise. They're expected to last until local sunset two weeks later, although there are plans to try and wake them both up after the long lunar night. The primary mission of the orbiter should last one year.

The mission will study water ice near the lunar south pole. Vikram carries a seismometer, thermal probe, and an instrument to monitor electron density and temperature near the lunar surface. The lander also carries a small laser retro-reflector, supplied by NASA. The Pragyan rover includes a laser and X-ray spectrometer to analyze lunar regolith, along with navigational cameras.

If all goes well, Chandrayaan 2 will make India the fourth nation to land softly on the Moon.

■ **DAVID DICKINSON**

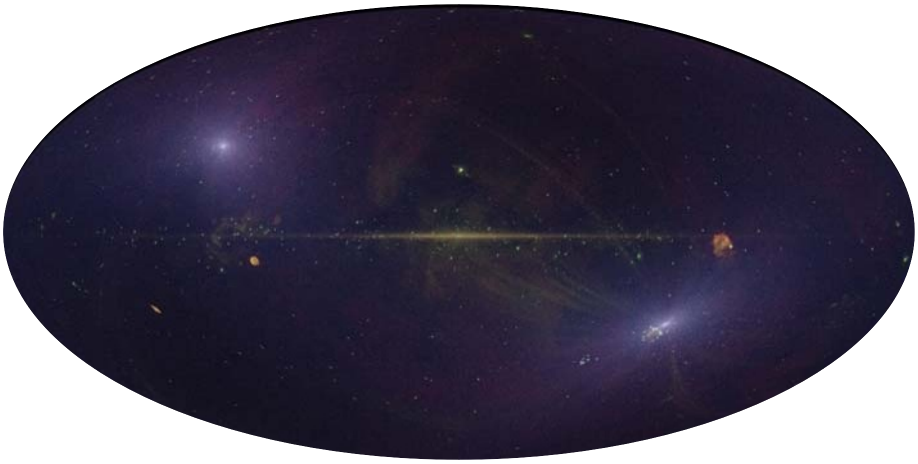
CHANDRAYAAN 2: ISRO; PROTESTORS: HAWAII NEWS NOW

ASTRONOMY & SOCIETY

Protestors Block Thirty Meter Telescope Construction

ON JULY 10TH, HAWAIIAN Governor David Ige and Thirty Meter Telescope (TMT) officials announced that construction of the $1.4 billion, 18-story megatelescope would begin. Shortly thereafter, roughly 1,000 Native Hawaiian activists blockaded the mountain's access road, preventing the passage of construction vehicles.

The protests have remained peaceful, even as 38 protestors, most of them Native Hawaiian elders, were arrested on July 17th. However, due to safety concerns for both vehicles and pedestrians along the only road that ascends to the summit, the directors of the existing Maunakea Observatories took the unprecedented move of shuttering the telescopes on July 16th. The ensuing four-week suspension marked the longest period that all telescopes have been simultaneously offline. Protests are



◀ This simulated image shows what EROSITA will see in its all-sky survey in galactic coordinates. The two bright spots are artifacts due to increased exposure time at the poles.

X-RAYS

German-Russian Satellite to Map X-ray Sky

THE SPEKTRUM-RÖNTGEN-GAMMA (SPEKTR-RG) satellite, a long-delayed and much-modified X-ray astronomy package, launched successfully from the Baikonur Cosmodrome in Kazakhstan on July 13th.

Once Spektr-RG reaches a stable solar orbit 1.5 million kilometers (1 million miles) from Earth, at Lagrangian point L_2, two telescopes onboard will commence mapping the X-ray sky. The first is the German space agency's Extended Röntgen Survey with an Imaging Telescope Array (EROSITA); the second is the Russian-built Astronomical Röntgen Telescope – X-ray Concentrator (ART-XC).

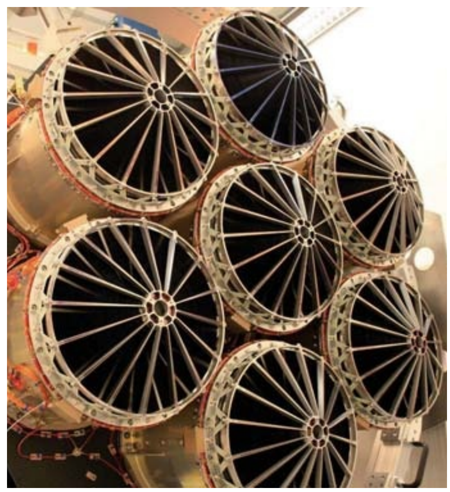
Each telescope contains multiple modules of concentric mirror pairs. X-rays will skip off these mirrors at grazing incidence angles, like smooth pebbles off a pond, before coming to a focus on the detectors. EROSITA's vision is the sharper, with 18-arcsecond resolution, and its wide field of view enables it to survey the full sky eight times over four years. With 25 times the sensitivity of the last all-sky survey, conducted with ROSAT in the 1990s, EROSITA will discover millions of new sources.

ART-XC will focus higher X-ray energies, from 5,000 to 30,000 electron volts (eV), complementing the lower-energy photons that EROSITA is sensitive to (200 to 10,000 eV). The tradeoff for access to higher energies is fuzzier images: The resolution of ART-XC images will be 45 arcseconds.

One of the aims of the joint mission is to better characterize dark energy, the unknown force that determines the universe's expansion rate and ultimate fate. Via its all-sky surveys, EROSITA will detect the tenuous gas swirling in some 100,000 galaxy clusters, cataloging clusters back to when the universe was half its current age. By measuring changes in large-scale structure over cosmic time, astronomers will be able to study the nature of the mysterious repulsive force.

As of early August, both telescopes are undergoing commissioning and working as expected. "It will be exciting to see the sky slowly covered," says principal investigator Peter Predehl (Max Planck Institute for Extraterrestrial Physics, Germany).

■ **MONICA YOUNG**



▶ EROSITA's seven mirror modules on display

◀ Native Hawaiian activists at the base of Maunakea protest the start of Thirty Meter Telescope construction.

continuing at press time, but on August 8th, the observatories announced that they would resume normal operations.

Opposition to the TMT began building in 2009, when the Maunakea site was selected for construction; active protests have continued off and on since 2014. The mountain is sacred to Native Hawaiians, but wrapped in with this devotion is the sovereignty of the Hawaiian people.

"They're utilizing the funds of the people, to protect the rights of foreign investors over the rights of the people of this place," activist Kahoʻokahi Kanuha told the news outlet Big Island Now.

Rich Matsuda, chief of operations at the W. M. Keck Observatory, says that the ongoing tensions are painful for all involved. More than 500 employees work at the observatories, with about 50 to 75 of them at the summit on a typical day. "Observatory workers have been part of the communities of this island for five decades," Matsuda notes. "We're very embedded into the community. Those conversations are happening at the family level. . . . It's very difficult."

The TMT collaboration has applied for a building permit at the secondary site in Spain's Canary Islands, but only to keep options open; for now, TMT officials remain committed to building in Hawaiʻi. Meanwhile, work on the 574 hexagonal mirror segments continues at other locations.

■ **MONICA YOUNG**

● **Read the latest updates at https://is.gd/TMTprotest.**

ALL-SKY VIEW: T. DAUSER / REMEIS-OBSERVATORY / FAU / EROSITA TEAM; EROSITA MIRROR MODULES: P. FRIEDRICH / MPE

EXOPLANETS

TESS Finds Hundreds of Planet Candidates in Southern Sky

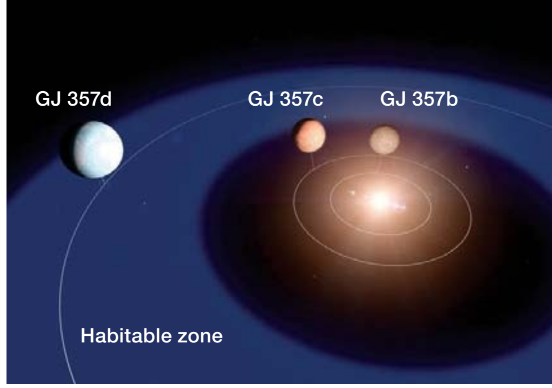
NASA'S LATEST exoplanet hunter, the Transiting Exoplanet Survey Satellite (TESS), has found more than two dozen new worlds that have been confirmed in follow-up observations. Scientists shared their findings late July at the mission's first science conference since the spacecraft's launch in April 2018.

TESS's goal is to find planets around bright stars within 200 light-years of Earth. The spacecraft has scanned all 13 sectors of the Southern Hemisphere sky during its first year of operations. So far, TESS scientists have identified 993 planet candidates in 12 of the 13 southern sectors; 271 of these are smaller than Neptune. A total of 28 of these exoplanets have been confirmed as real via follow-up observations.

One of the newest systems, anchored by a small, *M* dwarf star called GJ 357, hosts three exoplanets. TESS found the innermost world, then astronomers discovered two more planets with ground-based observations of the star's wobble in response to its orbiting exoplanets. The system lies 31 light-years away. The team reports the trio in the August issue of *Astronomy & Astrophysics*.

The outermost planet, GJ 357d, is at least six times Earth's mass. Technically, it orbits on the outer edge of the star's habitable zone, but unless it has a thick atmosphere to trap heat, its surface temperature is likely well below zero. Lisa Kaltenegger (Cornell University) is particularly excited about GJ 357d because the planet should also be relatively bright in reflected light, which means near-future telescopes could characterize its atmosphere.

Besides cataloging exoplanets, TESS is also catching supernovae, asteroids, and other transient events, and even providing evidence of exocomets (*S&T:* Sept. 2019, p. 12).



▲ The outermost planet of the GJ 357 system orbits within the star's habitable zone, so if it has a dense enough atmosphere and a surface, liquid water might exist there.

The TESS mission is set to go at least through 2022. The team will map the northern sky over the next year before moving to an extended observing phase. By the end of the extended mission, TESS will have surveyed 94% of the sky. Among other goals, the extra observations are expected to net long-period planets and multiple-planet systems.

■ DIANA HANNIKAINEN

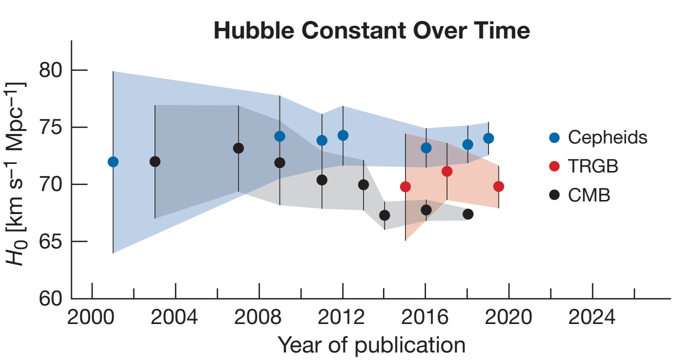
COSMOLOGY

Hubble Constant Tension Continues

A NEW STUDY of a special class of red giant stars fuels a dispute about the rate at which today's universe is expanding.

The universe's expansion rate has changed throughout time. However, the crux of an ongoing debate is that observations of the early universe predict a *current* expansion rate that doesn't match measurements of galaxy recession speeds (*S&T:* June 2019, p. 22). Observations of the cosmic microwave background pin today's expansion rate, also called the *Hubble constant* (H_0), between 66.9 and 67.9 km s^{-1} Mpc^{-1}. However, measurements of galaxies' recession speeds — based on so-called *standard candles* such as Cepheid variable stars — find H_0 to be significantly higher, between 73 and 76 km s^{-1} Mpc^{-1}.

Now, Wendy Freedman (University of Chicago) and colleagues have employed red giant stars — specifically, those that have just made the transition from burning hydrogen to igniting helium — to gauge the distances to galaxies. Their study, which will appear in the *Astrophysical Journal*, reports a Hubble constant between 67.9 and 71.7 km s^{-1} Mpc^{-1}.



◀ Measurements of the universe's current expansion rate differ depending on whether cosmologists assess its value based on measurements of the cosmic microwave background (black), Cepheid variable stars (blue), or a special class of red giant stars (red).

Taken on its own, this result agrees both with measurements of the cosmic microwave background and with nearby standard candles. However, as Freedman and colleagues point out in their paper, the near-far discrepancy remains. Statistically speaking, if CMB measurements represented the true value of the Hubble constant, then you'd expect at least a couple of measurements to fall below that number; however, the red giant measurements still give a Hubble constant that's higher compared to studies of the early universe.

Ultimately, current data won't settle the debate. Freedman's team is looking to the European Space Agency's Gaia mission, which will enable astronomers to estimate the Hubble constant to better than 1% precision within the next few years.

■ MONICA YOUNG

● Read more details at **https://is.gd/HubbleConstant**.

MILKY WAY

Astronomers Map Our Galaxy's Warp

A SURVEY OF MORE THAN 2,400 Cepheid variable stars has revealed the Milky Way's warped disk in new detail, Dorota Skowron (University of Warsaw, Poland) and colleagues report in the August 2nd *Science*.

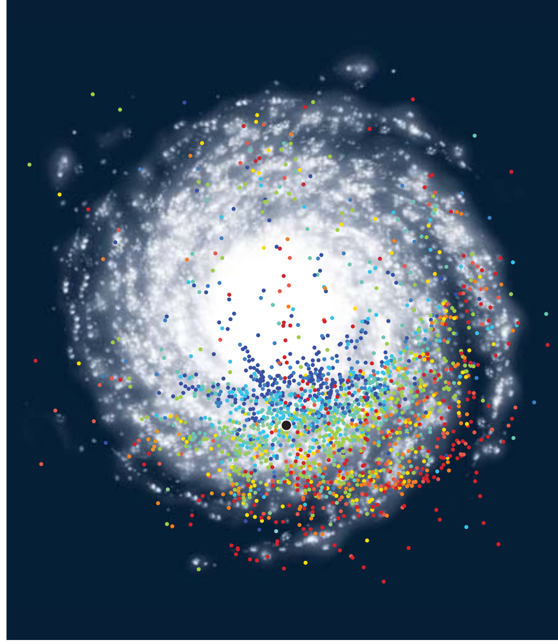
Cepheids are giant stars that breathe in and out at a rate proportional to their intrinsic brightness, a relationship that makes them superb distance markers. Skowron used the Optical Gravitational Lensing Experiment (OGLE), as well as data from five other surveys and catalogs, to map the locations of Cepheids within a few tens of thousands of light-years of the Sun. The project confirms the existence of a severe warp in our galaxy's disk, reminiscent of pizza dough bent in mid-toss. The warp has also shown up in maps using neutral hydrogen gas, stars, dust, and stellar motions, as well as a recent infrared study that used roughly half as many Cepheids as Skowron's team did (*S&T:* June 2019, p. 12).

When they plotted the variable stars' locations looking down at our galaxy's disk, the astronomers noticed that the Cepheids clump together in space. Curious, the team took the three most prominent clumps and calculated the ages of the stars in them. They found that the stars in each group had a similar age to one another — the three groups are approximately 64, 113, and 175 million years old, respectively. The youngest clump's stars cluster tightly together, whereas the oldest clump's stars are the most spread out.

The team speculates that these Cepheid populations were born in three recent bursts of star formation. As time passed, stars that formed together would have naturally gone their separate ways, explaining why the oldest stars are the most spread out. Computer simulations confirm that the starbirth episodes would have stretched into the pattern that the team's map reveals in the Milky Way.

■ CAMILLE M. CARLISLE

● View a video that shows the 3D model of the Milky Way at **https://is.gd/warpedMilkyWay**.



▲ The Cepheids, overplotted on a Milky Way map, range from 30 million (blue) to 400 million (red) years old. The black circle marks the Sun.

▼ An artist's illustration shows how the Cepheids (green points) trace out the Milky Way's warp. A yellow circle marks the Sun's position.

J. SKOWRON / OGLE / ASTRONOMICAL OBSERVATORY, UNIVERSITY OF WARSAW (2)

IN BRIEF

Alpha Centauri Planet Hunt

A new instrument installed on the Very Large Telescope in Chile has completed a 100-hour campaign looking for planets in the Alpha Centauri system. While a planet has already been found around the red dwarf Proxima Centauri, it is probably dessicated (*S&T:* May 2017, p. 10) due to the small star's outsize magnetic activity. Alpha Centauri A and B, however, are larger Sun-like stars whose lower activity levels give planets a better shot at holding onto their atmospheres. Astronomers conducted an observing campaign of the system that ended June 22nd using the Near Earths in the AlphaCen Region (NEAR) instrument. NEAR could detect the presence of planets twice Earth's size or bigger. The astronomers expect to announce the presence — or absence — of large Earth-like planets in the Alpha Centauri system by October.

■ MONICA YOUNG

Galactic Center Gravity Test Confirmed

A team of astronomers has confirmed that the light from a star passing near our galaxy's central black hole behaved as predicted by Einstein's theory of gravity. The star made its closest approach in May 2018, whizzing within 120 astronomical units of the black hole (*S&T:* Sept. 2018, p. 22). Tuan Do, Andrea Ghez (both at the University of California, Los Angeles), and colleagues used the Keck telescopes and other facilities to measure the star's redshift during its close pass, testing Einstein's general theory of relativity. They report in the August 16th *Science* a relativistic redshift of about 200 km/s, confirming an earlier result from a team led by Reinhard Genzel (Max Planck Institute for Extraterrestrial Physics, Germany). The teams' next goal is to measure the star's orbital precession. Explaining how much Mercury's orbit precesses around the Sun was one of the original selling points for general relativity. Now, astronomers want to see if the physics works the same way in the most extreme gravitational environments we can probe. The teams may have results on that front within a year or so.

■ CAMILLE M. CARLISLE

Incoming Asteroid Spotted

Two asteroid hunters, the Asteroid Terrestrial-impact Last Alert System (ATLAS) and the second Pan-STARRS telescope (PS2), worked together to find and calculate the entry path of a tiny, 4-meter space rock that ultimately burned up in Earth's atmosphere. ATLAS is designed to provide early warning of incoming asteroids. The newest discovery, designated 2019 MO, came in the early morning hours of June 22nd. An automated system initially gave the space rock a modest impact rating of 2, but that was upgraded to a "likely" impact rating of 4 when astronomers located the asteroid using additional observations with PS2, which sits atop Haleakalā in Hawai'i. Twelve hours after the asteroid's discovery, Nexrad weather radar in San Juan, Puerto Rico, detected the asteroid as it burned up in the atmosphere over the ocean.

■ MONICA YOUNG

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Saslong Night - Sassolungo da Col Raiser (Italy) – Photo: Cristian Fattinnanzi

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An image of the Saturn V that lofted Apollo 11 into space graces the east face of the Washington Monument on July 18, 2019.

A Fitting Apollo Monument

Fifty years after the fact, the National Mall hosts a spectacular, and deeply moving, celebration.

ON JULY 19TH, I headed down to the National Mall at dusk for a 17-minute show entitled "Apollo 50: Go for the Moon," which the National Air and Space Museum had commissioned. I went with some trepidation. How could they possibly honor Apollo 11 in a way that would live up to the magnitude of the mission? As I've written (*S&T:* July 2016, p. 16), Apollo 11 was an event of evolutionary significance, akin to the moment some 60,000 years ago when humans first left Africa.

I arrived as daylight was fading. The 363-foot (110-meter) Saturn V rocket was projected onto the 555-foot Washington Monument. Klieg lights pointed up at just the right angle to facilitate the remarkably good illusion, and full darkness fell just before the show began. Fueled up and ready to launch, the colossal virtual rocket vented steam, just like the real thing. It looked extremely cool. But what would happen now? Obviously, the monument wouldn't launch into space. So how could what was to follow not be anticlimactic?

A PA system blasted sounds from Mission Control 50 years ago, enhanced by a spacey soundtrack. A hush fell over the Mall as we heard that technicians had closed the protective cover over the hatch and the cabin air had been purged. Beneath the rocket, a 40-foot-wide recreation of the historic Kennedy Space Center countdown clock suddenly illuminated and began ticking down from 5 minutes. A series of enormous screens flanking the monument showed original footage of the scene around the launch — the crowds, Mission Control, and the astronauts themselves.

Then the famous inspirational words of John F. Kennedy, spoken at Rice University in 1962, rang out: "[W]e meet in an hour of change and challenge, in a decade of hope and fear, in an age of both knowledge and ignorance." The monument itself began displaying a sequence of images as the great orator recounted humanity's long path from caves, through the printing press, the steam engine, and the Space Age, and told us why "we choose to go to the Moon in this decade and do the other things, not because they are easy, but because they are hard . . ."

After the vast digital clock counted down to 1 minute, we were "live," watching the steaming spacecraft with the sounds of the penultimate countdown. During the final 10 seconds we all screamed along. The mighty rocket engines fountained flame. No, the monument didn't lift off, but it served as a towering screen where footage of the slow, fiery rise, the acceleration into the blue, and the dramatic first-stage separation all "aired" to brilliant effect. It was simply glorious. I felt wistful, humbled, and proud. Was there a dry eye on the grounds? It was too dark to see, and anyway I had to keep wiping my own tears away just to follow along.

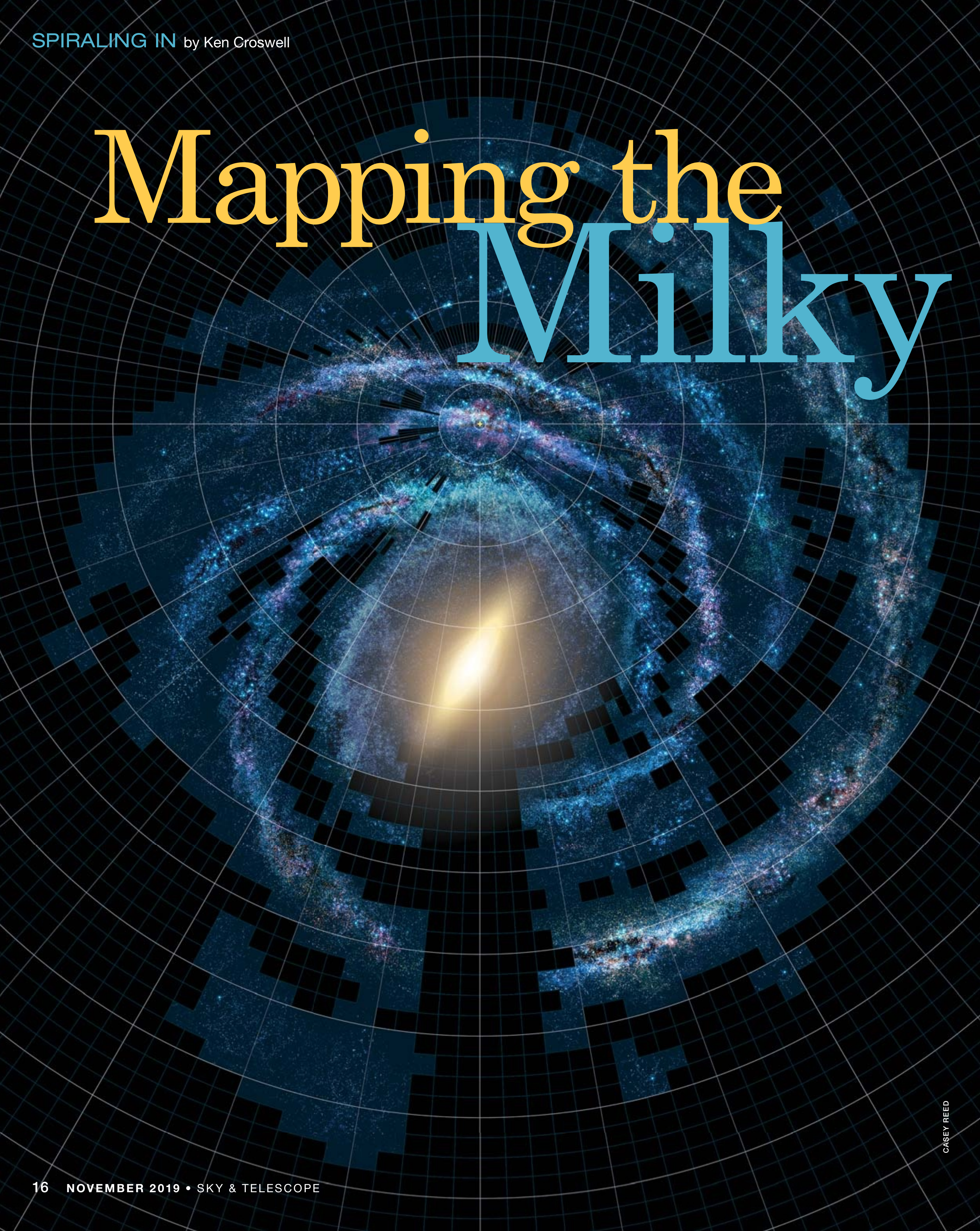
In this divisive time, so rife with anxiety about the future, it was a special gift to be among that throng of thousands all cheering and gasping in unison, embracing a common goal. It was wonderful to be reminded, so viscerally, of a time when the future felt full of promise, and to remember that when we pull together we can solve seemingly insurmountable problems and achieve any future we want.

■ Contributing Editor **DAVID GRINSPOON** is a senior scientist at the Planetary Science Institute.

MATTHEW CARREIRO / SHUTTERSTOCK.COM

 by Ken Croswell

Mapping the Milky



CASEY REED

Recent years have seen tremendous strides in unraveling the galaxy's spiral arms, and the next decade promises the best maps ever made of our celestial home.

Way

If the Milky Way were just an average galaxy, mapping its structure would be a cinch. The average galaxy is a dim, ghostly dwarf roughly a thousand light-years across, so astronomers could easily chart it by measuring the parallaxes of its stars to determine their distances.

But the Milky Way is a galactic colossus, one of the great Goliaths of the cosmos. From end to end the spiral arms inhabit a disk spanning some 120,000 light-years. So huge is the galaxy that nearly every star the naked eye can see belongs to the local spiral arm in which the Sun and Earth dwell. As a result, many astronomers have long despaired of ever knowing how our galaxy would appear from afar.

In recent years, however, visible, infrared, and radio observations have delivered the crispest views yet of the Milky Way's structure. Surprises abound. At least one spiral arm seems to make a complete turn around the galaxy. And precise parallaxes of far-off stellar nurseries have upgraded the status of the spiral feature lodging the Sun.

Best of all, the Milky Way may be much more majestic than many of its spiral peers. "We potentially live in quite a lovely barred spiral," says Thomas Dame (Center for Astrophysics, Harvard & Smithsonian), "and I wouldn't have thought that 15 years ago."

Open Arms

The Milky Way has four main spiral arms, winding out from its central regions and whipped up by its rapid rotation (*S&T:* Apr. 2019, p. 14). If you were above the galactic plane, you'd see the Milky Way's disk spinning clockwise — *opposite* the direction planets orbit the Sun. Because of this clockwise rotation, the arms wend their way counterclockwise from the inner galaxy to the outer. The same thing happens when you stir cream into coffee clockwise: The resulting spiral arms coil counterclockwise from center to edge.

Spiral arms squeeze interstellar gas and dust, making it collapse and give birth to stars. The most massive of these newborn stars are hot blue *O*- and early *B*-type stars that light the arms. That's what Ireland's Lord Rosse saw in 1845 when he spotted the first spiral "nebula," the Whirlpool Galaxy.

Because we are tangled in the thicket of the Milky Way's arms, a full century passed before astronomers established that our galactic home is also a spiral. In 1951 William Morgan (Yerkes Observatory) and his colleagues searched for the red light of gas clouds that newborn *O* and early *B* stars had ionized. These stellar nurseries lay along two parallel arms (*S&T:* Jul. 1984, p. 10). Two years later, he discovered a third spiral arm.

The names of these three arms first appeared in a 1954 scientific paper from the Netherlands, where astronomers were mapping them by observing radio waves from neutral hydrogen gas. Unlike light, radio waves zip through the dust that cloaks the Milky Way's disk. After consulting Morgan, the Dutch astronomers named the spiral arm that winds through the Sun the Orion Arm for its best-known stellar nursery, the Orion Nebula, which lies farther from the galactic center than we do. Today, however, astronomers are more likely to call this arm the Local Arm instead. The Sun is near the Local Arm's inner edge.

The next spiral arm between us and the Milky Way's heart took the name of the galactic center's home, Sagittarius. The Sagittarius Arm boasts such stellar nurseries as the Lagoon, Omega, and Trifid nebulae in Sagittarius, the Cat's Paw Nebula in Scorpius, and the Eagle Nebula in Serpens Cauda.

We view this arm's first tangent point, where it approaches us, in Aquila, and its second tangent point, where it winds away, in Carina. In fact, Carina hosts the Sagittarius Arm's famous resident Eta Carinae, a star system so luminous the naked eye can see it despite its distance of 7,500 light-years.

> "The Local Arm is bigger and more massive and more active in star formation than people had thought." —Mark Reid

On the other side of us, the arm just outside our own became the Perseus Arm, after the young Double Cluster h and Chi Persei. This, too, is visible to the eye, even though no individual star in the Double Cluster surpasses the standard naked-eye threshold of magnitude 6. Despite coursing through the outer galaxy, the Perseus Arm starts closer to the galactic center than we are, arising from the far end of the Milky Way's central bar. The arm then spirals behind the galactic center and curves halfway around the galaxy before passing behind us at the galactic anticenter, the point opposite the Milky Way's core.

At least one spiral arm lurks beyond even Perseus. The so-called Outer Arm is about 49,000 light-years from the galactic center, measured along a straight line from center to anticenter. In 2019, astronomers reported signs of the Outer Arm's gravitational influence, finding that stars near the Outer Arm tend to move toward it, whether on our side of the arm or beyond it. If you follow the Outer Arm as it winds its way inward, it probably joins up with an inner segment called the Norma Arm, so named because we view the arm's tangent point in Norma, a small constellation southwest of Scorpius.

The Local Arm: Spurning the Spur

Decades ago, some astronomers had downgraded the Local Arm we inhabit to just a spur jutting off from either the Sagittarius or Perseus arms. But new observations have partially revived the original claim that the local feature is an arm in its own right — which is great news for us Earthlings, because it's far more exciting to live in a bright and well-lit spiral arm than a mere spur or, even worse, a dark and dreary interarm region.

You can thank radio astronomers for our new and improved standing in the galaxy. "The Local Arm is bigger and more massive and more active in star formation than people had thought," says radio astronomer Mark Reid (Center for Astrophysics, Harvard & Smithsonian). "I don't think this is anything like a spur."

Radio astronomers can link their telescopes into arrays that span entire continents, enabling the measurement of precise parallaxes across vast distances. Furthermore, the same young massive stars tracing the spiral arms also energize electrons in interstellar molecules such as water and methanol. The molecules then emit intense microwaves and become masers, allowing a radio astronomer to measure the parallaxes and thus the distances of the stellar nurseries.

"Maser parallaxes are vital," says Robert Benjamin (University of Wisconsin, Whitewater), who is not part of a team measuring them. "They remove one of the major uncertainties of trying to do galactic cartography."

The recent work has found new distances to numerous star-forming regions in Cygnus, where we look down the Local Arm but also see the more distant Perseus Arm. "Many masers thought to be in the Perseus Arm are instead associated with the Local Arm," says team member Ye Xu (Purple Mountain Observatory, China).

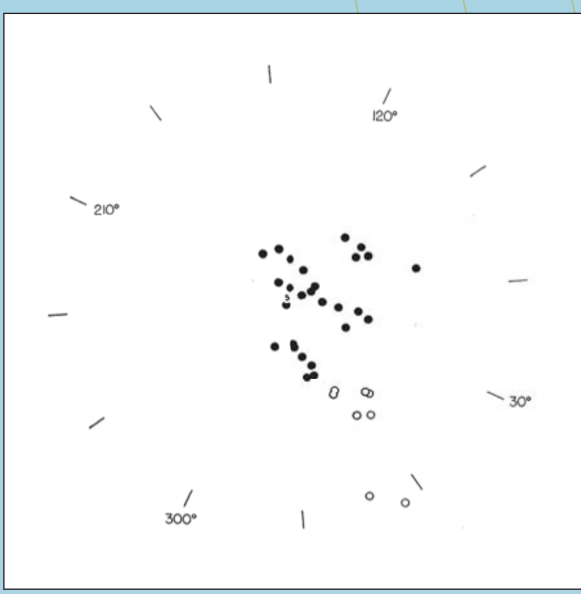
"That was a surprise," says Dame, another team member. "The Local Arm is a much larger feature than previously thought. The amount of star formation in the Local Arm seems comparable to Sagittarius and Perseus on either side. That's another surprising result."

Reid estimates the Local Arm is about 16,000 light-years long and runs about 30° around the galaxy. Xu says its length could exceed 20,000 light-years.

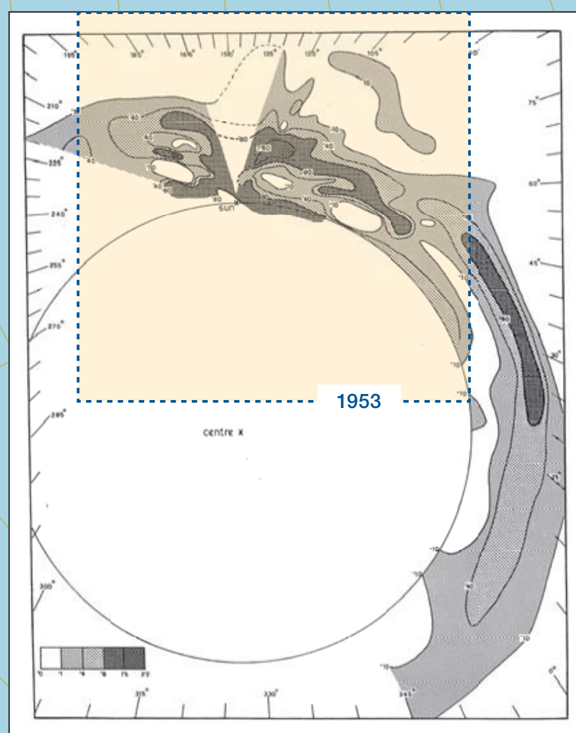
The Local Arm is certainly impressive to stargazers. All stars first-magnitude and brighter are in the Local Arm, even the four farthest: Antares in Scorpius, Deneb in Cygnus, and Rigel and Betelgeuse in Orion. So are nearly all other naked-eye stars. For example, when you look at Sagittarius, the eight stars that compose its beautiful teapot are foreground members of the Local Arm rather than distant denizens of the Sagittarius Arm.

BUILDING THE MAP Plotting the locations of young, massive collections of stars provided early glimpses of our galaxy's spiral arms *(left)*. Maps of neutral hydrogen gas extended our view farther *(center)*. Astronomers eventually identified four large arms *(right)*. Note: Galactic coordinate systems changed between the second and third maps.

1953

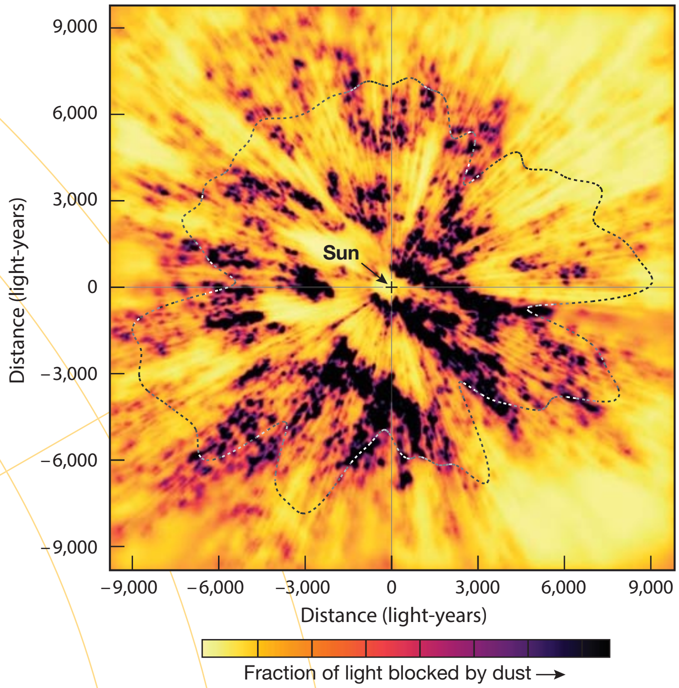


1954



HISTORICAL MAPS: 1953: W. W. MORGAN, A. E. WHITFORD, A. D. CODE / *ASTROPHYSICAL JOURNAL* 1953; 1954: H. C. VAN DE HULST, C. A. MULLER, J. H. OORT / *BULLETIN OF THE ASTRONOMICAL INSTITUTES OF THE NETHERLANDS* 1954; 1976: Y. M. GEORGELIN & Y. P. GEORGELIN / *ASTRONOMY & ASTROPHYSICS* 1976

DUSTY ARMS Because dust is more concentrated within spiral arms than between them, astronomers can map our galaxy's structure by determining how much light the dust blocks from stars of known distances and luminosities. The Sun sits at center, and outside the dotted line sources are too scarce for precise mapping. The burst pattern is merely a byproduct of the analysis.



DUST ARMS: R. LALLEMENT ET AL. / ASTRONOMY & ASTROPHYSICS 2019

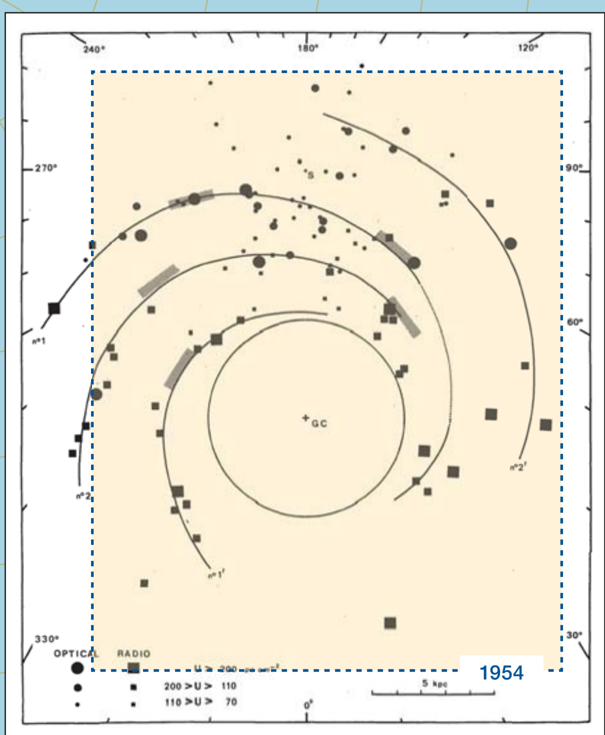
Red Antares and its blue neighbors in Scorpius also reside in the Local Arm. They spangle the Scorpius-Centaurus Association, the nearest group of massive stars, 400 to 500 light-years from Earth, right on the inner edge of the Local Arm. Beyond is the darkness of the interarm region between the Local and Sagittarius arms.

A 2017 paper analyzed different studies and plotted how far the Sun and various arms lie from the galactic center. The researchers put the middle of the Sagittarius Arm at 23,800 light-years, the Sun at 27,000 light-years, the middle of the Local Arm at 28,000 light-years, and the middle of the Perseus Arm at 33,600 light-years. These distances are along the line joining the galactic center with the anticenter. Each distance is probably uncertain by at least 1,000 light-years.

Alas, the separations between the Sagittarius, Local, and Perseus arms carry some bad news for us Earthlings. In other barred spiral galaxies, the major arms usually lie farther apart, which implies that the Local Arm — though lively and lustrous over its length — is not a full-fledged arm that encircles much of the galaxy. "I call it an armlet," says Jacques P. Vallée (Herzberg Astrophysics, Canada).

"The best word would be *arm segment*," says Reid, who thinks the Local Arm could be a branch from the Perseus Arm in the constellation Cygnus. Such forks split spiral arms in other galaxies, too, including beautiful M101 in Ursa Major. Still, over its length, the Local Arm seems as vigorous as its neighbors in Sagittarius and Perseus.

1976



A Call to Arms

It's not just radio observations that have sharpened our view of the Milky Way. So have observations in the infrared. In 2005 data from the Spitzer Space Telescope led to a controversial conclusion: "All arms are not created equal," Benjamin says. Instead, he explains, two of the main arms are grander than the other two; they extend from either end of the Milky Way's central bar, while the two lesser arms originate elsewhere in the galaxy's inner sanctum.

Theory says a spinning galaxy can indeed develop two different types of spiral arms. The first and more massive type is a density wave, full of stars old and new. These arms are so massive their gravity whips up additional arms midway between them in the galaxy's gas. These gas arms spawn new stars but have no excess of old ones.

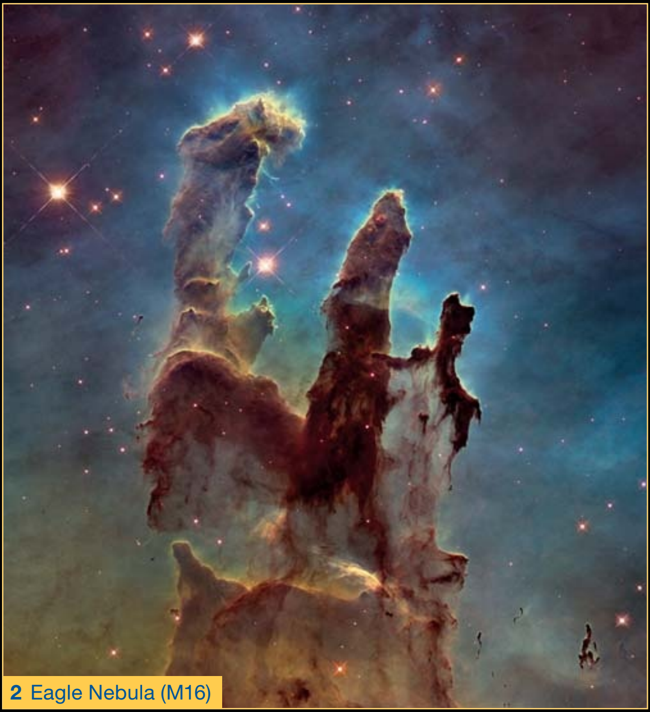
Benjamin considers the Milky Way's two greater arms to be the Perseus Arm and its twin, the Scutum-Centaurus Arm. The latter arises from the near end of the central bar and winds between the galactic center and the Sagittarius Arm, approaching us in Scutum, a small constellation squeezed between Aquila and Sagittarius. In Scutum we view the arm's tangent point, which explains the first half of the Scutum-Centaurus Arm's name. The arm continues through Sagittarius and Scorpius, then curls away from us in Centaurus, where we view the arm's other tangent point.

(continued on page 22)

OUR GALAXY

The Milky Way has a few main arms and several smaller ones. Since this diagram's creation in 2008, astronomers have detected the New Arm, probably an extension of the Scutum-Centaurus Arm. The Perseus Arm has proved patchier (sparse sections hazed out) and the Local Arm brighter and longer — observers suspect it might hook up with Perseus near 70° galactic longitude (dotted line). Locations of familiar citizens of the Perseus, Local, Sagittarius, and Scutum-Centaurus arms are highlighted.

1 h and Chi Persei



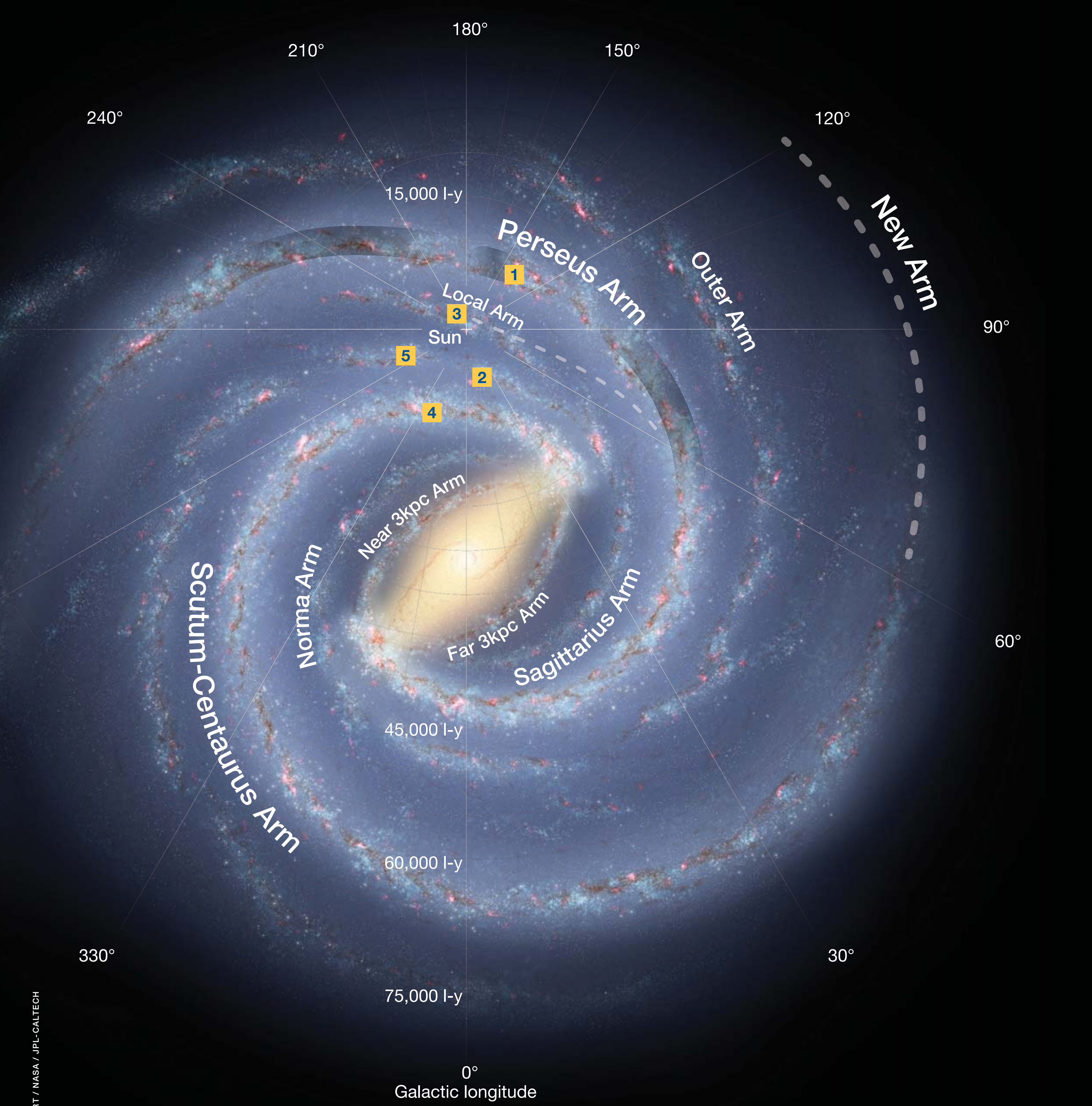
2 Eagle Nebula (M16)

3 Orion Nebula (M42)

4 Westerlund 1

5 Eta Carinae

PERSEI DOUBLE: ROTH RITTER; EAGLE: NASA / ESA / HUBBLE HERITAGE TEAM; ORION NEBULA: NASA, ESA, M. ROBBERTO (STSCI / ESA), HUBBLE SPACE TELESCOPE ORION TREASURY PROJECT TEAM; WESTERLUND 1 AND ETA CAR: NASA & ESA / HUBBLE



MAP: R. HURT / NASA / JPL-CALTECH

(continued from page 19)

Both these great arms, he explains, possess not only gas and young stars but also old stars: orange *K* and red *M* giants. These cool aging stars glow in infrared light, and the Spitzer data along the inner galactic plane show these old stars piling up in Centaurus, one of the tangent points of the Scutum-Centaurus Arm. Scutum may have a stellar excess, too, but things are less clear because here the galaxy's central bar also contributes red giants.

In contrast, Benjamin saw no pileup of old stars in Aquila, a tangent point of the Sagittarius Arm. This suggests the Sagittarius Arm has gas and young stars but no surplus of old stars. Ditto for the Outer Arm, because no rise in star counts appears in Norma, the Outer Arm's inner component.

In 2008, Benjamin's team asked astronomer and artist Robert Hurt (Caltech) to make a map that incorporated recent discoveries. This map is so beautiful and informative that it has since appeared in publications ranging from *National Geographic* to *The Astrophysical Journal*. The map depicts the prominent Scutum-Centaurus and Perseus arms leaving the Milky Way's central bar, mirror images of each other, with the Sagittarius and Outer arms less prominent. In most other barred spiral galaxies, the bar also gives rise to two dominant arms. This argues the Milky Way is similar.

"And my counterargument is the Milky Way is not like them," says Vallée, who thinks instead that the galaxy's four main arms — Scutum-Centaurus, Sagittarius, Perseus, and Outer — are equal, each having both young and old stars. A substantial minority of barred spirals, he notes, do sport arms that are all equally prominent.

Vallée says the Sagittarius Arm is so dusty it blocks Spitzer's view of the old stars there. Benjamin counters that infrared light normally penetrates such dust. Also, in 2000 Ronald Drimmel (National Institute of Astrophysics, Italy) saw only the two prominent arms in the infrared data he analyzed.

The Far Side: The Galaxy Imitates Art

In 2011, Dame and Patrick Thaddeus (Center for Astrophysics, Harvard & Smithsonian) discovered that the Scutum-Centaurus Arm wraps around not just the near side of the galaxy but also its far side. The astronomers mapped molecular clouds some 50,000 light-years beyond the galactic center and traced the arm from the constellation Sagittarius into Aquila and Vulpecula.

Ironically, that extension is on the map Hurt had made three years before. "I was shocked actually," Benjamin says. "I should have looked at that artist's picture and had the courage of its convictions." Because the map shows symmetry between the Scutum-Centaurus and Perseus arms, Dame and Thaddeus argued that their discovery upped the chances that the Milky Way is a fairly orderly galaxy, in contrast with the many spiral galaxies whose structure is less striking.

Another breakthrough came in a 2015 paper, when Yan Sun (Purple Mountain Observatory, China) and colleagues detected a "New Arm" by tracking molecular clouds from Cepheus and Cassiopeia into Perseus and Camelopardalis. The team proposed that the feature may be a further extension of the Scutum-Centaurus Arm. "It's just amazing that the Scutum-Centaurus Arm would still be going," Dame says.

GALACTIC TWIN? Depending on their picture of the Milky Way, astronomers favor one of these three galaxies as most resembling ours.

NGC 3953: HEWHOLOOKS / CC BY-SA 3.0; NGC 6744: ESO; UGC 12158: NASA & ESA / HUBBLE

The molecular clouds reside beyond even the Outer Arm, lying 46,000 to 71,000 light-years from the galactic center. The discovery suggests the Scutum-Centaurus Arm makes more than a full turn around the Milky Way.

Recent work has further elucidated the Scutum-Centaurus Arm. In 2017, Alberto Sanna (Max Planck Institute for Radio Astronomy, Germany) and colleagues measured the parallax of a maser on the far side of this arm, in the constellation Sagittarius, 67,000 light-years from Earth. This work indicates how fast the outer Milky Way spins on the opposite side of the galaxy and thus provides a glimpse of the Milky Way's rotation curve there.

Other recent work has illuminated the Perseus Arm. European astronomers looking near the galactic anticenter reported in 2015 that they saw an excess of stars in the Perseus Arm, some of which were old enough to have circled the galaxy more than once. The astronomers also detected dust in front of these stars. Similar dust lanes often line the inner edges of arms in other spiral galaxies.

But some parts of the Perseus Arm seem barren. "I'm beginning to get the feeling, especially for the Perseus Arm, that once you go too far into the outer galaxy, demanding that things are continuous and well-ordered is maybe asking too much of the Milky Way," Benjamin says. The Perseus Arm lacks much molecular gas and star formation over long stretches in Vulpecula and Cygnus. Such gaps exist in the outer arms of other spiral galaxies, too, including M101.

Despite recent progress, maser parallaxes currently suffer from a blind spot. Most radio telescopes are in the Northern Hemisphere, but mapping the Milky Way's southern domain requires radio telescopes in the Southern Hemisphere. To rectify this problem, Reid is working with astronomers in Australia and hopes to have a better map of the Milky Way in five years.

Still, even with our present understanding, the Milky Way now appears to be a giant and fairly symmetric barred spiral galaxy with four main arms — perhaps equal to one another, perhaps not — that may be a little ragged around the edges. And we ourselves belong to the vibrant Local Arm, whose massive stars, leading bright but brief lives, add splendor to the night.

What's in a Name?

Astronomers have sometimes used different names for individual spiral arms, which can cause confusion. Here's a list of some spiraliferous pseudonyms:

Scutum-Centaurus Arm: Scutum, Centaurus, Scutum-Crux

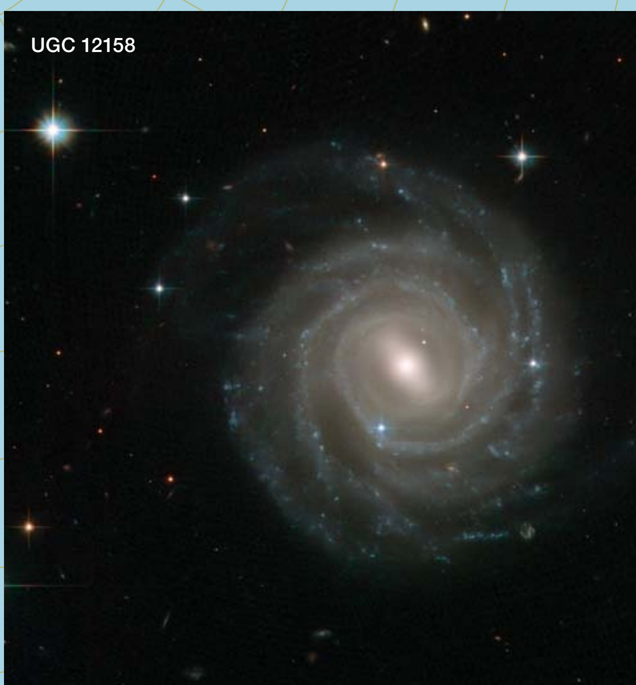
Sagittarius Arm: Sagittarius-Carina

Local Arm: Orion Arm, Orion Spur, Local Spur

Perseus Arm: always called Perseus

Outer Arm: Perseus+1, Cygnus-Norma

New Arm: always called New (at least for now)



UGC 12158

The Milky Way's Twin

Of all the galaxies that populate the cosmos, there must be some that look like the Milky Way. With our new knowledge of spiral structure, which galaxy do astronomers think most resembles ours?

Dame and Reid both cite UGC 12158, an attractive barred spiral 450 million light-years away in Pegasus. "You can match it up pretty well with the Milky Way in many ways," Reid says.

Vallée points to another barred spiral, NGC 6744 in Pavo, 30 million light-years from us. "It's a grand design with four arms," he says, and the arms are equally prominent, like his model for the Milky Way.

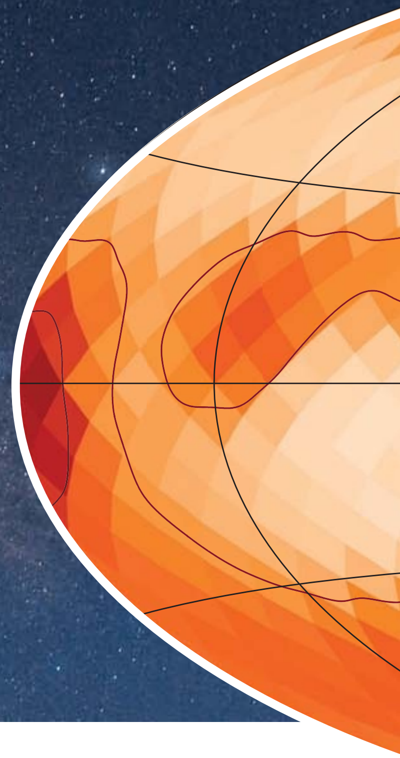
"My fave is NGC 3953," Benjamin says, referring to a barred spiral in Ursa Major some 50 million light-years away. "It's the kind of galaxy that has enough order so that you can see it as orderly but enough messiness that you can see it as messy."

And this may be the best news of all for Earthlings: The three galaxies these scientists choose are all stunning and striking celebrations of light. Thus, not only do we live in one of the largest of galaxies, but we may also be fortunate enough to inhabit one of the most beautiful.

■ **KEN CROSWELL** earned his PhD at Harvard University for studying the Milky Way, and his 1995 book about the galaxy, *The Alchemy of the Heavens*, was a *Los Angeles Times* Book Prize finalist.

STELLAR FAÇADES by Christopher Crockett

Seeing Stars



Astronomers are linking arrays of telescopes together to reveal the long-hidden visages of faraway suns.

For all the time that humanity has spent gazing at the stars, we still know shockingly little about what they actually look like. Even with the biggest telescopes, nearly every star except our Sun appears as a speck of light, their surfaces hidden from view.

Some stars, however, are ready for their close-up.

At the southern tip of the constellation Andromeda sits Zeta Andromedae, a moderately bright orange giant that is now part of an elite club: It is one of a handful of stars to have its surface mapped by astronomers. In 2016, Rachael Roettenbacher (Yale University) and colleagues revealed the star's portrait in new detail: a patchy orb 15 times as wide as the Sun and slathered in gargantuan dark spots.

"Everything we do in astronomy is based on our understanding of stars."

Zeta's portrait isn't like the gorgeous space images that grace magazine covers. This picture is blurry and pixelated. But to astronomers it is captivating, and a reminder that much about stars remains a mystery.

In the case of Zeta, the puzzle is its pockmarked face. Star spots mark where magnetic fields punch through the surface, and Zeta's spots are laid out differently than spots on the Sun. While sunspots gather in mid-latitude bands, symmetrically straddling the equator, Zeta's show up everywhere with no discernible pattern. The Sun is free of spots at its highest latitudes; Zeta has one large spot squatting on its north pole.

"Every star is uniquely complicated," Roettenbacher says. "We don't have too many of these surfaces, but we do see that they're all distinctly different."

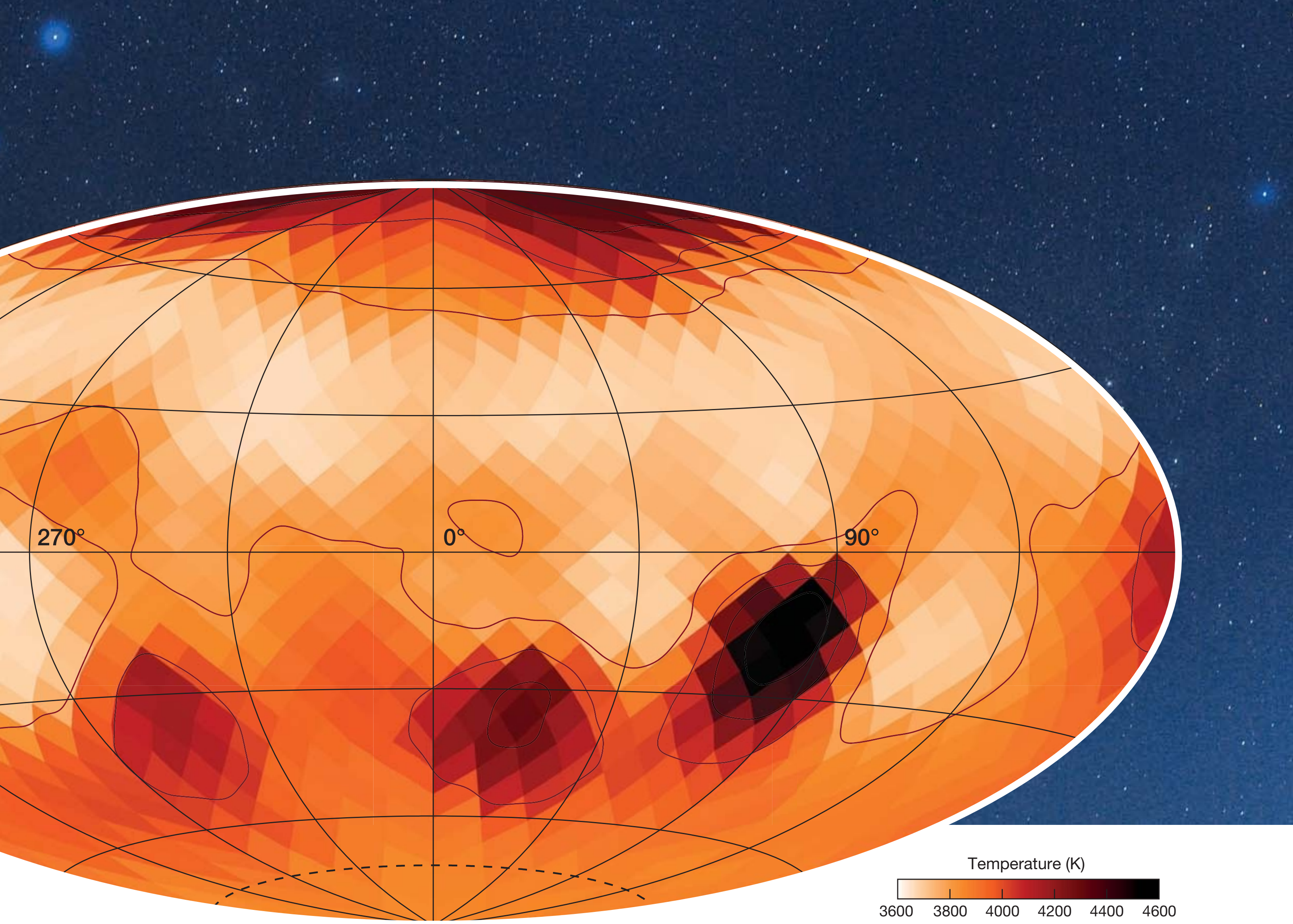
"People don't realize that stars are not that well known," says Fabien Baron (Georgia State University). But a handful of observatories are beginning to change all that. These facilities combine many telescopes to see details no single telescope can see and finally reveal the faces of the stars.

The Trouble with Stars

"Everything we do in astronomy is based on our understanding of stars," says Michelle Creech-Eakman (New Mexico Institute of Mining and Technology). Stars light up the darkness and churn out the raw ingredients needed to build more stars, planets, and people. "If we don't get the stellar physics right, we can't answer questions that are important for galaxies." Our knowledge of other planetary systems, she adds, also depends on assumptions about their host suns.

A star's surface is its primary connection with the universe. It's the gateway through which matter and energy pass,

BACKGROUND: ESO / BABAK TAFRESHI

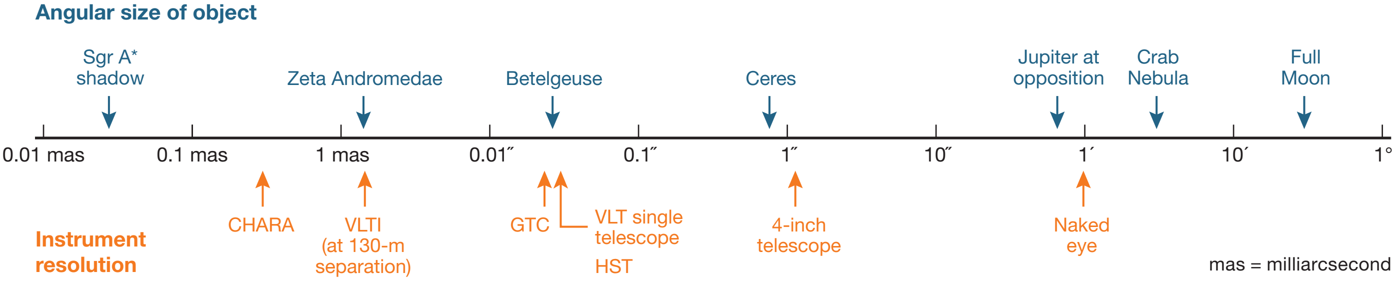


and for astronomers it's a window into what makes the star tick. Churning bubbles of plasma provide clues about how energy percolates into space. Dark spots trace out magnetic activity generated by swirling electrical currents far below.

But stars keep their surfaces well hidden from us. Look at a star through a telescope, and you see just a brighter point of light. A telescope's ability to distinguish features on some remote object is set by the diameter of its main lens or mirror (as well as the wavelengths of light it collects). The wider the telescope, the more detail it reveals.

▲ **MOTTLED STAR** This surface map of the star Zeta Andromedae reveals a giant spot at the star's north pole (top) and multiple spots at lower latitudes. Over time, the polar spot persisted, while the others proved transient. *Below:* Comparison of various sources' angular sizes and instrument resolutions.

The trouble with stars is that they are too far away to be resolved as anything but pinpricks. Seeing details is akin to discerning a mattress on the surface of the Moon. The largest optical telescope on Earth, the Gran Telescopio Canarias



SURFACE MAP: RACHAEL ROETTENBACHER; SIZE AND RESOLUTION COMPARISON: GREGG DINDERMAN / S&T

This ability is giving astronomers a chance to see what's in store for the Sun when its hydrogen fuel runs out nearly 7 billion years from now.

on the Canary Island of La Palma, is 10.4 meters (34.1 feet) across and could just make out a baseball diamond on the lunar terrain under optimal conditions. Seeing a mattress would require a telescope about 12 times as wide.

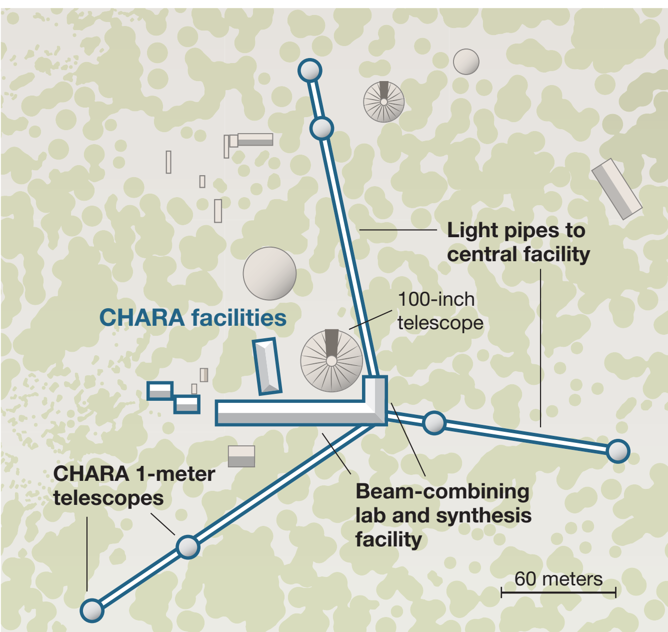
There are exceptions, if the star is big enough and close enough. Betelgeuse, the famous red supergiant on the shoulder of Orion, leads the pack here. In 1921, American physicist Albert Michelson and astronomer Francis Pease relied on Betelgeuse to make the first direct measurement of a star's size, coming up with a diameter of 390 million km (240 million miles) — a bit wider than the orbit of Earth. In 1995, the Hubble Space Telescope snapped a couple of fuzzy images of Betelgeuse's surface, the first direct image of a star other than the Sun (*S&T:* May 2019, p. 34). But if astronomers have to rely on the few stellar heavyweights in our neighborhood, they're not going to make much progress.

Fortunately, there is a workaround. One telescope hundreds of meters across is impractical. But intertwining the light from several small telescopes scattered across hundreds of meters of terrain delivers the same resolution. "We've cheated to build a big telescope without paying for it," says Gerard van Belle (Lowell Observatory).

Interfering with Light

A conventional telescope is a big bucket that collects light and focuses it to an eyepiece or detector, forming an image.

▼ **SPLAYED ARRAY** The CHARA Array combines the light from six 1-meter telescopes, laid out in a Y formation on Mount Wilson.



Before it gets focused, the light from a single star washes over the telescope's entire mirror (or lens), so you can remove a chunk of the mirror and still see the star. Keep smashing away until just a few patches of mirror remain, and the focused image won't be a picture in the traditional sense. Interfering light waves from the disparate mirrors will create a kaleidoscope of light that looks more like the rain-speckled surface of a pond than a cosmic vista. But those speckles encode much of the same information that would have ended up in the traditional image.

"We get the information that is connected to the picture, but we kind of get it in dribbles and drabs," says van Belle. With the help of software working through some clever math, it's possible to deduce what the image would have looked like.

Now, there's no reason the small mirrors have to sit in the same telescope. As long as the light waves from each mirror travel the same distance to their meeting point — dilly-dallying by no more than one millionth of a meter — the mirrors can sit anywhere.

So, place those mirrors hundreds of meters apart in telescopes of their own. Direct the light from each mirror into long vacuum tubes that use additional mirrors on sliding carts to maintain constant light travel times as the star traverses the sky. Steer the light into a central hub where the waves from each mirror can overlap and interfere with one another.

Congratulations: You just built an astronomical interferometer.

Radio astronomers have been doing this for decades, culminating recently in the first direct image of a black hole (*S&T:* Sept. 2019, p. 18). This feat was made possible by hooking up seven radio telescopes across the globe to simulate a single antenna as wide as the planet.

But radio astronomers have it a bit easier than optical ones do. To keep the radio waves from all telescopes in perfect synchrony, astronomers can record the full swell of each wave and line them up in a computer later. Interferometers that capture visible and infrared light don't have that luxury: The waves wiggle too fast to capture every crest and trough, so they must be lined up and merged on the fly.

"The light has traveled sometimes for thousands of light-years, and now you want to very precisely correct the path," Baron explains. "That has taken many years to refine the technique."

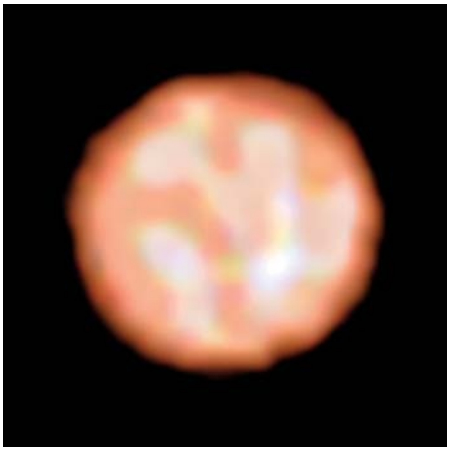
Only a few facilities have this ability. Atop Mount Wilson, just north of Los Angeles, lies the Center for High Angular Resolution Astronomy (CHARA). Run by Georgia State University, CHARA hosts six 1-meter telescopes that can simulate a single telescope up to 331 meters wide. It was here that Rachael Roettenbacher saw spots on Zeta Andromedae as well as on Sigma Geminorum, a comparable star also in its

CHARA: GREGG DINDERMAN / S&T

retirement years (and with yet another pattern of spots). The location is fitting — next to the center of the array sits the Hooker telescope, where Michelson used the same principles to size up Betelgeuse nearly a century ago.

A day's drive from Mount Wilson, in the pine forests of northern Arizona, sits the Naval Precision Optical Interferometer, the largest such facility, with telescope separations as large as 432 meters. Keep heading east and just outside Socorro, New Mexico, you'll run into the construction site for the Magdalena Ridge Observatory Interferometer, where scientists are assembling an array of 10 linked telescopes. Finally, in Chile's high-altitude Atacama Desert lies the European Southern Observatory's Very Large Telescope Interferometer, which can link as many as four telescopes up to 202 meters apart.

These observatories, with newfound abilities to simultaneously combine the light from all of their telescopes, are in the vanguard of the optical and infrared interferometry revolution. "We're starting to really get into the astrophysics of what's happening on the surfaces of stars," says Gail Schaefer (CHARA).



◀ **PI¹ GRUIS** Each of the convection cells on the surface of this aging star spans about 120 million km, grown to gigantic proportions due to the bloated star's weakened surface gravity.

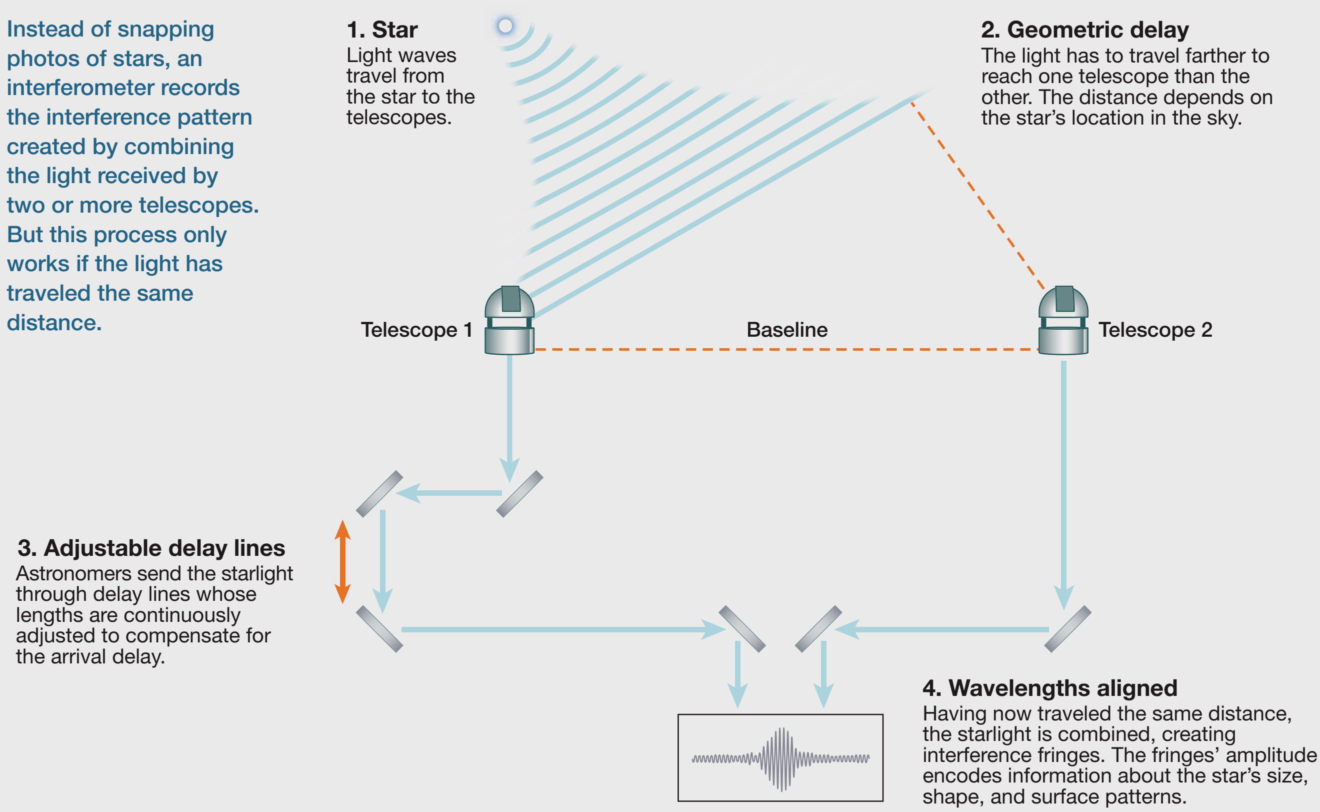
Getting Personal with the Stars

This ability is giving astronomers a chance to see what's in store for the Sun when its hydrogen fuel runs out nearly 7 billion years from now. They can do this by finding dying stars with comparable masses to the Sun. Zeta Andromedae was one such candidate. Another is a star designated Pi¹ Gruis, about 530 light-years away in the constellation Grus, the Crane. In 2017, researchers published this red giant's picture.

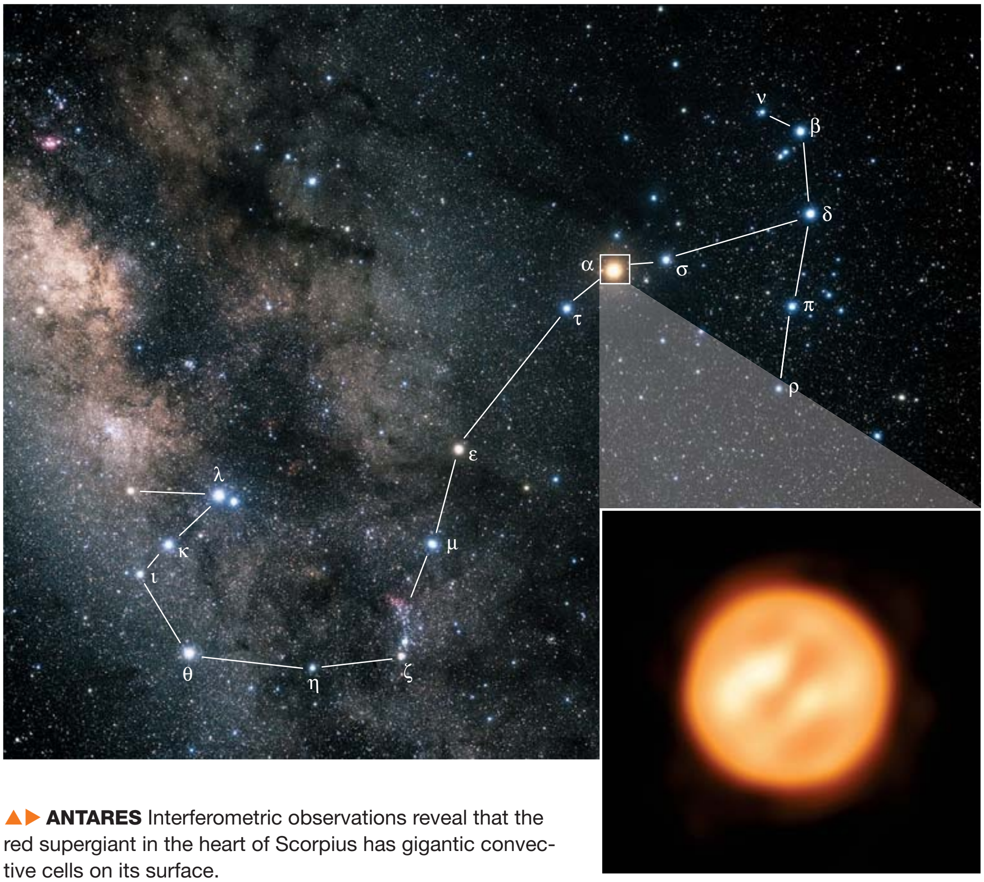
"I was disappointed that it was round," says Claudia Paladini (ESO), who led the project. Pi¹ Gruis is one step removed from shedding its gas and metamorphizing into a luminescent cloud known as a planetary nebula. But planetary nebulae are not round: Their glowing tendrils often stretch out more in one direction than another. And that transition is a bit of a mystery. "We don't know how to go from something round to that," says Paladini (*S&T:* Nov. 2014, p. 20).

While Pi¹ Gruis was mum about how planetary nebulae

HOW INTERFEROMETRY WORKS



STAR: ESO; INTERFEROMETRY: LEAH TISCIONE / S&T



▲▶ **ANTARES** Interferometric observations reveal that the red supergiant in the heart of Scorpius has gigantic convective cells on its surface.

get their shape, the researchers did see vast bubbles of plasma on the surface boiling up from the interior and spanning more than one-quarter of the star's diameter. Just one of those bubbles, known as convection cells, would fill about 80% of the space between Earth and the Sun.

This confirms what astronomers suspected from theoretical calculations: Weakening gravity on the surfaces of dying stars leads to oversized convection cells. But "there's so much physics going on that we still don't know," says Paladini. "The next step . . . is to see how long they last on the surface." Such details could help astronomers better understand how energy churns about in aging stars.

Pi[1] Gruis offers a potential glimpse into the Sun's future. But stars that are significantly heftier evolve in a different way. That's partly what drew Keiichi Ohnaka (Catholic University of the North, Chile) to aim the VLTI at Antares, the dazzling red star that marks the heart of the constellation Scorpius, the Scorpion.

Lying about 550 light-years away, Antares is roughly 12 times as massive as the Sun — heavy enough to one day explode in a supernova. "We know these dying stars are losing mass, but we still don't know yet how," says Ohnaka. Some force must be working against the star's gravity, but the exact physics is unknown. This phenomenon, he says, "is quite important to understanding how material is recycled in the universe."

To chip away at this mystery, Ohnaka and colleagues used the VLTI to chart gas motions on and near Antares. By measuring Doppler shifts in the light from the gas, the team found enormous gas clumps racing towards and away from us at speeds of up to 20 km/s (45,000 mph). The splotchy images revealed that this chaotic environment extends more than 330 million kilometers from the star's surface — a distance equal to about 70% of the star's radius.

The pattern of gas motion strongly resembles patterns generated on the star's surface from convection. That seems to suggest some link between convection and mass loss — but in computer simulations of supergiant stars, convection stirs up only gas that's snuggled up to the star.

"Convection exists, but it can't shoot up so high," he says. It appears that the computer simulations are missing some element. But it's not clear yet what that is.

Gonna Need a Bigger Interferometer

Getting to this point has been a long road. "For the longest time, it was a technical art to actually make this work," Schaefer says. But now, she says, we have arrays producing science on a routine basis.

The biggest limitation is that interferometers can see only fairly bright, relatively nearby stars. To widen their net, astronomers are going to need arrays of telescopes spread across a kilometer or more of terrain. "If we have these, then we will start being able to make images of our neighbors — of Tau Ceti, of Epsilon Eridani — and really see Sun-like stars," Baron says. Although an engineering challenge, when it comes to physics, "there's no real obstacle to it," he adds.

Since 2013, John Monnier (University of Michigan) has been leading the charge for a ground-based interferometer known as the Planet Formation Imager (PFI). As its name implies, PFI would be able to see the infrared glow of giant planets forming around young stars.

That kind of resolution demands about a dozen 3-meter-wide telescopes separated by up to 1.2 kilometers, which would be like having one telescope as wide as Meteor Crater in Arizona. "We can do it right now," says Monnier. "It's mostly the cost." He estimates the price tag at around a half billion dollars, though his team is looking at ways to knock that down by a few hundred million.

"We're just in this transition in our field . . . the next gen-

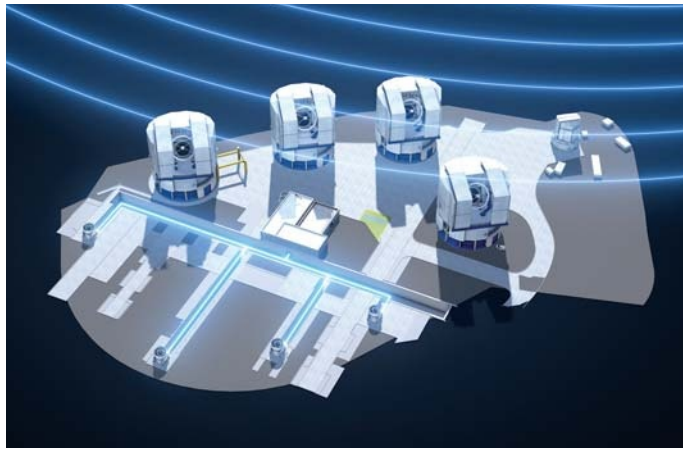
SCORPIUS: AKIRA FUJII; ANTARES SURFACE: ESO / K. OHNAKA eration is not cheap," he says. "The science we can do can be pretty incredible if we can find a way to pay for it." With PFI's resolution, astronomers could not only watch planets form, but they could also see dust circling behemoth black holes in other galaxies.

As for stars, researchers would no longer be limited to nearby giants. Their vision could even extend beyond our galaxy. Paladini says that PFI would allow her to study a star like Pi^1 Gruis in the Magellanic Clouds, which are roughly 340 times farther away than Pi^1 Gruis itself.

But some interferometer plans are aiming even higher — literally. "My dream interferometer would be in space," Roettenbacher says. Here, each telescope would get its own spacecraft. A fleet of these craft, relying on laser-based guidance to maintain precision formation, would collect starlight and focus it into a central mother ship, where the light from the separate scopes would be combined. This flotilla would get above the blurring effects of Earth's atmosphere and could be quickly reconfigured to meet science needs.

NASA has been tossing the idea around for nearly two decades, but other missions keep stealing the spotlight. However, Ken Carpenter (NASA Goddard), who has been pushing for a space interferometer since the early 2000s, remains optimistic.

"You have to go to interferometers at some point, because you can't make . . . telescopes large enough to do all the stuff that you want to do," he says. The next generation of interferometers, whether on the ground or in orbit, could reveal details about many types of stars in various stages of their lives. Those details could in turn put the Sun in context and help astronomers better predict solar activity that meddles with life and the environment on Earth.

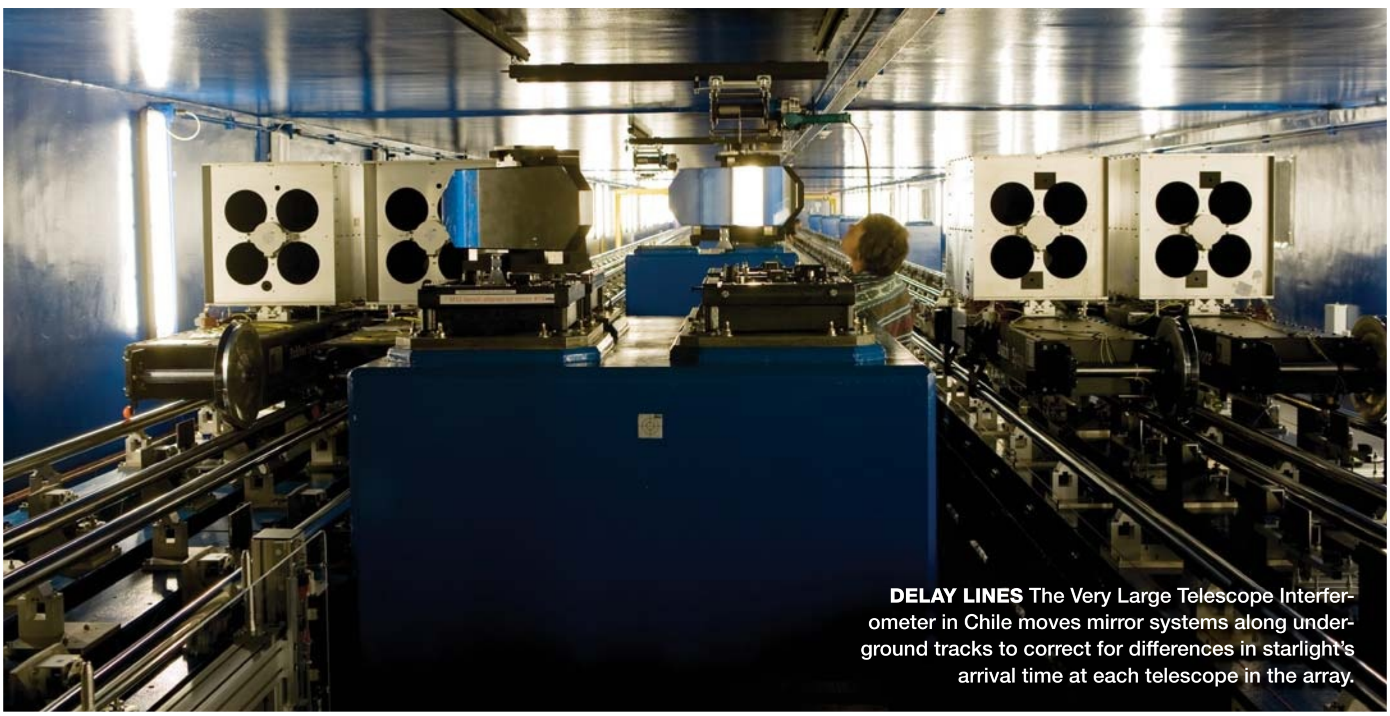


▲ **CHILEAN BEAMS** This illustration of the Very Large Telescope Interferometer in Chile shows light from the four 1.8-m Auxiliary Telescopes (which are movable) traveling through tunnels to be combined in the central laboratory. Astronomers can mix and match up to four ATs or 8.2-m Unit Telescopes (larger structures shown) as an interferometer.

"It's not just an abstract goal of understanding how stars work," says Carpenter. "It can actually have an impact on life and the habitability of planets."

Ultimately, all astronomy research is part of a quest to understand where we came from and where we're going. Today's fuzzy glimpses at the surfaces of stars may be just the first steps of a new generation of observatories that brings the universe — and our place in it — into much sharper view.

■ **CHRISTOPHER CROCKETT** is an astronomer-turned-science-journalist who dabbles in theater production with his wife (and three fur children) in the wilds of Washington, D.C.



DELAY LINES The Very Large Telescope Interferometer in Chile moves mirror systems along underground tracks to correct for differences in starlight's arrival time at each telescope in the array.

VLTI: ESO / L. CALÇADA; DELAY LINES: ESO / H. H. HEYER

ENCYCLOPAEDIA BRITANNICA / UNIVERSAL IMAGES GROUP / GETTY IMAGES

Orator *of the* Stars

A captivating speaker and educator, Ormsby MacKnight Mitchel helped popularize astronomy in America in the mid-19th century.

One clear evening, an older brother carried three-year-old Ormsby MacKnight Mitchel outdoors to behold the golden crescent Moon in the star-filled heavens. The brother later recalled, "With the apparent gravity of a savant, almost with a gasp, you exclaimed: 'Mans can't make moons.' . . . This was your first lecture."

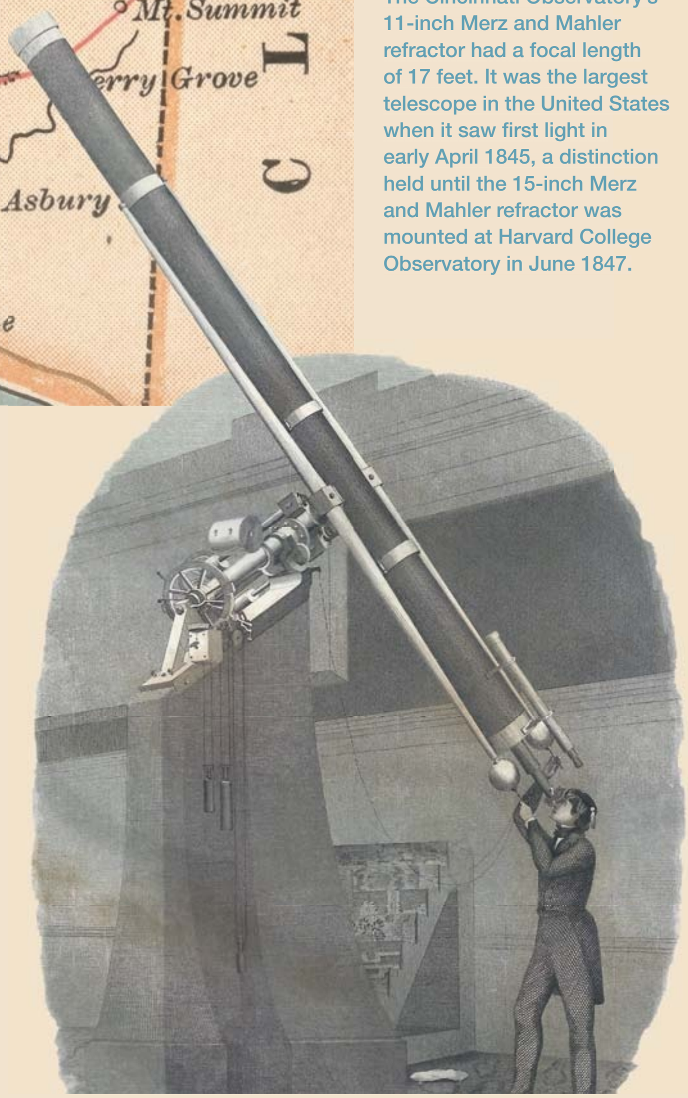
Mitchel never set out to be an astronomer — indeed, his twenties were spent trying out various professions. But the skills he developed doing other things became essential to his success in founding and funding the Cincinnati Observatory, and in inspiring passion for astronomy and observatories throughout 19th-century America. Moreover, as recent scholarship reveals, Mitchel was not merely a world-famous popularizer but also a respected research astronomer.

Born Scholar

Mitchel was born in Morganfield, in western Kentucky, in late July 1809, the youngest child of farmer/homesteader parents. The Kentucky acreage was poor and difficult to work. When he was two, his father, John Mitchel, died suddenly of stroke; his widowed mother, Elizabeth McAlister Mitchel, sold their land, freed their slaves, and moved the family to southwestern Ohio to live with her older, married children. There, Mitchel attended primary and secondary schools that had been opened in 1815 and 1818, respectively, by his eldest brother.

By all accounts, Mitchel was a child prodigy, an avid reader who mastered Greek and Latin. Drawn to the stage, he joined his school's thespian society and debating club. Elizabeth tried to apprentice him to a trade when he was 13, but he ran away and found a job with a shopkeeper.

◀ **SPREADING LIGHT** Groundbreaking for the Cincinnati Observatory took place on November 9, 1843, on the summit of Mount Ida, soon to be renamed Mount Adams in honor of John Quincy Adams, who laid the observatory's cornerstone. The land for the observatory, which was on a south-facing slope of the hill (marked with a bold black circle on this c. 1900 map), was provided by the Cincinnati banker and speculator Nicholas Longworth. By the 1870s, light pollution from the expanding city forced the construction of a new observatory on the top of Mount Lookout (marked with a bold black square).



▼ **LARGEST TELESCOPE** The Cincinnati Observatory's 11-inch Merz and Mahler refractor had a focal length of 17 feet. It was the largest telescope in the United States when it saw first light in early April 1845, a distinction held until the 15-inch Merz and Mahler refractor was mounted at Harvard College Observatory in June 1847.

THE SIDEREAL MESSENGER (JULY 1846) / PUBLIC DOMAIN / COURTESY OF AUTHOR

When Mitchel was 15, he happened across a notice stating that qualified young men could be appointed to attend the U.S. Military Academy at West Point, New York, tuition-free while receiving $28 per month. Founded in 1802, West Point overhauled its curriculum in 1817 to become the United States' first engineering school, modeled on the École Polytechnique of France. Instead of a traditional college classical education, cadets received a rigorous foundation in mathematics through calculus, and in civil engineering, learning how to design and construct bridges, railroads, canals, arsenals, and fortifications. Summers were spent setting up military camps and performing drills. Mitchel appealed to Ohio politicians for letters of recommendation to support his application. Early in 1825, he received his cadet's warrant to report for examination on June 1st.

In 1829, Mitchel graduated 15th out of a class of 46 (the other 92 cadets who entered with him washed out). After a summer working as an engineer for a railroad in Pennsylvania, Mitchel taught mathematics at West Point for two years while he studied law. In 1831, he married Louisa Clark Trask, the young widow of a classmate. After a brief stint at Fort Marion (Castillo de San Marcos) in St. Augustine, Florida, he left the Army and returned to Ohio.

Accidental Astronomer

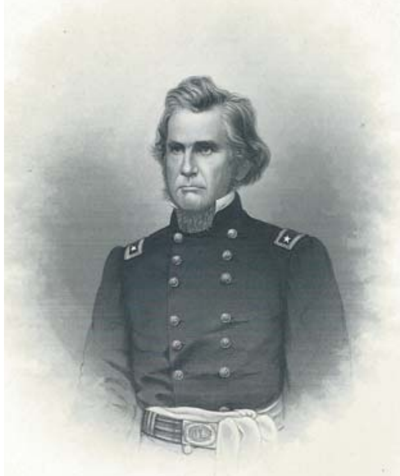
Settling in the booming city of Cincinnati where opportunities seemed boundless, Mitchel started a law practice in partnership with Edward D. Mansfield, son of one of his West Point professors. But as Mansfield later recollected, both were literary men: Mansfield often spent his office hours writing a book on politics while Mitchel read a Latin text on oratory. Unsurprisingly, their law practice foundered. Mansfield became a newspaper editor, and, in 1836, Mitchel joined the faculty of Cincinnati College, where he taught mathematics, civil engineering, mechanics, machinery, astronomy, and French.

Around that same time, Cincinnati chartered the Little Miami Railroad. On the side, Mitchel surveyed the prospective route. He also promoted and sold 800 shares of railroad stock at $50 each to investors. In so doing, he learned how a joint-stock corporation worked and how to approach prospects for money — skills that would be crucial when raising funds to found the Cincinnati Observatory.

Mitchel also joined several of fast-growing Cincinnati's literary, cultural, and religious groups, and in 1839–40 cofounded the Cincinnati Society for the Promotion of Useful Knowledge. The society sponsored public lectures that immediately gained attention and popularity. In late 1841, Mitchel himself was invited to give a "course" or series of lectures on astronomy for the winter and spring of 1842 — an invitation that set the direction for the rest of his life.

Audacious Astronomy

Mitchel was likely exposed to astronomy in his third year at West Point, when cadets took classes in the sciences. At that time (1827–28), West Point used William Enfield's 300-page textbook *Institutes of Natural Philosophy, Theoretical and Experimental*. Fully two-thirds of the 1824 fourth American edition was devoted to optics and astronomy, progressing from basic definitions to tables for calculating eclipses.



◀ **ARMY OF THE OHIO** This engraving, which shows Ormsby MacKnight Mitchel as a major general in the Union Army, is unusual in that it portrays him bearded instead of clean-shaven.

For his 1842 public lectures, however, Mitchel wanted something dramatic to hold the interest of a general audience. So he devised an apparatus to project images of nebulae, double stars, and comets as "revealed by the powerful telescopes of Europe." (Just what Mitchel's projection apparatus was is nowhere detailed, but the optics section of Enfield included a diagram of a magic lantern.)

Audiences were enraptured not only by Mitchel's projected images, but also by his captivating descriptions. Each lecture drew bigger crowds. In April, he was invited to repeat his last lecture at the Wesley Chapel, whose standing-room capacity could have been as high as 3,000. There he announced an audacious plan: to raise $7,500 for a magnificent telescope by selling 300 shares of stock at $25 each. No subscription would become binding until all 300 shares were sold. Each share would make its purchaser a member of a proposed astronomical society "and forever enjoy the privilege" of looking through the telescope.

No one was more surprised than Mitchel himself when he sold all 300 shares within three weeks. In May, at the first meeting of stockholders, the Cincinnati Astronomical Society

▶ **HILL TOWN** *Top:* This circa 1861 view of Cincinnati shows the city's hilly terrain. The lettered sites are: a) public landing; b) suburb of Fulton, through which passed the Little Miami Railroad; c) Mount Adams with Cincinnati Observatory; d) Walnut Hills; e) Mount Auburn; f) Vine Street Hill; g) Mill Creek.

▶ **GREEK REVIVAL** *Bottom:* The original two-story building of the Cincinnati Observatory, which was entered via a classically ornamented portico, sat atop Mount Ida (later renamed Mount Adams). Depicted here as it appeared in late 1846, the observatory was capped with a roll-off roof that exposed the equatorial room to the night sky for observations.

MITCHEL PORTRAIT: PUBLIC DOMAIN / COURTESY OF AUTHOR; CINCINNATI: *OUR WHOLE COUNTRY: OR THE PAST AND PRESENT OF THE UNITED STATES, HISTORICAL AND DESCRIPTIVE (1861)* / PUBLIC DOMAIN; OBSERVATORY: *THE SIDEREAL MESSENGER* (OCT. 1846) / PUBLIC DOMAIN / COURTESY OF AUTHOR was formed, officers were elected, a constitution was adopted, and Mitchel was directed to travel to Europe to procure a telescope. By mid-June, after stopping in Washington, DC, to solicit political support for the effort, in Philadelphia to examine the Central High School's observatory, and at West Point to procure letters of introduction to European astronomers, he embarked across the Atlantic.

In whirlwind travel through England, France, and Germany, Mitchel visited renowned astronomers and telescope makers. At the optical works of the Munich firm of Merz and Mahler, he found a completed 11-inch lens (which Mitchel usually called a 12-inch, the inch not yet having been standardized). He ordered a telescope to be made with it, exceeding his $7,500 budget by more than $2,000. He also received intensive hands-on tutorials on effectively using a large equatorial refractor and a transit instrument by no less than the Astronomer Royal George Biddell Airy himself at the Royal Observatory, Greenwich, and at the private observatory of well-known British astronomer Sir James South.

Back in Cincinnati, a wealthy landowner offered four acres atop a nearby hill named Mount Ida for the prospective observatory. To lay the cornerstone in November 1843, Mitchel invited 76-year-old former U.S. President John Quincy Adams, who for decades had been advocating for a national observatory; the hill was subsequently renamed Mount Adams in his honor.

To economize on money and time, each day after teaching at Cincinnati College, Mitchel himself toiled alongside his day laborers in constructing the building. He further pledged to work as observatory director for 10 years without pay. Finally, in January 1845, after an arduous journey across the Atlantic to New Orleans and up the Mississippi River, the heavy wooden crates containing the disassembled telescope finally arrived.

Two days earlier, however, disaster had struck: Cincinnati College burned to the ground, taking with it Mitchel's $2,000-per-year teaching job. Nonetheless, Mitchel and his workmen labored through the snows of February and March to finish the observatory building. The first weekend of April, the mighty refractor was mounted. Although first light is traditionally celebrated as April 14, 1845, Mitchel first looked through the telescope on April 7th, when he used the largest telescope in the United States, second largest in the world, to observe the waxing crescent Moon and the Orion Nebula.

"Mans Can't Make Moons"

Because Mitchel's day job had literally gone up in smoke, he needed income to support his growing family as well as the observatory itself. Since his lectures had been so successful in Cincinnati, he decided to try his luck speaking in other cities. In December 1845, he lugged his projection apparatus to Boston and placed advertisements in local newspapers, announcing a spectacular and novel attraction: telescopic images of celestial objects as viewed through the Cincinnati Observatory refractor.

PABLOHART / GETTY IMAGES

Books by Ormsby MacKnight Mitchel

Mitchel wrote or edited half a dozen books in his short life. They sold extremely well and for decades were reissued in multiple editions in the U.S. and the UK. His last book, nearly finished at the time of his death, was published posthumously. In chronological order:

An Elementary Treatise on Algebra (Cincinnati: E. Morgan, 1845).

The Planetary and Stellar Worlds: A Popular Exposition of the Great Discoveries and Theories of Modern Astronomy (New York: Baker & Scribner, 1848). The most famous of Mitchel's books, this work purports to be a compilation of his lectures, but its text differs substantially from verbatim lecture transcripts printed in various newspapers. Mitchel lectured extemporaneously and seems to have reconstructed his lectures after the fact. ***The Planetary and Stellar Worlds*** was reissued at least 18 times in the last half of the 19th century. A British edition was published under the title ***The Orbs of Heaven*** in 1851 and reissued at least another 10 times in the 1800s.

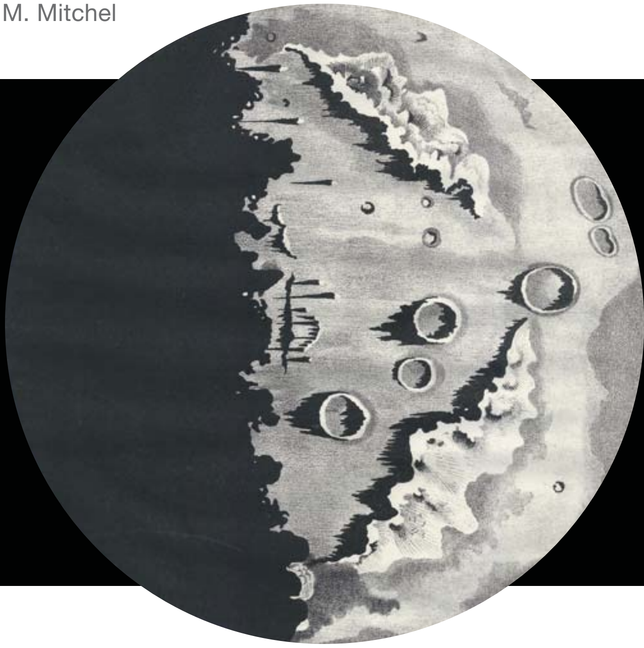
Atlas, Designed to Illustrate Mitchel's Edition of the Geography of the Heavens (New York: Huntington & Savage, 1848).

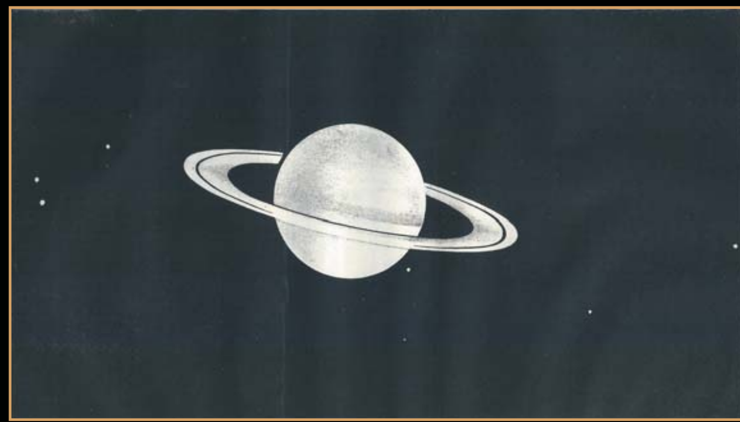
E. H. Burritt, ***The Geography of the Heavens, and Class Book on Astronomy***. Revised and corrected by O. M. Mitchel (New York: Huntington & Savage, 1849).

Popular Astronomy, or the Sun, Planets, Satellites, and Comets (New York: Phinney, Blakeman & Mason, 1860).

The Astronomy of the Bible. (New York: Blakeman and Mason, 1863). Published posthumously.

FURTHER READING: F. A. Mitchel's *Astronomer and General* (Boston: Houghton, Mifflin & Co., 1887) is an important primary source about Mitchel. Kevin J. Weddle's biography of Mitchel appeared in *S&T* almost 35 years ago (*S&T:* Jan. 1986, p. 14). This article draws on Philip S. Shoemaker's PhD dissertation *Stellar Impact: Ormsby MacKnight Mitchel and Astronomy in Antebellum America* (Madison: University of Wisconsin, 1991) and numerous newspaper advertisements, accounts, and transcripts of most of Mitchel's public lectures from 1842 through 1859, which were amassed by the late historian Craig B. Waff. Gratitude is also expressed to the Cincinnati Observatory Center's historian John E. Ventre and director Craig Niemi for additional primary source materials and to Shoemaker and Ventre for manuscript review.





▲ **NEXT-DOOR NEIGHBOR** *Left:* This undated lunar image, which highlights Montes Apenninus (Apennine Mountains) and Archimedes Crater (below center), shows the eyepiece field of view through the 11-inch Merz and Mahler refractor at 500×. In his early lectures, Mitchel projected a few spectacular telescopic views at the end of his lectures. Sometime after January 1851, however, he stopped including images and relied exclusively on the power of the spoken word.

▲ **THE RINGED PLANET** *Right:* Mitchel's drawing of Saturn, made the night of October 13, 1846, shows the planet's orb and rings, as well as six of the seven then-known satellites. Mitchel compressed the proportional positions of the satellites at left, possibly because he wanted to show as much detail as he could on the planet itself.

MOON: *THE SIDEREAL MESSENGER* (AUG. 1846) / PUBLIC DOMAIN / COURTESY OF AUTHOR; SATURN: *THE SIDEREAL MESSENGER* (DEC. 1846) / PUBLIC DOMAIN / COURTESY OF AUTHOR

Neither his projector nor the images for it survives, so we don't know exactly how they looked. However, eight months later, Mitchel launched his monthly journal *The Sidereal Messenger*, the first U.S. periodical exclusively dedicated to astronomy. In print from July 1846 through October 1848, almost every issue of *The Sidereal Messenger* featured a dramatic frontispiece of an astronomical object, half a dozen of which were drawn at the eyepiece of the Cincinnati telescope. It's likely his projected telescopic views were similar.

From all accounts, the emotional impact made by celestial objects as seen through the nation's largest telescope was akin to that felt by the NASA generation on seeing the first spectacular images returned from the Hubble Space Telescope in the 1990s. Immediately, the Boston organizers invited him to repeat the course the next month (January 1846). One audience member invited him to offer a course in Brooklyn, New York. Mitchel's brilliant lecturing career was launched.

Over the next decade and a half, Mitchel lectured almost every winter, ultimately speaking in at least 21 cities in 10 states to audiences of between 1,000 and 4,000 per night and returning to several cities year after year for repeat visits. By 1859, he was in such great demand that he offered three concurrent lecture series at three separate venues around New York City!

Although his lectures were not easy material, he had a supreme gift for clarity and simplicity. He led his audiences through the nebular hypothesis and discussions of the stability of the solar system, detailing such complex concepts as aberration of starlight and nutation. He excited audiences by updating them on the latest news regarding the discovery of the new planet Neptune and controversy over the determination of its orbit. He swept his listeners far out into space on vivid imaginary journeys through the solar system to the very edges of our Milky Way, and far back in time to the discoveries of ancient naked-eye astronomers.

Through all his lectures, Mitchel, a devout Protestant, emphasized the sublime glory of God as creator and lord of the universe — a message that deeply resonated with his audiences, and that indeed was what he first spoke when he beheld the crescent Moon at age three from his brother's arms. In later years, he also gave entire courses of lectures on the astronomy of the Bible.

Not only were Mitchel's lecturing proceeds each winter enough to support his family and the Cincinnati Observatory for the rest of the year, but they also permitted him to raise funds for other causes, including new astronomical observatories. One such beneficiary of his efforts was the Dudley Observatory in Albany, New York, for which he chose the site and designed the building in 1851–52. In 1859, Mitchel became Dudley's second director, moving to Albany in spring 1860 — while still remaining director at Cincinnati. He was scarcely at Dudley a year, however, when the Confederacy fired on the U.S. garrison at Fort Sumter, opening the Civil War in April 1861.

"Old Stars"

Ever since his days as a West Point cadet, Mitchel yearned to command an army. In August 1861, Abraham Lincoln offered him a commission as Brigadier General of Volunteers. In early 1862, his commanding general tasked Mitchel — dubbed by his troops as "Old Stars" because of his fame as an astronomer — with protecting the Union army's left flank and capturing the railroad that served as a Confederate supply line from the east. Mitchel undertook a rapid forced march and captured Huntsville, Alabama, with its large depot and repair station for the Memphis and Charleston Railroad line.

But most famous was Mitchel's role in enabling a daring raid intended to split the Confederacy and change the course of the war. En route to Huntsville, a spy named J. J. Andrews approached him with the idea of disabling a major Confederate railroad that connected Marietta, Georgia, with Chattanooga, Tennessee. Andrews's plan was to steal a train, burn the bridges behind him, and, just south of Chattanooga, turn the train west and join Mitchel in Huntsville. Mitchel supplied specially chosen troops. The Andrews Raiders made it to Marietta, stole a train and got away, but were unable to burn any of the bridges because they were hotly pursued for 87 miles in the legendary "Great Locomotive Chase," immortalized in Buster Keaton's 1927 film *The General* and Walt Disney's 1956 suspense film *The Great Locomotive Chase*. The raiders were caught, tried, and some were hung, but after the war some of the survivors were awarded the first Medals of Honor.

In September 1862, Mitchel, by then promoted to Major General, was reassigned to the Department of the South, in Hilton Head, South Carolina, where he founded Mitchelville, the first town deliberately designed for African-Americans transitioning from slavery. The next month, on October 30th, he died from yellow fever at the age of 53.

Mitchel as an Astronomer

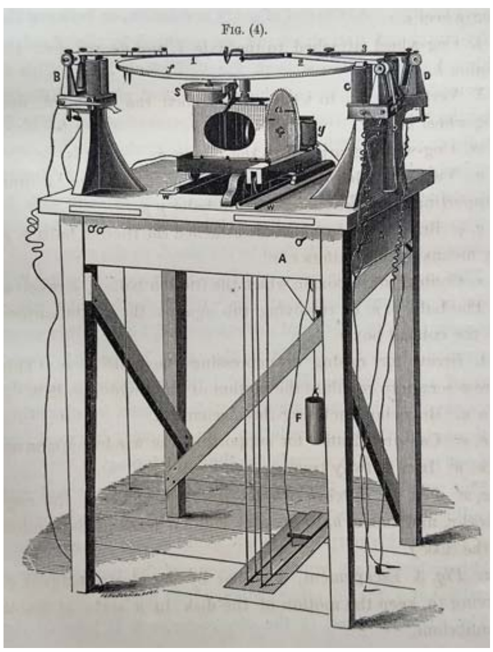
In 2003, the late historian Donald E. Osterbrock described Mitchel as "America's First Carl Sagan" (although more accurately, Sagan should have been called "America's Second O. M. Mitchel"). Like Sagan, Mitchel was a gifted speaker whose astronomical lectures electrified a generation. Like Sagan, Mitchel believed in the possibility of life on other worlds. But also like Sagan, Mitchel was a serious research astronomer.

In June 1846, Mitchel found that first-magnitude Alpha Scorpii (Antares) had a faint, 5.5-magnitude companion star. In October 1846, he became one of the first American astronomers to observe the planet Neptune after its discovery had been announced. In October 1848, Mitchel participated in a pioneering experiment using the telegraph to determine the longitude of Cincinnati west of Philadelphia; for the experiment, Mitchel invented an electrochronograph, a mechanism for simultaneously recording clock signals along with the timings of observations; his design was adopted by several observatories.

Less well known are Mitchel's systematic micrometrical measurements of double stars at declinations below the celestial equator, performed at the direct request of the great Russian astronomer Wilhelm Struve, founding director of Pulkovo, who wanted to take advantage of both the Cincinnati telescope's large aperture and its more southerly latitude. Also important were Mitchel's thousands of transit-telescope observations of stellar positions for the U.S. Coast Survey. In addition, *The Sidereal Messenger* was widely read by American astronomers, in part because Mitchel published his own translations of French and German articles from foreign journals, and reprinted correspondence surrounding the discovery of Neptune.

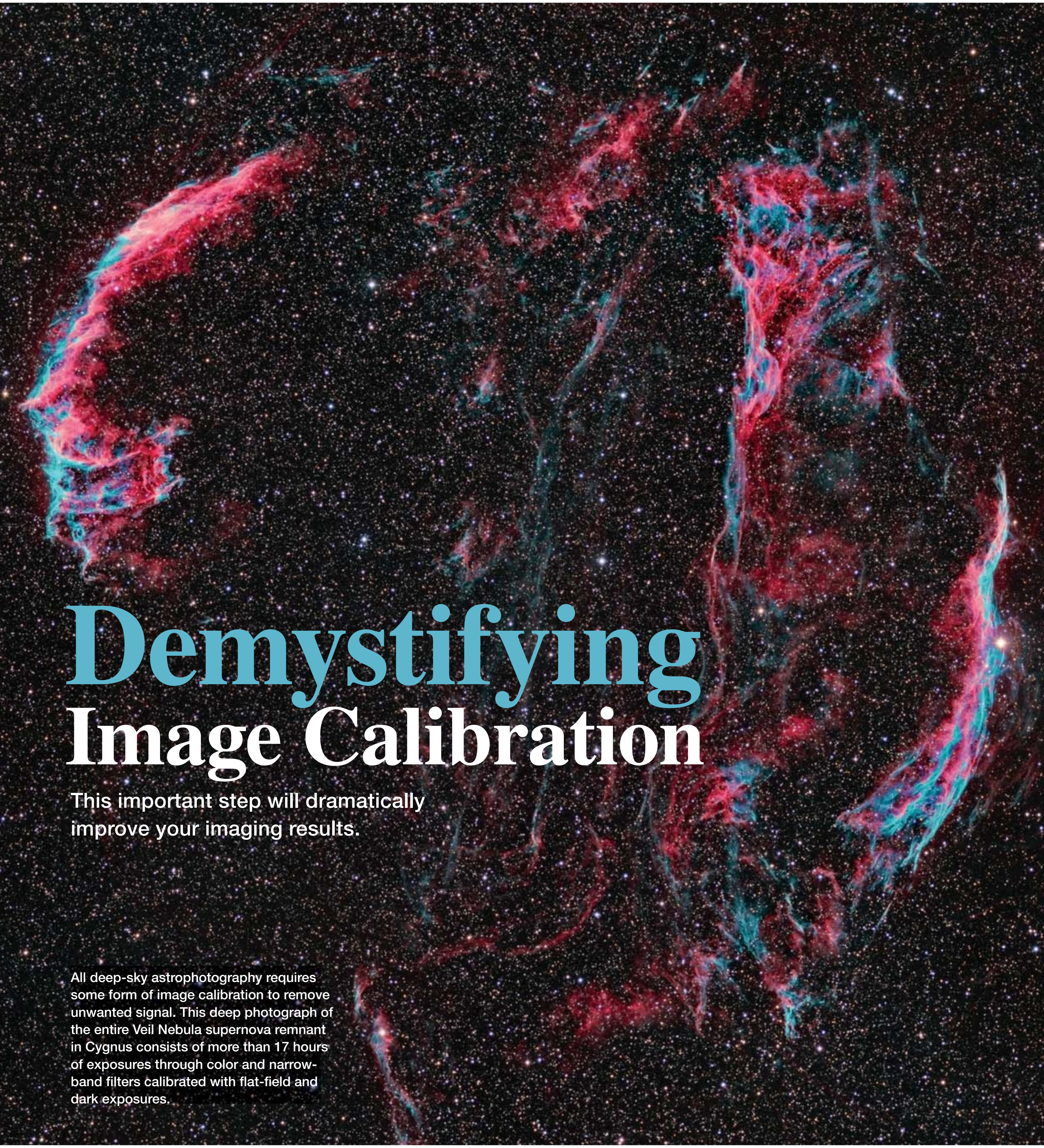
Mitchel was recognized with honorary degrees and other accolades. Among others, in 1846, he was offered the Rumford Professorship at Harvard University, which he declined because he didn't want to relocate to Cambridge. In 1850, he was one of the first five Americans elected to be a Foreign Associate of the Royal Astronomical Society, and was elected a member of the American Philosophical Society in 1853.

But Mitchel's most enduring legacy is probably his description of our Milky Way and other galaxies as "island universes." Although that marvelous image has been ascribed to several 19th-century scientists, Mitchel was gifted in coining memorable turns of phrase. He used the phrase "island universe" in lectures and *The Sidereal Messenger* numerous times as early as 1847 when describing research by Johann Heinrich von Mädler, which Mitchel translated from German.



▶ **PERFECT TIMING** In the revolving-disk electrochronograph Mitchel invented in late 1848, a make-circuit clock marked every other second with a dot on a 22-inch paper disk. At the end of every revolution, the paper shifted and a new concentric circle of dots began. The moment an astronomer observed a star to be bisected by the vertical wire in the eyepiece of a meridian telescope, he pressed a telegraph key to make an additional mark on the revolving disk. In this way, the time of the meridian transit was recorded in relation to the dots that marked the time.

■ Contributing Editor **TRUDY E. BELL**, formerly an editor for *Scientific American* and *IEEE Spectrum* and senior writer for the University of California High-Performance AstroComputing Center, is author of a dozen books and over 500 articles. Her journalism prizes include the 2006 David N. Schramm Award of the American Astronomical Society. In 2017, asteroid (323552) was named Trudybell 2004 TB in recognition of her career. She can be reached at **t.e.bell@ieee.org**.



Demystifying Image Calibration

This important step will dramatically improve your imaging results.

All deep-sky astrophotography requires some form of image calibration to remove unwanted signal. This deep photograph of the entire Veil Nebula supernova remnant in Cygnus consists of more than 17 hours of exposures through color and narrow-band filters calibrated with flat-field and dark exposures.

Just five words is all it takes to highlight one of the main things that makes astrophotography so challenging: It is dark at night. With very few exceptions, there are big differences in how to photograph dim targets under low-light conditions as compared with daytime photography.

Beyond the solar system, targets visible in the night sky are very dim and often barely brighter than the background sky. The cameras we use to image deep-sky objects are inherently noisy. And to further compound the problem, images from telescopes, astrographs, and camera lenses suffer from uneven field illumination due to a host of reasons, including varying sensitivity across your astronomical camera's CCD or CMOS detector, vignetting, and even dust on optical surfaces. These deficiencies are seen in every image that downloads from your camera's detector.

Fortunately, the standardized process known as image calibration can clean up the majority of these issues in our photos prior to combining and processing them further, which then allows you to get the most out of your astrophotography.

Raw, unprocessed deep-sky images can look quite unappealing directly out of the camera. They generally appear dark with just a smattering of stars. If you stretch that image, you'll begin to see your target, but such image manipulation reveals countless white and black specks scattered across the image. This is a combination of unwanted signal and noise that has to be removed from each of your target exposures before they can be combined and then further processed.

Most experienced deep-sky astrophotographers consider calibration an essential step in the process of making top-notch images of galaxies, nebulae, and star clusters. Although calibration isn't difficult in practice, it does require a modest investment of time to learn, and it has associated jargon that can make it seem hard. Don't let this discourage you from learning how to calibrate your images. Here's what you need to know.

The Cleanup Crew

Three types of calibration frames are applied in the calibration routine to address specific issues unique to long-exposure astrophotography. These are known as dark frames, bias frames, and flat-field images. Dark frames are used to correct for the electronic signal that builds up over time during a long exposure. Bias frames characterize and correct readout noise — the noise generated when information on the sensor is transferred to a computer — but it is only really necessary for advanced calibration procedures when scaling dark frames made at different temperatures than the light frames were made. Flat-field images are then applied to correct for uneven field illumination, making vignetting and dust-doughnuts seem to magically disappear.

Dark frames are captured in complete darkness (with the telescope or camera covered), at the same detector temperature and exposure duration as your target images. All other settings, such as ISO, gain, and offset (if your camera allows you to change these settings), should also be the same as for the light frames. Make sure that no light can reach the camera's sensor, and record a series of dark frames using your preferred acquisition software in the same way as you would capture light frames. You can then combine them into what's called a "master" dark frame using either an average or pixel-rejection method, which helps to remove random signal. A camera's noise characteristics will change over time, so shoot new dark frames every few months even if all other shooting parameters remain the same.

> Calibration should be the first step in any image-processing workflow. This is true for both CCD and CMOS cameras, regardless of whether they are monochrome with filters, cooled one-shot color (OSC), DSLR, or mirrorless cameras.

Note that off-the-shelf DSLRs and their mirrorless cousins do not include temperature regulation. When imaging with these cameras, try to match the temperature of the calibration frames to the light frames as closely as possible. You can record dark frames periodically throughout your imaging run so that their average temperature is similar to that of the light images. Another strategy for cold-weather imaging is to put the camera in the refrigerator or freezer and record dark and bias calibration frames to mimic expected nighttime temperatures.

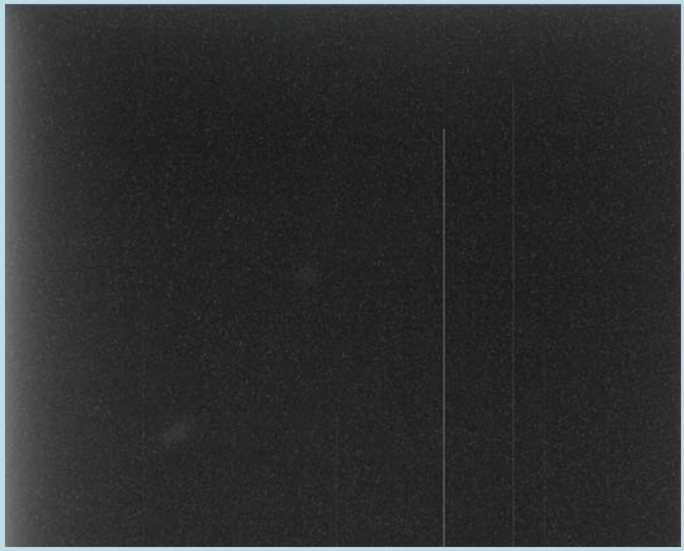
This brings us to the third type of calibration used in deep-sky imaging, called flat-field calibration. Flat-field calibration frames are images of an evenly illuminated blank target, such as a projection screen. Their acquisition is more complex than either bias or dark frames. A properly exposed flat-field image records uneven field illumination (vignetting), regional differences in sensor response, and the shadows of dust spots, which appear as round spots when shooting through a refractor or doughnuts when imaging through reflecting telescopes.

Unlike bias and dark frames, you can acquire flat-field images with different camera settings than used for your light images, though if you shoot your flat-field frames at a different temperature, you'll need to record a full set of matching dark frames and apply them to the flats before assembling them into a master flat-field image. It's far simpler to keep temperature and other camera settings consistent with your other calibration frames. Regardless of the method used to acquire flats, the exposure time should be set to produce a moderately bright image, roughly 30% to 50% of the full-well capacity of your camera (the point at which a pixel saturates) in order to be effective in correcting your light frames.

Shooting flat-fields can be tricky. If your camera has a mechanical shutter, you'll need to expose your flats for at least several seconds in order to ensure the frame isn't affected by the brief time the shutter passes through the image. Additionally, if you are using a monochrome camera

ALL IMAGES BY THE AUTHOR

▲ This image of the globular cluster M5 in Serpens was processed without calibration frames, showing several artifacts that are easily corrected in calibration.



▲ Dark frames record electronic signal that builds up during an exposure. A proper dark frame needs to be shot at the same temperature setting in your camera and must be exposed for the same length as the light frames it is meant to be subtracted from. The vertical lines are due to stuck pixels and are completely corrected during dark subtraction.

with multiple filters, dust motes may be in a different place on each filter. This requires a set of flats for each filter. While opinions differ on how many flat frames to acquire, I prefer 16 flat-field frames per filter to produce a good master flat.

You should acquire a new set of flat frames every time the camera is rotated on the telescope, and also when you bin (group pixels) on the detector. The focus position should be identical to that used while recording your target images. Here are three methods for shooting flats, depending on your setup and level of experience.

Capturing Flat-Field Images

Recording good flat-field frames can be challenging — the target needs to be extremely evenly illuminated, or else it will introduce gradients across your light images. When performed carefully, these popular techniques can work well.

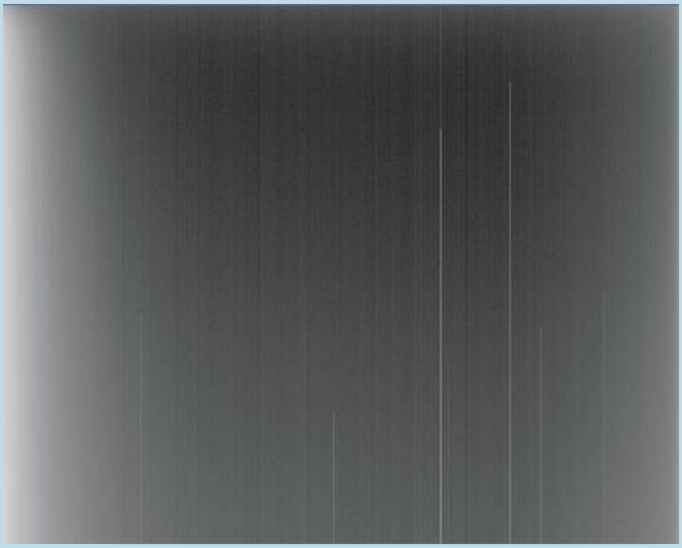
T-shirt flats A white or light-gray T-shirt can be used as a diffuser to produce a flat-field by targeting the daytime sky. Stretch two layers of a clean T-shirt over the objective of the telescope or lens and fasten it in place, ensuring there are no wrinkles. Point the telescope towards an evenly illuminated part of the sky or other bright target — an overcast sky works particularly well. Adjust the exposure time as necessary and acquire flat frames the same way you would acquire light frames.

◀ One quick and low-cost technique to record decent flat-field images involves stretching two layers of a white or light-gray T-shirt over the front aperture of the lens or telescope and exposing on the sky. New T-shirts work best, and be sure to smooth out any wrinkles. Use of an electroluminescent panel to record flat-field images can be seen on page 69.

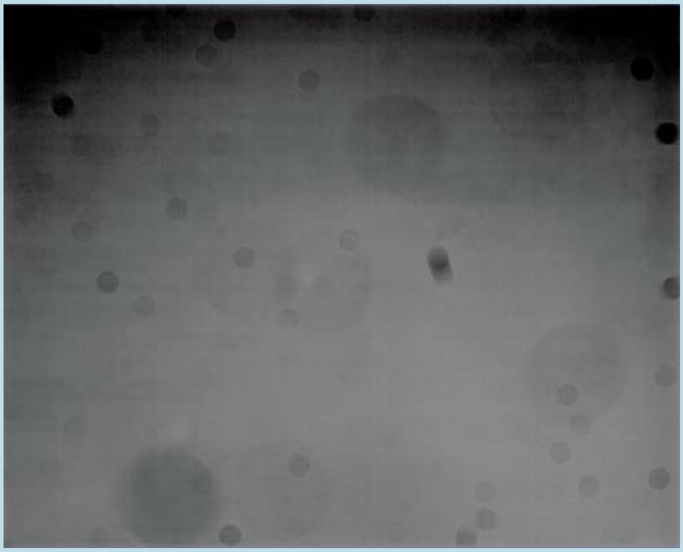
This is perhaps the least expensive and easiest method for producing flat-field images, though it can be tricky finding a good T-shirt that works well.

Flat panel An electroluminescent panel makes excellent flat-field images. Make sure the flat panel is larger than the diameter of your objective. Simply point your telescope or lens straight up and lay the panel on the dew shield or lens shade. Set the panel's brightness so that it reaches the target level of illumination with exposures of a few seconds or so. This method is low-tech and very reliable, but it does has some associated cost: Flat panels can cost up to several hundred dollars.

Twilight flats (sky flats) Beginning immediately after sunset on a clear evening, point your telescope or lens about 5° east of the meridian (85° altitude, 90° azimuth). This is the most evenly illuminated area of the twilight sky. You can also collect twilight flats beginning about half an hour before sunrise pointed 5° west of the meridian (85° altitude, 270° azimuth). Turn the mount's tracking off so that stars will trail and appear in different locations in each flat frame; they will average out when combined into the master flat. This method works very well, but it can be challenging since the sky brightness changes rapidly during twilight, and the window for collecting flats is brief. To simplify collecting twilight flats, consider using software to automate the process and vary the exposure times as required to keep the brightness consistent within your set of flat frames. Compared with the other two



▲ Bias frames, which are zero-length exposures, record only the readout noise generated with every exposure. Bias calibration isn't often necessary unless you need to scale dark frames.



▲ Possibly the most critical calibration frame for imagers is the flat-field image. This records uneven field illumination like vignetting seen in the corners of the image, as well as the out-of-focus silhouettes of dust specks found on any optical surfaces. The smaller the spot is, the closer it is to the camera's detector.

methods described above, twilight flats produce superior results for some of my telescopes. Like T-shirt flats, this is a low-cost option, but it is significantly more challenging.

Applying Calibration

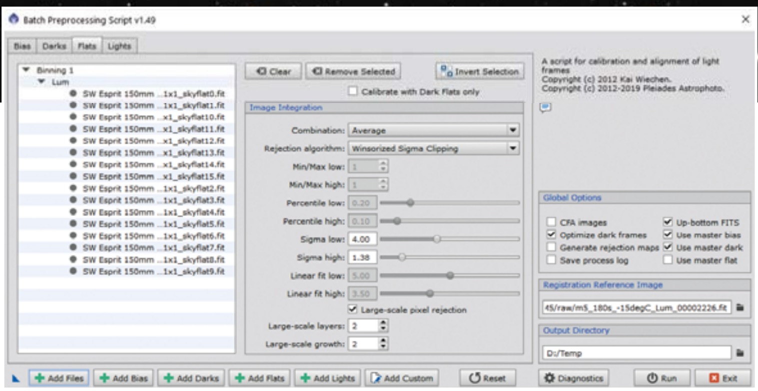
So now you have your calibration frames. The next step is to combine them into master calibration frames and apply those masters to your light images. Fortunately, we don't need to work with all of these files manually. Every major image-processing software package designed for astronomy includes an image-calibration function, and most also produce master calibration frames in the process. I prefer to use *PixInsight*, though excellent results can also be had with most any astronomical image-processing software.

Calibration should be the first step in any image-processing workflow. This is true for both CCD and CMOS cameras, regardless of whether they are monochrome with filters, cooled one-shot color (OSC), DSLR, or mirrorless cameras. Calibration comes before debayering, which creates a color image from the monochrome data produced by OSC, DSLR, and mirrorless cameras.

All calibration tools are used in basically the same way. First you load up your light images and dark, bias, and flat frames. Some software will automatically sort them into their respective groups; if not, you can specify file types manually. Choose a destination folder for the calibrated files, then simply apply the process. The result will be a set of fully calibrated light frames, and, for some software, a set of master calibration frames. If your software made master calibration frames, use these on all your future images taken with the same equipment, temperature, and exposure settings, at least until a new speck of dust appears.

Although you don't need to be a computer whiz or a mathematician to successfully perform image calibration, some may want a better understanding of what's going on while the software is chugging away during an image-calibration run. Here's a peek under the hood:

▶ The same image of M5 as seen on page 38 appears without any artifacts after calibration with a master dark and master flat-field image.



◀ The popular image-processing program *PixInsight* handles calibration in its Batch Preprocessing scripts.

▲ After calibrating and combining all the color exposures, the author reveals thousands of faint stars in the outer halo of M5. The final result includes 8 hours and 42 minutes of exposures through LRGB filters with a QHY 16200A CCD camera and a Sky-Watcher Esprit 150-mm ED f/7 Triplet APO refractor.

First, bias and dark calibration masters are generated by averaging all the bias frames and dark frames, producing a master bias and a master dark image. The master flat-field image is usually created by subtracting the master bias from each flat frame and then averaging the bias-corrected flat frames. Users of CMOS cameras that produce unreliable results with bias correction need to make a master flat-dark and subtract it from each flat frame; These are then averaged together to make the master flat.

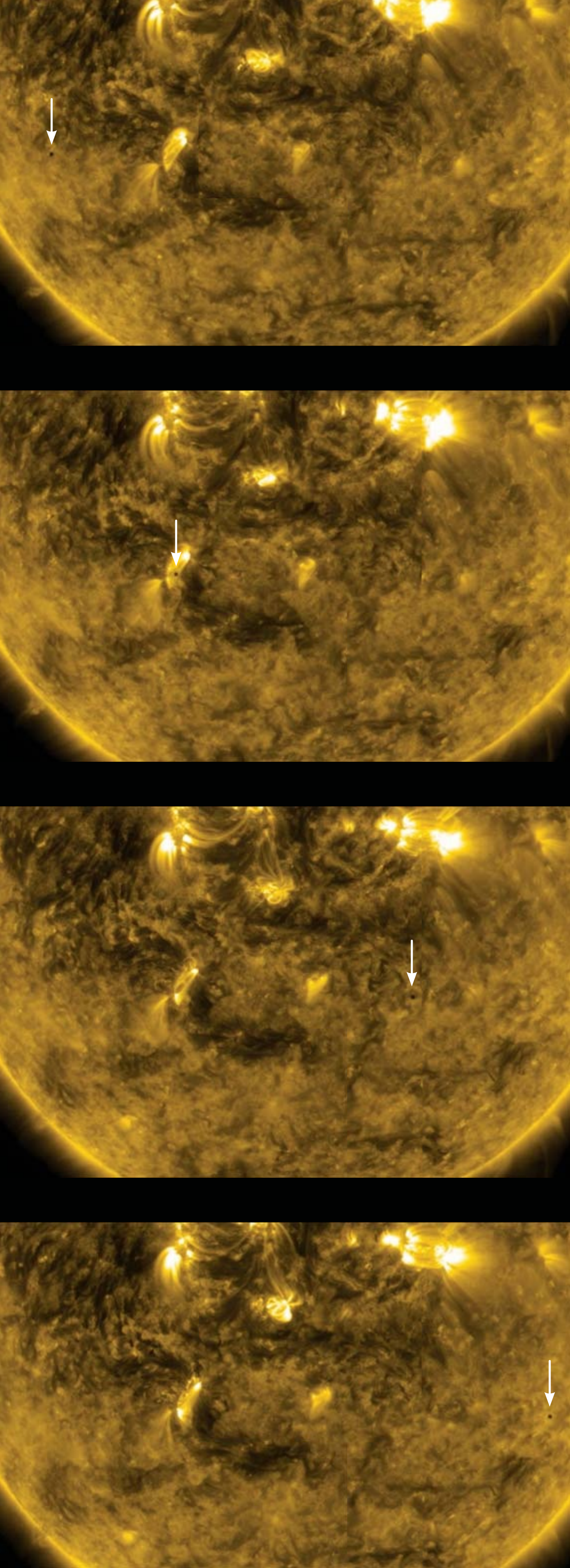
The target images are then calibrated using the master calibration frames: The master dark frame is subtracted from each light image, and then each light frame is divided by the master flat, producing your clean, calibrated light images that are now ready for stacking and further processing.

Conclusion

Cameras record the precious photons that we crave, but this signal becomes tainted by undesirable signal from electronic noise and flaws in the optical train. Image processing is likely to accentuate these unwanted features if left uncorrected, leading to unsightly artifacts in processed images.

Processing calibrated data is also easier, since there are no blemishes like dust doughnuts that need additional attention. Given the huge benefits to the resulting images we produce, it's clear that it's worth investing your time to master calibration, an essential ingredient to every great deep-sky astrophoto.

■ **RON BRECHER** images targets from his observatory in Guelph, Ontario. See more of his images at **astrodoc.ca**.



OBSERVING
November 2019

1 **DUSK:** Saturn, the waxing lunar crescent, and Jupiter form a line 22° long in the south-southwest after sunset. The two gas giants linger in this part of the sky throughout the month.

3 **DAYLIGHT-SAVING TIME ENDS** at 2 a.m. for most of the U.S. and Canada.

8 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 11:57 p.m. PST; see page 50.

9, 10, 11 **DAWN:** Mars, in Virgo, passes within 2½° of Spica. Look for the Red Planet upper left and left of the blue-white star.

11 **DAYTIME:** Tiny Mercury will transit across the face of the Sun, with the midpoint occurring at 10:20 a.m. EST. The Americas, Africa, and most of Europe will see all or part of this event. See page 48 for details and instructions on how to view the transit safely.

11 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 11:46 p.m. EST (8:46 p.m. PST).

14 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 8:35 p.m. EST.

16 **EVENING:** The waning gibbous Moon rises in Gemini, some 5° to 6° right of Pollux.

16–17 **ALL NIGHT:** The Leonids are predicted to peak this night, but the waning gibbous Moon will greatly interfere with viewing this typically weak shower. See page 50.

23, 24 **DUSK:** Look toward the southwest shortly after sunset to be treated to the sight of Venus and Jupiter, a smidgen more than 1° separating the two planets.

25 **DAWN:** Shortly before sunrise on the east-southeastern horizon, the thinnest sliver of the waning Moon is a little more than 5° lower left of Mercury. Mars hovers some 10° upper right of the tiny world.

27, 28, 29, 30 **DUSK:** The month closes with three planets and the waxing crescent Moon gracing the southwestern sky. Watch as the growing Moon climbs along the ecliptic, visiting Venus and then Saturn along the way. Jupiter anchors the quartet, lowest on the horizon.
— DIANA HANNIKAINEN

◀ Mercury will pass across the face of the Sun on November 11th. This series of images was obtained by the Solar Dynamics Observatory during the latest transit event in 2016. The images, taken in the extreme ultraviolet, highlight activity in the Sun's chromosphere, such as magnetic loops.
SOLAR DYNAMICS OBSERVATORY / NASA

NOVEMBER 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

FIRST QUARTER
November 4
10:23 UT

FULL MOON
November 12
13:34 UT

LAST QUARTER
November 19
21:11 UT

NEW MOON
November 26
15:06 UT

DISTANCES

Apogee	November 7, 09^h UT
405,058 km	Diameter 29′ 30″
Perigee	November 23, 08^h UT
366,716 km	Diameter 32′ 35″

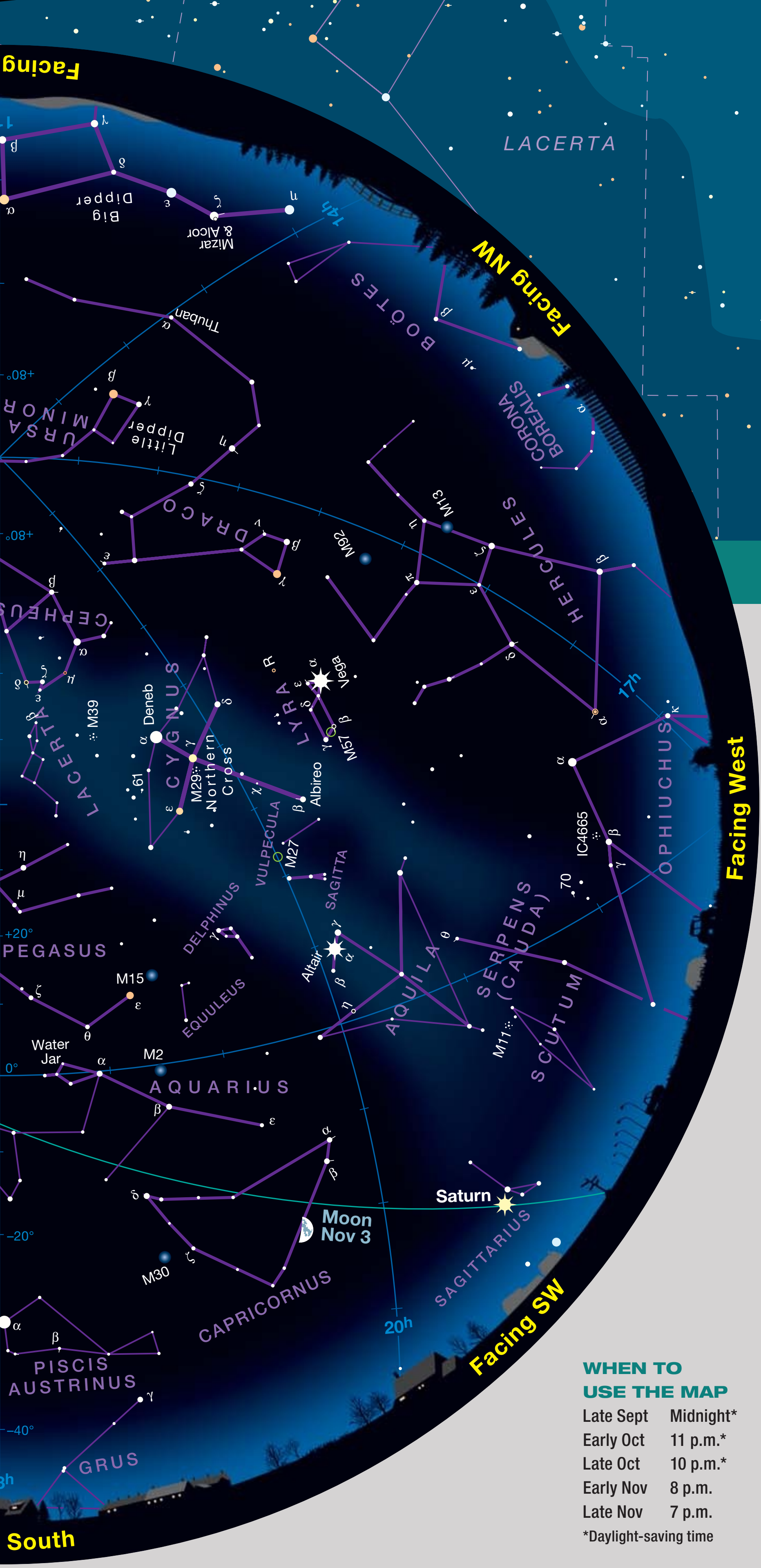
FAVORABLE LIBRATIONS

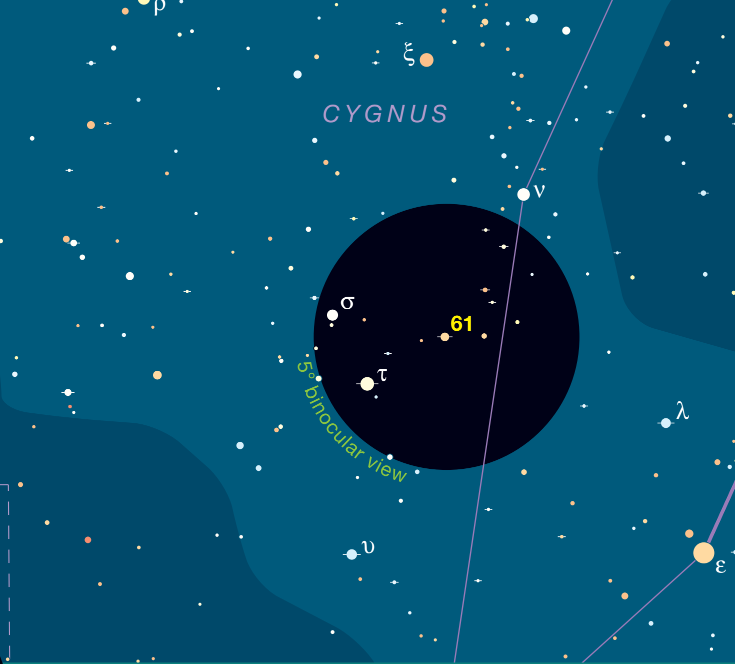
• Mare Smythii	November 3
• Xenophanes Crater	November 12
• Drygalski Crater	November 22
• Mare Marginis	November 30

Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing.





Binocular Highlight by Mathew Wedel

See for Yourself

Trailing behind the southeastern wing of Cygnus, the Swan, is one of the most fascinating double stars in the sky: **61 Cygni**, also known as "Piazzi's Flying Star." In 1792, the Italian astronomer Giuseppe Piazzi noted that his own observations of 61 Cygni differed from those of 40 years earlier. Piazzi made repeated measurements and published his own results in 1806. The system is moving across the sky at 5″ per year, which in technical terms is "really trucking." This is one of those happy cases in which a historical discovery can be re-enacted by any interested amateur today — more on that in a bit.

I have three pieces of homework for you, each requiring different gear. The first uses no optical equipment at all: Try and pick out 61 Cygni with your naked eyes. It's not easy, especially if there's any light pollution, but it's doable, and I find that I have a better gut-level knowledge of where things are in the sky if I've directly laid eyes on them.

The second assignment is to split 61 Cygni using binoculars. The two stars are currently separated by 31.8″, which makes them a bit tighter than Albireo (34.6″). The split is technically feasible with 10× binos, but I need 15× to "black-line" this close pair. See what you can do.

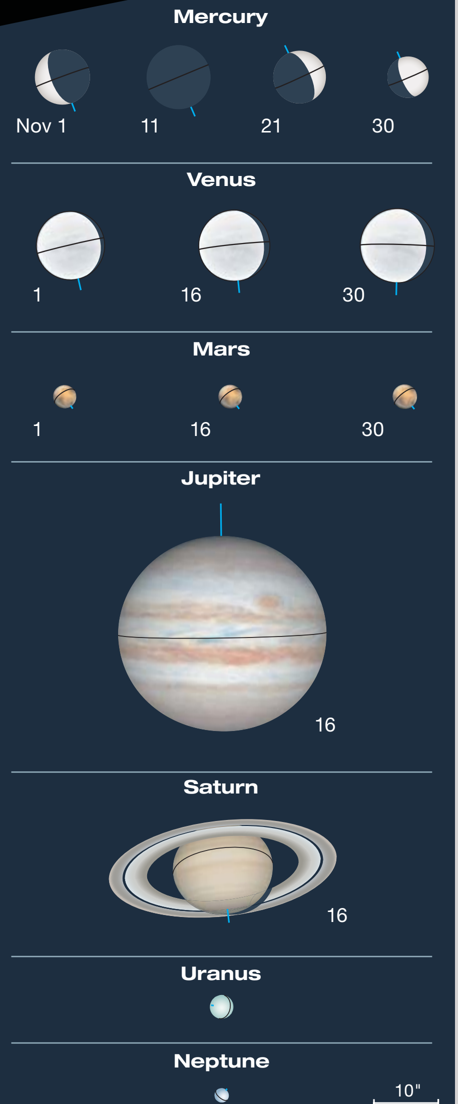
The final step is to follow in Piazzi's footsteps: Grab a scope, crank up the magnification, and sketch 61 Cygni and its surrounding star field. Amateur astronomers armed with webcams have measured the proper motion of 61 Cygni in as few as four years. With pencil and paper it might take a little longer — as it did for Piazzi! — but if you start now, you'll have a record you can revisit many times in years to come.

■ **MATT WEDEL** thinks that any discovery is thrilling, even if many others have made the same discovery before.

WHEN TO USE THE MAP

Late Sept	Midnight*
Early Oct	11 p.m.*
Late Oct	10 p.m.*
Early Nov	8 p.m.
Late Nov	7 p.m.

*Daylight-saving time



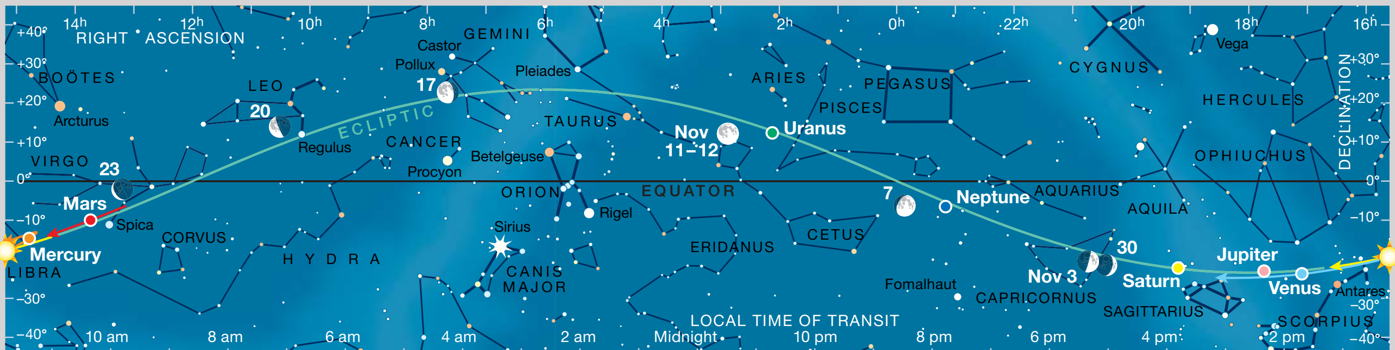
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY **Mercury:** visible at dawn after the 18th • **Venus:** visible at dusk all month • **Mars:** visible at dawn all month • **Jupiter:** visible at dusk all month • **Saturn:** visible at dusk, sets early evening

November Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$14^h\ 22.5^m$	–14° 10′	—	–26.8	32′ 13″	—	0.993
	30	$16^h\ 21.5^m$	–21° 31′	—	–26.8	32′ 26″	—	0.986
Mercury	1	$15^h\ 37.7^m$	–22° 12′	20° Ev	+0.5	8.6″	29%	0.785
	11	$15^h\ 08.1^m$	–17° 48′	2° Ev	—	10.0″	0%	0.675
	21	$14^h\ 38.5^m$	–13° 02′	17° Mo	+0.3	8.2″	30%	0.818
	30	$15^h\ 02.2^m$	–14° 50′	20° Mo	–0.6	6.4″	66%	1.043
Venus	1	$15^h\ 45.5^m$	–20° 09′	21° Ev	–3.8	10.7	94%	1.565
	11	$16^h\ 37.7^m$	–22° 50′	23° Ev	–3.8	10.9″	92%	1.526
	21	$17^h\ 31.5^m$	–24° 24′	25° Ev	–3.9	11.2″	91%	1.484
	30	$18^h\ 20.6^m$	–24° 47′	28° Ev	–3.9	11.6″	89%	1.443
Mars	1	$13^h\ 06.7^m$	–6° 12′	20° Mo	+1.8	3.7″	99%	2.539
	16	$13^h\ 43.4^m$	–9° 55′	26° Mo	+1.8	3.8″	98%	2.470
	30	$14^h\ 18.6^m$	–13° 10′	30° Mo	+1.7	3.9″	98%	2.394
Jupiter	1	$17^h\ 29.9^m$	–23° 04′	45° Ev	–1.9	33.4″	100%	5.903
	30	$17^h\ 56.2^m$	–23° 18′	22° Ev	–1.8	32.1″	100%	6.141
Saturn	1	$19^h\ 05.8^m$	–22° 27′	67° Ev	+0.6	16.0″	100%	10.384
	30	$19^h\ 16.3^m$	–22° 11′	40° Ev	+0.6	15.4″	100%	10.768
Uranus	16	$2^h\ 06.1^m$	+12° 14′	161° Ev	+5.7	3.7″	100%	18.889
Neptune	16	$23^h\ 08.9^m$	–6° 36′	113° Ev	+7.9	2.3″	100%	29.539

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-November; 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.

An Assortment of Asterisms

Sometimes overlooked, asterisms pepper the autumn night sky. See which ones you can spot.

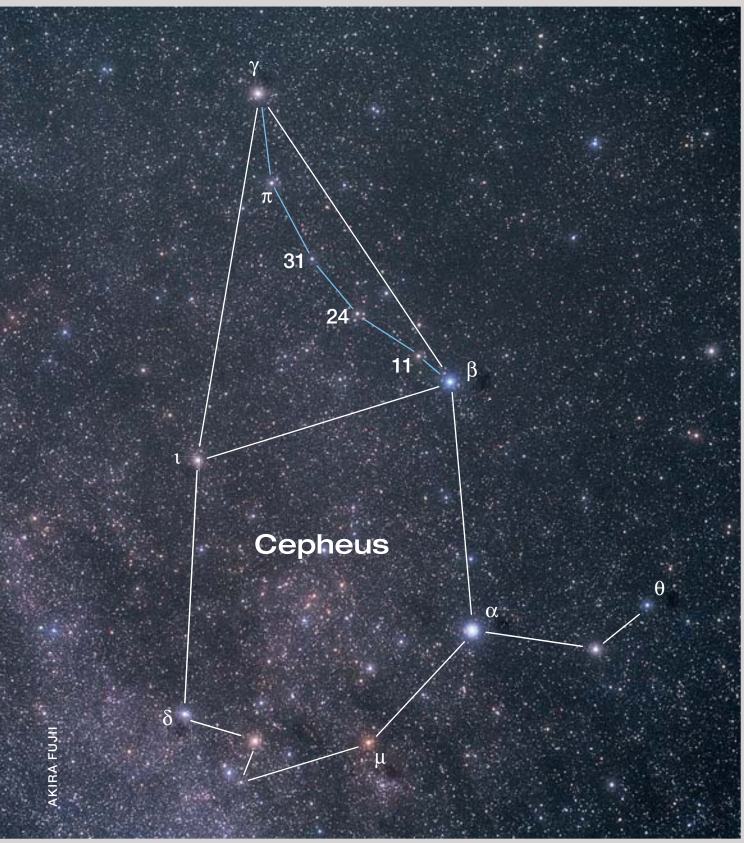
The autumn sky can be faulted for having many dim constellations. But something that always pleases me about it is the number of fascinating faint asterisms and even patches of naked-eye glow that enliven its dark expanse.

Some of these sights are well known, even famous. I'll be discussing them in this column. But I'm also mentioning two that I discovered for myself and that don't seem to be mentioned by anybody else.

Autumn's famous asterisms. When a section of the heavens isn't rich enough with many stars to make showcases of entire constellations, or is missing a few individual brilliant stars, we have to resort to compact asterisms to find our way around and enjoy ourselves. Much of autumn's realm of the heavens needs these delicate star patterns — and has them.

Of course, the Great Square of Pegasus is not a small asterism, being a bit too big to hide with your fist held at arm's length. But near the Great Square are two small asterisms that help organize, and draw our eyes to, two of the dimmest zodiac constellations.

Directly under the Great Square and just above the celestial equator shines the Circlet, marking the head of the western fish of Pisces. The Circlet is like a dim lasso flung in an attempt to catch the very red star TX Piscium, or the vernal equinox point in the heavens. Not far west of the Circlet and notably right on the celestial equator is the Y-shaped Water Jar or Urn of Aquarius (used by Aquarius the Water Carrier to pour out his water). This little pattern aids in finding the impressive globular star cluster M2, directly west of the Water Jar and Alpha Aquarii.



Autumn's famous glows. How wonderful it is, far from city lights, to look with the naked eye and see the different extended glows of autumn's celestial objects — and to know that several of them are very important in the hierarchy of the local universe.

One, of course, is M31, the Great Galaxy in Andromeda, the Milky Way's big sister with which it will collide in 4 billion years or so. One feat of the great Walter Scott Houston I've been able to replicate is to trace M31's soft blur, its elongated smear of light, out to over 5° in length — in a sky dark enough to reveal to the naked eye the elusive glow of M33, the lesser local galaxy in Triangulum.

Between the little pattern of Triangulum and Almach (the wonderful double star Gamma Andromedae), the naked eye can see the glow of the large open cluster NGC 752, which is itself adjacent to the binocular asterism the Golf Putter. NGC 752 in fact serves as the stellar golf ball at the end of the club. Almost directly between Almach and Perseus's Algol is another naked-eye glow, that of the open cluster M34. But of course the most prominent cluster of autumn that looks to the naked eye like a glow — an elongated, two-lobed glow — is the Double Cluster of Perseus.

The Arc of the King and 1 Cas Patch. A few years ago, while watching the Perseid meteor shower, I first hit upon a new asterism visible to the naked eye in rather dark and clear skies. This is a perfect curve of faint but equally spaced stars extending all the way from Gamma (γ) Cephei (Errai) to Beta (β) Cephei (Alfirk). The other component stars are Pi Cephei, 31 Cephei, 24 Cephei, and 11 Cephei. I find this asterism's visibility a good measure of sky conditions and for now we could call it the Arc of the King.

I'm going to set as a goal for any interested readers an area of star-specked glow that I first noticed two summers ago. I call it 1 Cas Patch. Find the magnitude-4.8 star 1 Cassiopeiae and tell me what you see there with the naked eye. I'll have more to say about it in an upcoming column.

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

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

A Transit and a Close Conjunction

The big event this month is the passage of Mercury across the face of the Sun, but the other planets put on a pretty fine show, too.

It's an unusually exciting month for observing the planets. All of Africa and the Americas (apart from Alaska and northernmost Canada) and most of Europe get a chance — weather permitting — to see Mercury cross the face of the Sun. The two brightest planets, Venus and Jupiter, have a close conjunction in evening twilight late in the month — and then Venus races onward toward Saturn. Meanwhile, November dawns see Mars climbing into plain visibility (as it passes brighter Spica) and later in the month offer Mercury, shooting fresh from its transit of the Sun into its best morning apparition of the year.

DAYTIME

Mercury transits the Sun on November 11th. The East Coast of the U.S. and Canada get to see this event in its entirety — but then will have to wait until 2049 for the next one. For full information on the transit, see page 48.

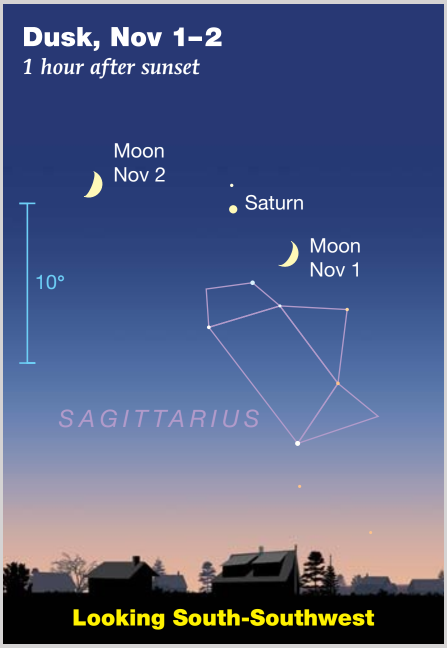
DUSK AND EVENING

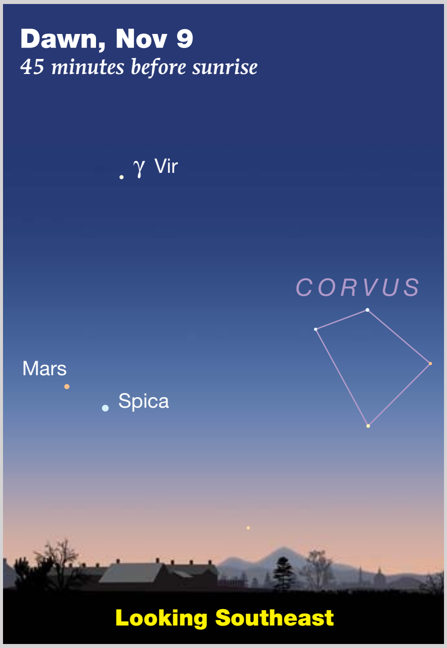
Venus and **Jupiter** shine in mid-twilight in the southwest on the first day of November. Their separation then is 23½°. The gap shrinks to almost 14° by November 10th, 9° by November 15th, and 4° by November 20th.

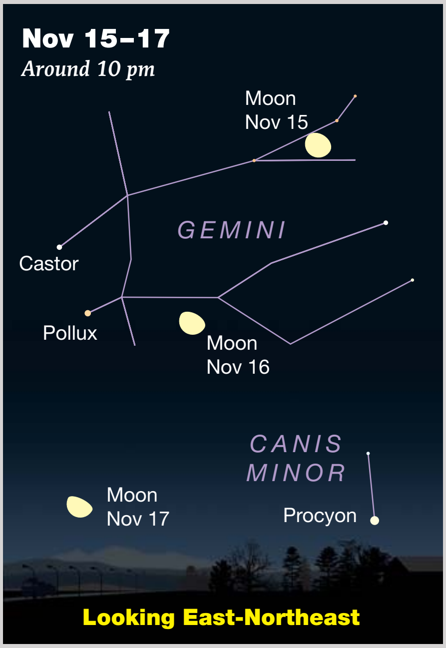
On November 10th, Venus passes about 4° above low-in-twilight Antares (easier for viewers in more southerly locations). On November 22nd the brilliant planet, blazing at magnitude –3.9, is about 2° below Jupiter, at magnitude –1.9; for viewers around latitude 40° north, the gas giant stands about 10° high around 30 minutes after sunset. Then the two planets are 2° or less apart for the next three days, with the closest pairing at about 1½° on November 23rd and 24th.

Can you fit both planets in the same field of view of your telescope those nights, with enough magnification to perceive and compare their disks? Jupiter's disk at just a little more than 32″ in diameter is a bit less than three times as wide as Venus's now, but Venus has a very much greater surface brightness. Can you get a sharp enough image of Venus in the unsteady atmosphere low in the sky to see it as slightly gibbous? Venus will be about 90% lit at the time of its conjunction with 100%-lit Jupiter.

Venus is racing to attain its southernmost declination this year on







November 28th — about one hour before it happens to reach aphelion.

On the final evening of November, the gap between Venus and Jupiter to its lower right is around 6½°. Venus sets some 105 minutes after the Sun, and Jupiter only about 80 minutes after the Sun. Early that evening a telescope shows 3rd-magnitude Kaus Borealis less than 1° from Venus.

Saturn starts the month as part of a long line of three planets, with Jupiter in the middle, almost halfway between Saturn and Venus. But Venus overtakes Jupiter in their race eastward relative to the background stars and then starts closing the gap on Saturn. Venus is 12° lower right of Saturn on the last day of November. Saturn on November 1st sets 4½ hours after the Sun but on November 30th about 2⅔ hours. Saturn shines at magnitude +0.6 this month and its globe, less than 16″ wide after November 1st, is encircled by rings that span about 35″ to 36″ — and continue to be near their maximum tilt.

EVENING AND MOST OF NIGHT

Neptune and **Uranus** reach their highest in the evening, Neptune about 3 hours before Uranus. Finder charts for these two planets are in the September issue, pages 48–49, and can also be accessed at **https://is.gd/urnep**.

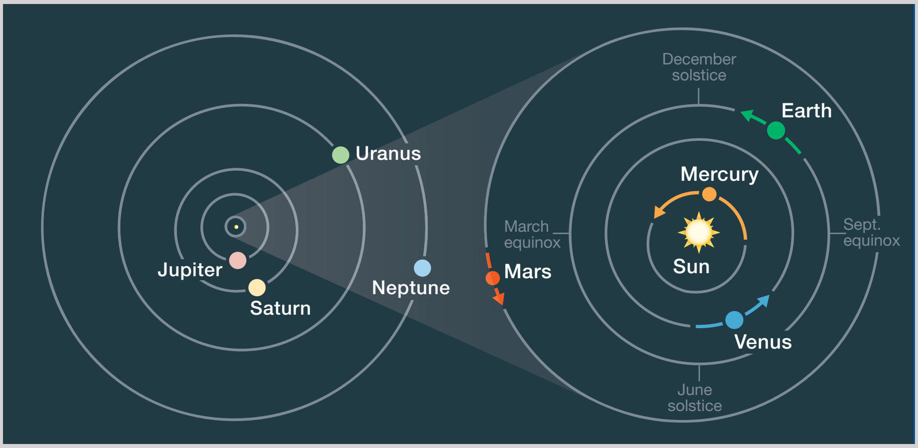
PRE-DAWN AND DAWN

Mars rises not long before the start of morning astronomical twilight in early November but about 2½ hours before the Sun at month's end. The magnitude-1.8 planet is golden-orange. Compare it with magnitude-1.0 blue-white Spica that it passes less than 3° upper left of on November 8–12. Mars remains less than 4″ wide in telescopes this month.

Mercury rockets up into the dawn sky away from its November 11th transit of the Sun. About a week after the transit, Mercury brightens by about half a magnitude each day and rises about 7 minutes earlier each day. The rates then slow down rapidly; but by November 28th, the day Mercury reaches greatest western elongation of 20° from the Sun, Mercury has brightened to magnitude –0.5 and rises 1¼ hours before the Sun.

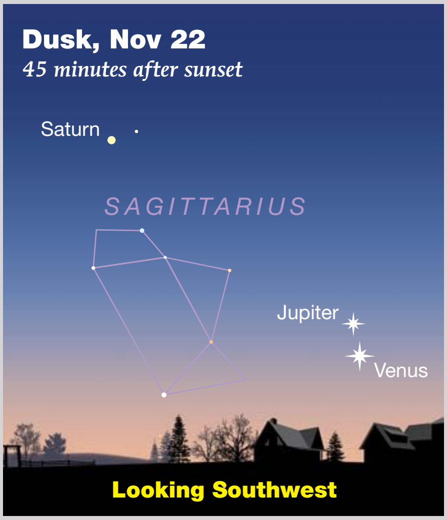
MOON PASSAGES

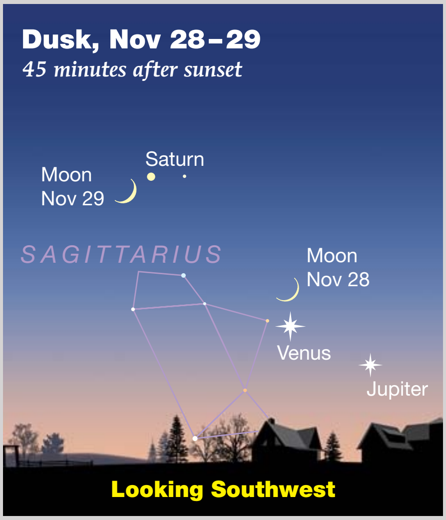
The Moon is a waxing crescent 3° to 4° lower right of Saturn on the evening of November 1st. The Moon is just past full phase on the evening of November 13th when it's less than 2° from Aldebaran. The night of November 16–17, the waning gibbous Moon is some 5° or 6° lower right of Pollux. On the morning of November 20th, the thinning Moon is about 6° left or lower left of Regulus. The waning lunar crescent is about 3° to 4° left or upper left of Mars at dawn on November 24th. The slender sliver of the Moon is close to Mercury the next morning. Back in the twilight sky, a lineup of Venus, Jupiter, and a very low Moon is visible about 45 minutes after sunset on November 27th. The next night, the narrow slip of a Moon is about 1½° above Venus (with Jupiter to their lower right). On November 29th, the crescent Moon is very close, just a little more than 1°, lower left of Saturn.



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

◀▼ 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.





■ **FRED SCHAAF** has penned this column since 1993.

Transit of Mercury

The mighty mite of planets gets between us and our star this month.

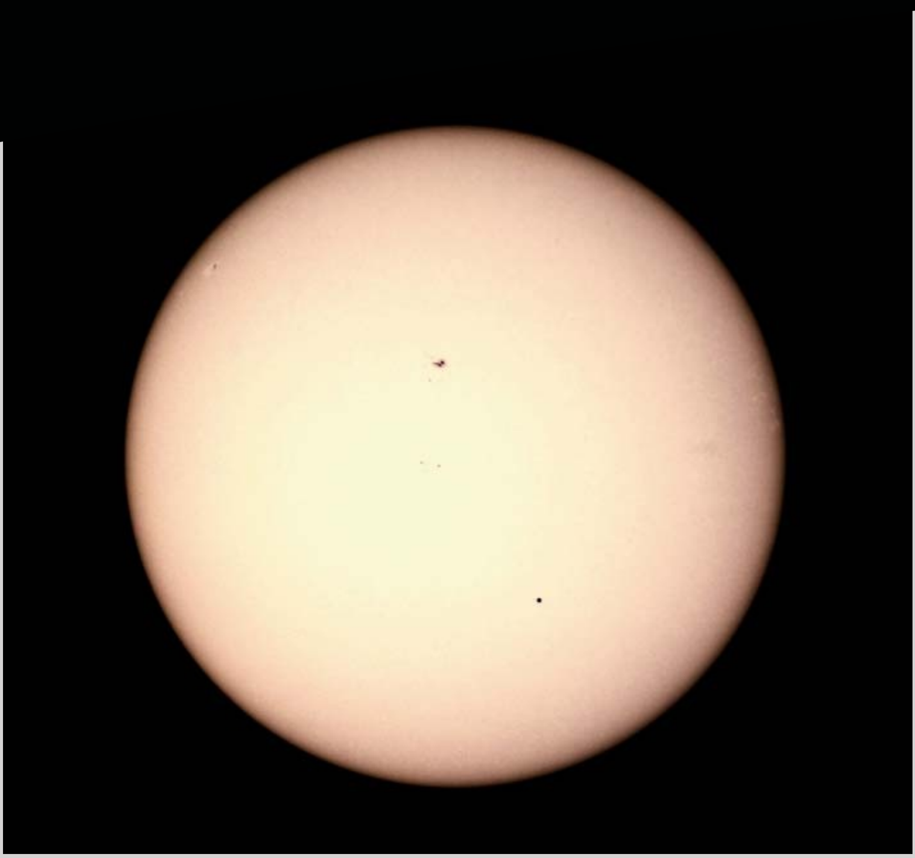
On Monday, November 11th, the tiny planet Mercury will cross the face of the Sun as viewed from Earth. Mercury's orbit is inclined 7° to the ecliptic and intersects Earth's orbital path at two nodes. The first intersection (the *descending node*, when Mercury is moving south through the ecliptic plane) occurs near May 8th in the modern era. The second (the *ascending node*, when Mercury is moving north through the ecliptic plane) falls around November 10th. If Mercury passes through inferior conjunction at one of those two times, a transit will occur.

In 2019, the eastern United States, Canada, and Central America, South America, and westernmost Africa will be able to watch the entire event, from the moment Mercury first "touches" the Sun to the instant it departs the Sun's face. If you're in western North America (excluding most of Alaska and far northern Canada, who won't see any of the event), the transit will already be in progress when the Sun rises. For most of Africa, Europe, and western Asia, Mercury's passage begins in the daytime, with the Sun setting before the crossing is complete.

Use the world map on the facing page to determine your general circumstances. The timetable at right shows, in Universal Time and standard time for North America, when Mercury's leading edge crosses the Sun's boundary and when its trailing edge slips from the Sun. The timings are geocentric, so they may differ from local standard times by a minute or two.

If you didn't buy a white-light filter for your telescope for the 2017 total solar eclipse, now's the time to get one. The filter should fit snugly on the front end of your telescope (eyepiece filters aren't safe!) and be free of defects. Don't use a scratched or torn filter — eye damage from sunlight is irreversible.

Hydrogen-alpha filters are significantly more expensive and have a slightly higher learning curve than white-light filters — it takes practice to produce the best looks at the Sun's chromosphere and prominences. But an H-alpha setup can offer stunning views of the transit, particularly if Mercury passes a prominence as it moves onto/off the Sun's face.



It's difficult to mistake Mercury for a sunspot. Mercury's silhouette has a sharp edge and is uniformly opaque, as shown in this image captured by David H. Timm during the last transit event on May 9, 2016.

Transit Timetable

Time Zone	Transit Begins	Transit Midpoint	Transit Ends
Universal (GMT)	12:35	15:20	18:04
Eastern (EST)	7:35 a.m.	10:19 a.m.	1:04 p.m.
Central (CST)	6:35 a.m.	9:19 a.m.	12:04 p.m.
Mountain (MST)*	—	8:19 a.m.	11:04 a.m.
Pacific (PST)*	—	7:19 a.m.	10:04 a.m.
Alaskan (AKST)*	—	—	9:04 a.m.
Hawaiian (HST)*	—	—	8:04 a.m.

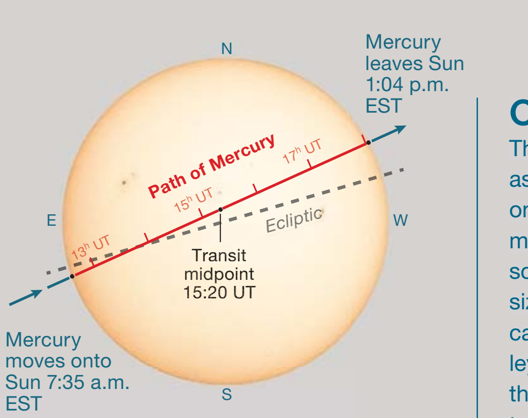
Times for your location may differ by several minutes. *Transit time begins before sunrise.

If you don't have access to a white-light or H-alpha filter-equipped telescope, you can use an unfiltered scope with a low-power eyepiece to project an image of the solar disk onto paper or a screen. For ideas, see Jack Day's design for a projection system at **https://is.gd/SolarProjection**. A filtered-but-direct magnified view will be better, though, since Mercury is notably small: It's just 4,880 km (3,030 miles) across, less than half the size of Earth and only 1⁄194 of the Sun's apparent diameter. In addition, even though Mercury's at inferior conjunction at the time of transit, it's also near perihelion, so it appears just 10″ (arcseconds) across. That's too small to see without optical aid.

With a bit of magnification, Mercury's orb is easy to find, though. The smallest planet appears distinctly disk-like against the Sun, with a defined edge and no penumbra. Hopefully, the Sun will sport a few spots, as it did during the 2016 transit. Dedicated viewers can track the planet's motion throughout the day by comparing relative positions of planet and sunspot, or planet and Sun's edge, which appears reasonably defined through white-light filters.

Mercury makes its ingress (the moment known as *first contact*) on the east-southeastern rim of the Sun at 12:35:27 UT. It takes 1 minute and 41 seconds for the trailing edge of the diminutive dot to fully cross the border and for the entire disk to be visible in front of the Sun (at *second contact*). As the moment of second contact approaches, watch for the *black-drop effect*, when Mercury appears as a small black "teardrop" attached to the Sun's edge. This and other anomalous effects can often be viewed in amateur telescopes (*S&T:* May 2016, p. 38).

Mercury's entire passage across the Sun takes almost 5½ hours. *Third contact*, when Mercury's leading edge touches the Sun's west-northwestern edge, occurs at 18:02:33 UT. *Fourth contact*, when Mercury's egress is complete, occurs 1 minute and 41 seconds later. The event is over.

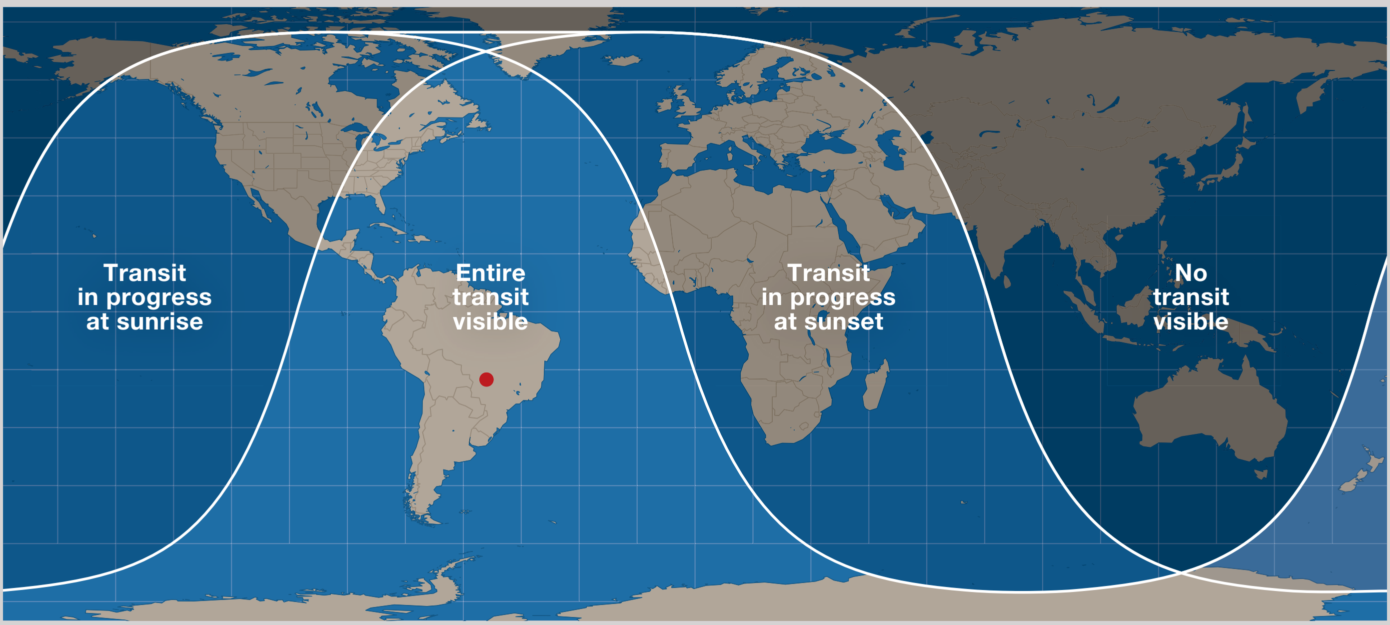


Citizen TOM & the A.U.

The distance from Earth to the Sun (the astronomical unit, or a.u. for short) was one of the most important measurements in early modern astronomy. Once scientists had that distance, the true size and scale of the solar system became clear. It wasn't until Edmond Halley turned his attention to the problem that anyone was able to figure out how to measure the a.u. Halley determined that during a transit of Venus, observers at widely separated locations would see Venus's silhouette at different positions against the Sun's face due to parallax. By measuring the shift in Venus's apparent position, astronomers could calculate the mileage between Earth and the Sun. Halley died before the next transit of Venus, and so he never saw his technique in action.

On November 11th, the Citizen TOM (Transit of Mercury) Project will use Halley's technique with a transit of Mercury instead of Venus. Observers at multiple sites across the country, using identical equipment (from the 2017 Citizen CATE total solar eclipse project), will take simultaneous images of the transit. Most participants are students, offering them a rare opportunity to make one of the most important measurements in astronomy from scratch.

▼ All of South America and parts of Central America, North America, and Africa will be able see the entire event, weather permitting. The rest of North America, Africa, and Europe will see at least part of the transit. Asia, Oceania, and Australia are out of luck this time around.



S&T ILLUSTRATION / SOURCE: FRED ESPENAK (2)

Poor Year for the Leonids

NOVEMBER IS THE MONTH Earth passes through the dust trails that Comet 55P/Tempel-Tuttle leaves behind when it travels through the inner solar system. We experience this interaction as the Leonid meteor shower, which this year is predicted to peak on the night of November 16–17. Shower meteors start to be visible after the radiant, near Gamma (γ) Leonis, rises above the horizon, around midnight for mid-northern latitudes. Unfortunately, the dark skies required for viewing are nonexistent this year, as the Moon rises mid-evening and doesn't set until mid-morning. The waning gibbous Moon, approximately 77% lit, stands high in the east by the time the shower radiant reaches a decent altitude.

Asteroid at Opposition

ASTEROID 4 VESTA is conveniently placed this month, rising in early evening sunset and remaining above the horizon almost the entire night. In the first week of November, Vesta shines at magnitude 6.6, easily within range of small scopes and 10×50 binoculars. Look for it in western Taurus, less than 1° from Omicron (ο) and Xi (ξ) Tauri. The minor planet brightens slightly, to magnitude 6.5, just before it crosses the northeastern border of Cetus on November 7th. Vesta reaches opposition on November 12th, just two nights after its closest approach — 1.56 a.u. — to Earth.

Minima of Algol

Oct.	UT	Nov.	UT
3	1:23	3	14:19
5	22:12	6	11:08
8	19:00	9	7:57
11	15:49	12	4:46
14	12:38	15	1:35
17	9:27	17	22:24
20	6:15	20	19:13
23	3:04	23	16:02
25	23:53	26	12:51
28	20:42	29	9:40
31	17:30		

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**.

Ready for the Big Time?

Comets are unpredictable, but by the end of November, we should have some idea of how Comet PanSTARRS (C/2017 T2) is going to behave. This particular Comet PanSTARRS won't reach perihelion until May 2020, when it's predicted to reach 7th magnitude, but it should begin brightening before that and could be as bright as 10.5 by the end of this month. That's still a telescopic target, but from November 20–30, the comet travels between Alpha (α) Aurigae (Capella) and the trio of Epsilon (ε), Eta (η), and Zeta (ζ) Aurigae, making it relatively easy to locate. Moving westward, PanSTARRS crosses into Perseus in early December and may reach magnitude 9.5 by New Year's Day.

Action at Jupiter

JUPITER SHINES LOW in the southwest at dusk this month. By early December, it will be unobservable.

Though Jupiter hangs low, this is still a good time to seek out its satellites. Any telescope shows the four big Galilean moons, and binoculars usually show at least two or three. They orbit Jupiter at different rates, changing positions along a straight line from our point of view. Use the diagram on the facing page to identify them by their relative positions.

Since late 2016, the tilt of Jupiter's axis has been such that its outermost Galilean moon, Callisto, hasn't passed in front of or behind the planet from our perspective. That changes on November 9th with the beginning of a 3-year eclipse series. Between now and August 10, 2022, Callisto will be hidden by Jupiter 61 times.

All of the November interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

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

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

November 1: 5:06, 15:02; **2:** 0:58, 10:54, 20:49; **3:** 6:45, 16:41; **4:** 2:37, 12:33, 22:29; **5:** 8:24, 18:20; **6:** 4:16, 14:12; **7:** 0:08, 10:04, 20:00; **8:** 5:55, 15:51; **9:** 1:47, 11:43, 21:39; **10:** 7:35, 17:30; **11:** 3:26, 13:22, 23:18; **12:** 9:14, 19:10; **13:** 5:06, 15:01; **14:** 0:57, 10:53, 20:49; **15:** 6:45, 16:41; **16:** 2:36, 12:32, 22:28; **17:** 8:24, 18:20; **18:** 4:16, 14:12; **19:** 0:07, 10:03, 19:59; **20:** 5:55, 15:51; **21:** 1:47, 11:43, 21:38; **22:** 7:34, 17:30; **23:** 3:26, 13:22, 23:18; **24:** 9:13, 19:09; **25:** 5:05, 15:01; **26:** 0:57, 10:53, 20:49; 27: 6:44, 16:40; **28:** 2:36, 12:32, 22:28; **29:** 8:24, 18:19; **30:** 4:15, 14:11.

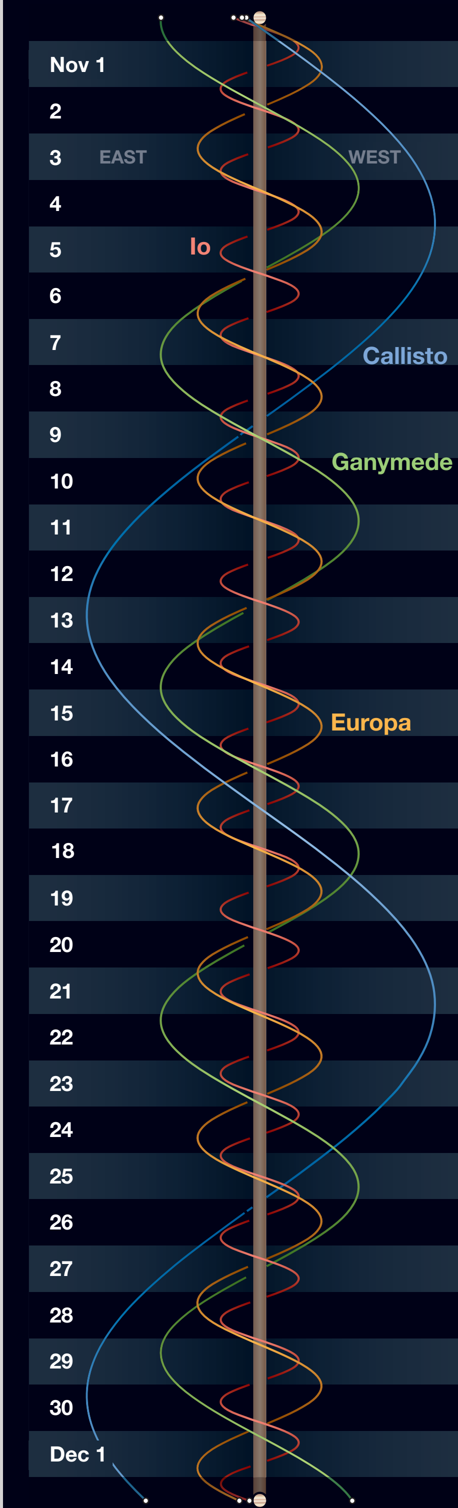
These times assume that the spot will be centered at System II longitude 315°. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 315° and 1⅔ minutes later for each degree more than 315°.

Phenomena of Jupiter's Moons, November 2019

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

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

Jupiter's Moons



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

Neptune as imaged by the Voyager 2 spacecraft during its monumental flyby in 1989. The Great Dark Spot is visible on the right limb.

Monitoring the Sun with Neptune

A long campaign to measure the variability of our star produced unexpected results.

On the night of September 23, 1846, German astronomer Johann Gottfried Galle called out the configurations of stars in the field of view of the 9-inch refractor at the Berlin Observatory, while an assistant, Heinrich Louis d'Arrest, checked them on a map. Just after midnight, Galle called out that a star of 8th magnitude was in a particular location. D'Arrest immediately exclaimed: "That star is not on the map!"

That "star," of course, was a new planet, Neptune. Although a giant planet with an equatorial diameter almost four times larger than Earth's, it appears almost starlike in small telescopes. It takes a magnification of 200× or so to clearly resolve its pale blue disk.

The smallness of its disk, so discouraging to the casual viewer, proved an asset to a very important investigation, in which Neptune wasn't the actual target of study but just an innocent bystander. The real target was the Sun.

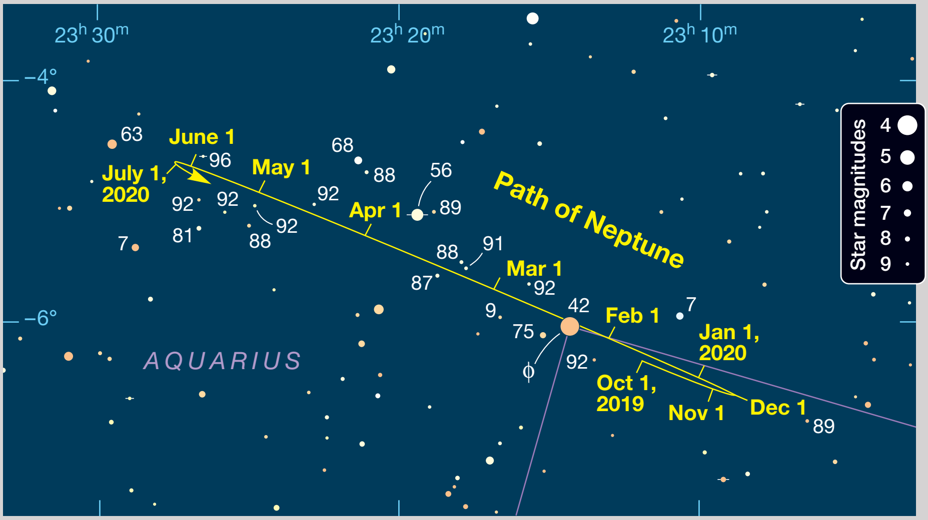
The question astronomers hoped to use Neptune for was, is the Sun a variable star? Determining whether or not the solar constant might, in fact, vary has been one of the holy grails of solar physics, going back at least to William Herschel. He thought it did vary in brightness, and that its variability must affect the climate; he even attempted to correlate wheat prices with his own historical data on sunspots. A more empirical approach to the problem began with the invention of the first solar radiometers in the 1840s, and the idea of using the brightness of planets and satellites to monitor solar brightness seems to have first occurred to Gustav Müller, a German astronomer at the Potsdam Observatory, in 1897.

Like all the other planets, Neptune shines by reflecting sunlight in optical wavelengths, and so by measuring the planet's brightness with a photometer it should, at least in principle, be possible to measure the intensity of sunlight indirectly. The Sun's brightness variation will then be reflected in the corresponding variation of the sunlight scattered from Neptune's atmosphere. Most importantly, such measurements are technically far easier to carry out on the minute disks of Uranus and Neptune than directly on the Sun itself, a huge, boiling, far-from-homogeneous disk.

Photometric monitoring of Neptune began in 1953 at Lowell Observatory as part of the Solar Variations program, one component of the Project for the Study of Planetary Atmospheres funded by Air Force Cambridge Research Laboratories. Measurements were taken with a manually operated 21-inch reflecting telescope at Lowell Observatory fitted with a photometer resembling an old-fashioned radio tube. In those days, data were recorded as squiggly traces on a moving strip of chart paper, similar to the readout on a seismometer used to detect earthquakes.

The precise magnitude of Neptune in the blue region of the spectrum was determined relative to the magnitudes and colors of comparison stars situated along the planet's path as it slowly crossed the sky. The observers were hoping to detect solar variation of a few percent, if it indeed occurred. The project involved several distinguished observers, including the Polish astronomers Krzysztof Serkowski and Mikolaj Jerzykiewicz. Operations ceased in 1966 due to a lack of funding, but in 1972 Wes Lockwood revived the project with the help of associate Don Thompson. Over a period of 43 years they spent thousands of nights at the controls of the 21-inch telescope, located in a

NASA / JPL



▲This finder chart plots the path of Neptune through the end of the current apparition. The magnitude of stars that the planet passes near are listed to the nearest tenth of magnitude and omit decimal points.

▲Wes Lockwood at the controls of the 21-inch reflector. He used the telescope to monitor Neptune for nearly half a century.

roll-off-roof observatory only several hundred yards from the famed 24-inch Clark refractor used by Percival Lowell to observe Mars.

It was already clear by 1965 that the original goal had been quixotic all along. Any actual solar variations were much too small to be detected using ground-based instruments. Instead of a few percent, solar variability is now known from satellite measurements to vary by less than 0.1% over the Sun's 11-year solar cycle — and so cannot be the main driver of climate change. However, as so often in astronomy, the Solar Variations program produced unexpected discoveries. Many of the comparison stars proved to be slowly variable, and some of the Sun-like stars varied more than the Sun itself.

Seasonal variations in Neptune's brightness were also apparent in the measurements. Thus, there was a steady, relatively smooth seasonal rise in brightness beginning about halfway between the planet's equinox and solstice as the sub-solar point on the planet's disk moved southward. This was followed in 2005 by a more delayed drop in post-solstice brightness due to the continued presence of long-lived bright atmospheric features. Remarkably, the measurements were sensitive enough to pick up a variation in brightness a few years before NASA's Voyager 2 spacecraft arrived in 1989, which proved to be due to the Great Dark Spot and bright companion clouds seen in the Voyager images. A similar change in brightness from 1972 to 1977 indicated that a similar but much larger feature had been present at the time.

Today, the photometer has been replaced by near-infrared adaptive optics and Hubble Space Telescope imaging in the monitoring of the Neptunian atmosphere. The loyally dependable and mule-like 21-inch telescope has been shut down, but it deserves to be remembered with appreciation. As Neptune drifts slowly among the star fields of Aquarius this year, observers may follow it with their own telescopes and use the star chart here to estimate the brightness of Neptune relative to stars along its path. As they do so they may ponder how, by spying on distant Neptune, astronomers also contributed significantly to understanding the variations of distant Sun-like stars and the causes of climate change on our own planet.

■ Contributing Editor **WILLIAM SHEEHAN** is a researcher for Lowell Observatory.

▶ Astronomers used the 21-inch reflector at Lowell Observatory (shown) to monitor Neptune.

LOCKWOOD AT SCOPE: WILLIAM SHEEHAN; 21-INCH SCOPE: WES LOCKWOOD

▲ Most of the light in Abell 78's outer shell comes from red hydrogen-alpha emissions, while the inner ring puts out mostly blue-green light from doubly ionized oxygen (O III).

ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA / CC BY-SA 3.0 US

Come the Night

Explore the sky northeast of the Veil Nebula.

Come, gentle Sister of the starry eyes,
With sable fingers open to our sight
Those fields of unimaginable skies —
Your vast demesne — Come, gentle
Sister, Night

— Albert Durrant Watson,
Night, 1924

When night sweeps her velvet robes across the sky and casts her glittering gaze our way, she offers us an unending vista of deep-sky wonders to enjoy. Sights new to my eye patiently await discovery in every realm of the heavens. Thanks to a much-appreciated note from accomplished observer and author Steve Gottlieb, I have a novel addition to my roll of favorites: **Lassell 1**.

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

The constellation Lyra is famed for the Double-Double (Epsilon Lyrae), two widely separated stars that are each close pairs. But Cygnus has a Triple-Double! It was discovered in 1856 by the British astronomer William Lassell and reported in the Monthly Notices of the Royal Astronomical Society the following year. Lassell called it "a singular group of three stars, each attended by a small companion." The pairs mark the corners of a northeast-pointing isosceles triangle with a 1.6′ base and 1.2′ sides.

To locate Lassell 1, hop 2.1° east-northeast from Zeta (ζ) Cygni to a golden 6th-magnitude star, the brightest in the area. Through a finder, this star marks the shared point of two diverging 3-star arcs sweeping northeast for 2.3°, each component shining at magnitude 6 or 7. The stars at the arcs' ends make a shallow curve with a somewhat fainter 7th-magnitude star to their east. Lassell 1 is 18′ north of that star and looks like a hazy star clump at low power. Don't be fooled by a similar clump 8½′ northeast.

The members of this unique stellar arrangement are listed as having magnitudes from 10.6 to 13.5, so I was pleasantly surprised to spot them all at 117× in my 130-mm (5.1-inch) scope. When showing off Lassell 1 at the Peach State Star Gaze in Georgia, I boosted the magnification to 164× to evict a distractingly bright star from the field of view. Clockwise starting with the northeastern pair, the component separations are 19″, 22″, and 12″.

The online Washington Double Star Catalog lists a 7th star in the system. Faint and rather close to Lassell 1's brightest component, this star wasn't visible through the 130-mm scope. It did make an appearance with my 10-inch reflector at 299×, and it showed better at 374× even though atmospheric turbulence made the stars look furry at that power.

Let's return to the star 18′ south of Lassell 1 and look for a slightly dimmer, orange star 16′ to its southeast. The planetary nebula **Abell 78** sits midway between these stars. While I was star-hopping my way to Abell 78 with my 130-mm scope at 102×, it conveniently popped into view by a fortunate chance of averted vision. Only the central star was evident when looking straight at the nebula. With a slightly higher magnification, I detected a fairly large but vague presence, like a fleeting memory of moonlight. This fragile apparition is attended by a faint star off its east-northeastern edge and a little bunch of stars near its northwestern edge. A narrowband nebula filter makes the planetary a bit clearer, but an O III filter gives a displeasingly dim view in a scope this small. The 10-inch scope at 166× reveals a slightly darker area around the central star.

Images of Abell 78 show a knotty, east-west ring approximately 1.5′ × 0.9′ within a 2′ faint and slightly oval glow tilted northwest. The planetary's outer shell is composed mostly of hydrogen that once made up the outer layers of its progenitor star. The knotty ring is hydrogen-deficient and shines largely by the light of doubly ionized oxygen (O III). It contains large amounts of helium forged in the fires of its parent star and dredged up to the surface along with heavier elements by a late flash of energy from fusion in the star's helium shell. The star, formerly on its way to white dwarfhood, was temporarily reborn as a red giant that entered a second planetary nebula phase and ejected its hydrogen-depleted envelope into the previous nebular shroud.

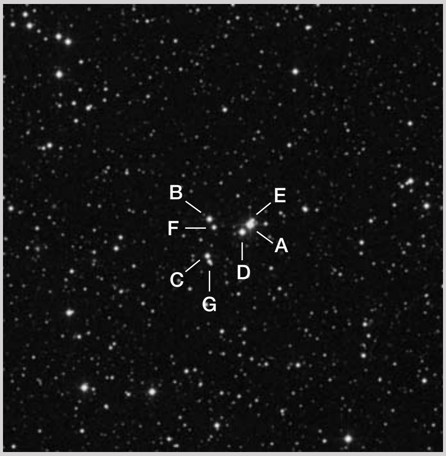
Cygnus seldom comes to mind when we think of galaxies, but let's take a peek at **NGC 7013**, located 2.1° west-southwest of Zeta Cygni. It's the second-brightest galaxy in Cygnus, topped only by NGC 6946, which straddles the Cygnus-Cepheus border far to the north.

NGC 7013 is merely a faint, elongated glow through my 105-mm refractor at 47×, but the view is much nicer at 87×. The galaxy appears about 2½′ long, tipped north-northwest, and grows considerably brighter toward the center. A 10th-magnitude star dances on its northern tip, while a faint star guards its western flank.

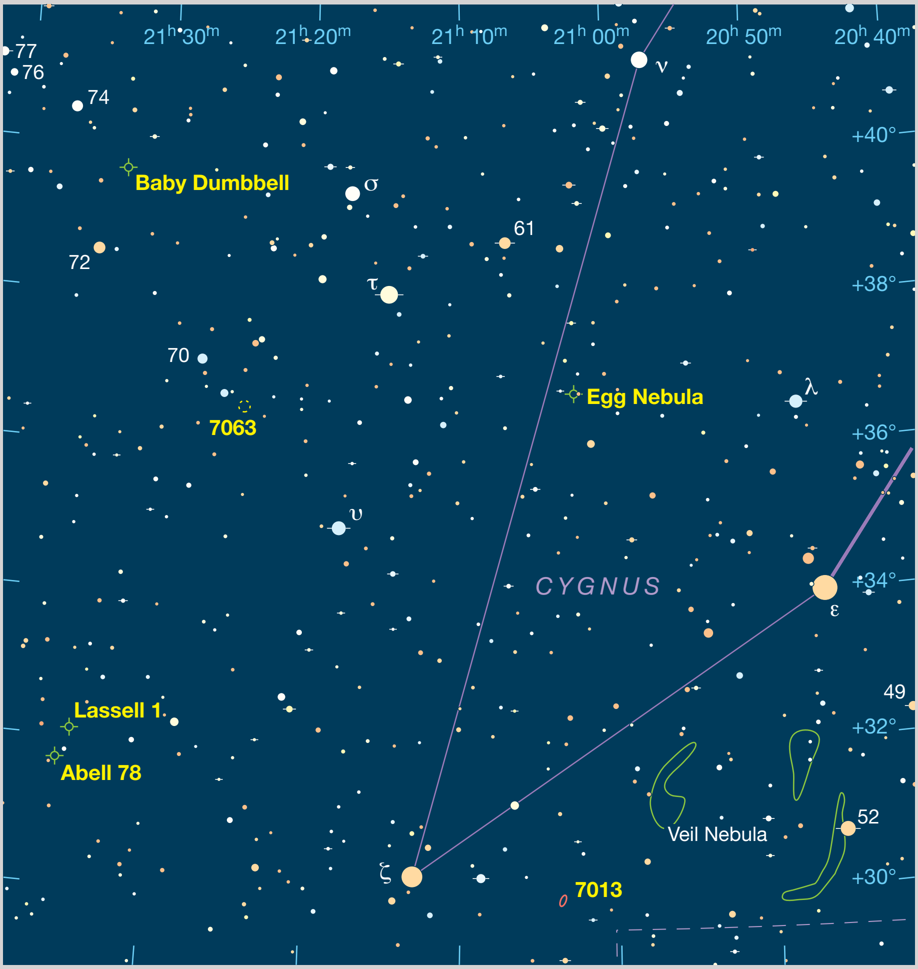
Through my 10-inch reflector at 213×, NGC 7013 covers 3¾′ × 1¼′ with a 1½′-long core and a bright nucleus. The core runs nearly north-south and shows subtle structure. I think it looks like a fat, squashed, indistinct Z, but images indicate that my eye is blending parts of the galaxy's interior ring and its nucleus. Can anyone with a large telescope discern this circumnuclear ring?

Now sweep 3.0° east from Lambda (λ) Cygni to the protoplanetary **Egg Nebula** (PK 80-6 1). Such nebulae are rare because they live for an astronomically brief time. When an aging star a little more massive than our Sun exhausts its hydrogen fuel, it sheds its

▼ The components of Lassell 1 are labeled here by their Washington Double Star Catalog designations. The field is 15′ wide, and the "false double" described by the author is in the upper-left corner.



POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY



▲ NGC 7013 is classified as type SA0/a(r), a ringed lenticular galaxy.

▶ The Egg Nebula has a complex structure that includes a thick dust band that obscures the central star together with shells of dust that were thrown off during the star's death throes. The source of the twin light beams is poorly understood. This false-color image uses red, green, and blue to indicate different polarizations of the reflected light.

▲ The bright blue stars of NGC 7063 indicate that it's a young cluster.

outer layers while its core contracts. For a few thousand years, the cocoon of cast-off material simply reflects light from the star, and we see a protoplanetary nebula. As the collapsing star grows hotter, it eventually warms the nebula enough to emit its own light, and a planetary nebula is born.

The Egg Nebula is easily visible as a little fuzzy spot even in my 130-mm scope at 63×. It's elongated south-southwest to north-northeast and has a bright point within. At 117× the nebula appears 25″ long and half as wide. At 234× the brighter parts look like a little shoe print, with the heel (south) being smaller and considerably dimmer than the sole (north). The bright point noticed at 63× resides in the northern section.

The Egg Nebula's common name was bestowed by Mike Merrill due to its oval appearance on the photographic prints of the National Geographic Society–Palomar Observatory Sky Survey (*S&T:* Jan. 1975, p. 21).

Farther east we come to the open cluster **NGC 7063**, 2.1° northeast of Upsilon (υ) Cygni. In my 130-mm refractor at 23×, it's a conspicuous little group of nine stars, most shining at 10th magnitude and arranged in an X with one bent leg. At 117× two of these stars prove to be doubles, and 10 more suns join this cute little group.

NGC 7063 is a youthful cluster like the Pleiades (M45) in Taurus, but it's about five times as distant and thus appears much dimmer than its splashy cousin.

Our last target is the **Baby Dumbbell** (PK 86-8 1), which lies 3.0° east-northeast of Sigma (σ) Cygni. The tiny disk of this planetary nebula is visible in my 130-mm scope at 63×, and at 164× it appears brighter in the center with a very faint star off its southeastern side. At 234× it shows a slight east-northeast to west-southwest elongation and hints of fainter fuzz along the long sides. The nebula is bluish in my 10-inch scope at low power, while at 299× it's a fairly bright bar with a slightly pinched-in waist and faint extensions along its flanks. A narrowband filter enhances the bar a bit. This planetary gets its nickname from its resemblance to the much larger Dumbbell Nebula (M27) in Vulpecula.

When Night comes, let her open new wonders to your sight and see if you can find a favorite among them.

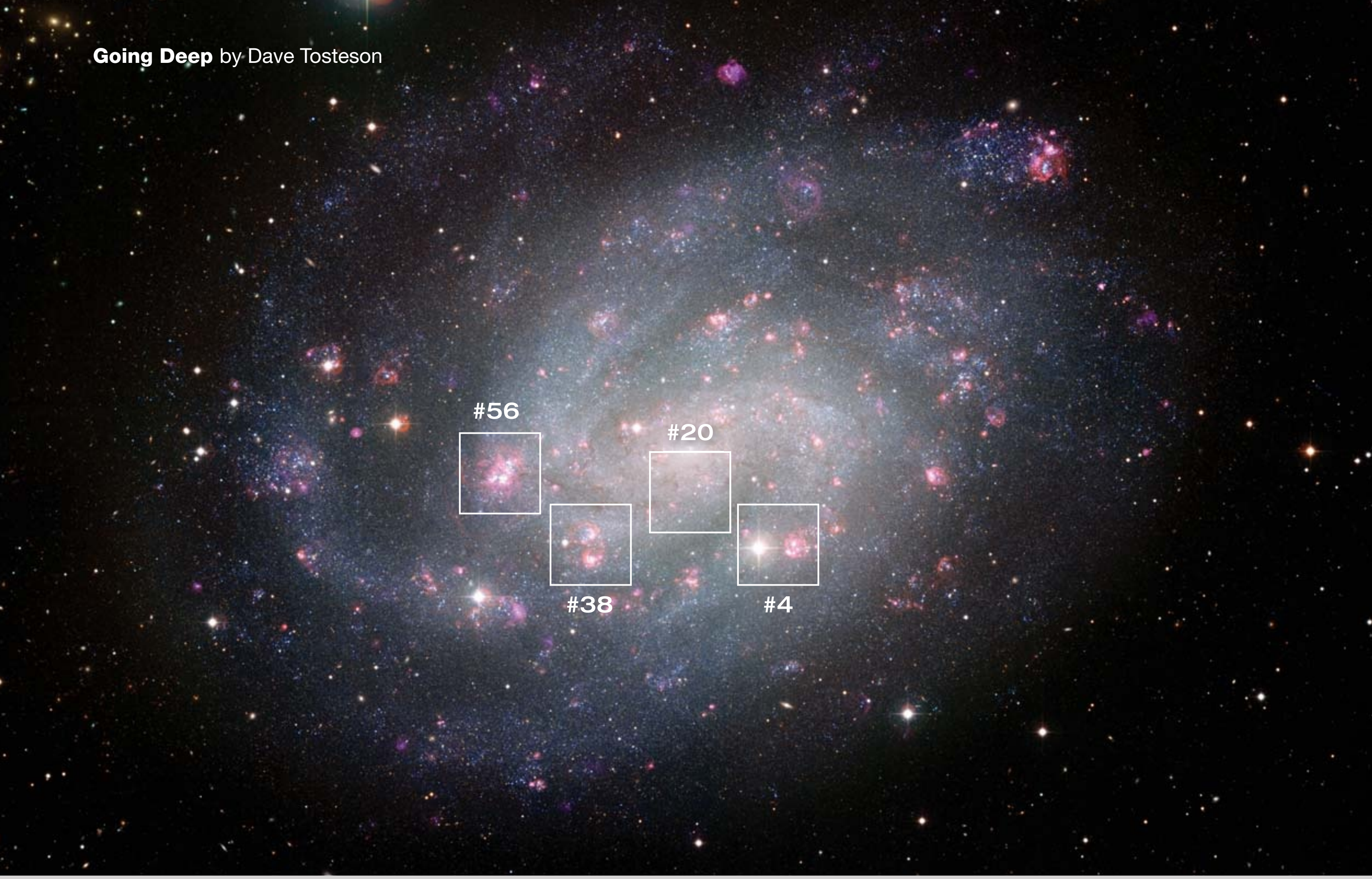
■ Contributing Editor **SUE FRENCH** penned this column for the November 2011 issue.

Treasures Northeast of the Veil Nebula

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Lassell 1	Triple-double star	10.6–13.5	19″, 22″, 12″	21^h 34.8^m	+32° 05′
Abell 78	Planetary nebula	13.4	2.0′ × 1.7′	21^h 35.5^m	+31° 42′
NGC 7013	Lenticular ring galaxy	11.3	4.4′ × 1.4′	21^h 03.6^m	+29° 54′
Egg Nebula	Protoplanetary nebula	12.2	1.0′ × 0.5′	21^h 02.3^m	+36° 42′
NGC 7063	Open cluster	7.0	9.0′	21^h 24.5^m	+36° 30′
Baby Dumbbell	Planetary nebula	11.8	32″ × 20″	21^h 33.1^m	+39° 38′

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.

NGC 7013 & NGC 7063: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; EGG NEBULA: NASA / HUBBLE HERITAGE TEAM / BILL SPARKS / RAGHVENDRA SAHAI



The Farthest Star

The author walks us through progressive steps outside of our solar system in his quest for the farthest visible star.

▲ **PRIME HUNTING GROUNDS** At a distance of 6.3 million light-years in the constellation Sculptor, NGC 300 is an ideal target in the search for the farthest star visible from Earth.

ESO

Have you ever stood on a bit of land where you could climb no higher, or go no farther in the direction toward a place you always dreamed of visiting? During the week of the total solar eclipse in 1991, my wife and I visited Ka Lae, Hawaiʻi, the southernmost point of the island chain and also of the United States. To linger there for a time and wonder what lay beyond was like a prescient moment. What I didn't know then was that two decades later I would venture to Australia, the first land a Hawaiian sailor would find if setting off in the correct direction. Five thousand miles away I would again watch the Moon's shadow block the Sun. Between Ka Lae and Kona, where we saw totality, lies a small memorial to James Cook. The British explorer mapped many of the most distant points on Earth in the 18th century, was the first European to visit eastern Australia, and died on the western shore of Hawaiʻi.

In a cosmic correlation, I often wonder when I view the sky how far I can see in a given direction. Using only our eyes, looking toward Sagittarius we run into the dense gas and dust of our galaxy's plane before we reach its center, around 26,000 light-years away. Turning to Andromeda and its iconic galaxy, we have 2.5 million light-years to M31, and in Centaurus it's about five times farther to the brightest radio galaxy, Centaurus A (NGC 5128), possibly the most distant object visible to the naked eye. With binoculars or a telescope the exercise becomes more complex.

Choosing Our Targets

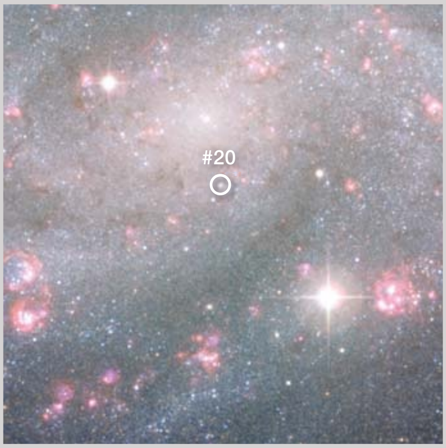
I recently wondered which is the farthest star that can be seen. It's not a trivial problem, as many factors, such as experience, site conditions, and weather affect the answer. Assuming a clear view to the object, the two most important factors are the limiting magnitude of the instrument used and the characteristics of the individual star. The latter are easily looked up in standard star charts and catalogs, and most observers have a good feel for how faint a star will be visible in their telescopes under good conditions. The challenge is picking a well-studied, intrinsically brilliant star near that limit.

Massive stars burn brightly and use their fuel at prodigious rates, often becoming unstable and variable in brightness toward the end of their lives. Eta Carinae in our galaxy, for example, underwent a brightening event in the mid-1800s during which it briefly became the second-brightest star in our night sky, despite being around 7,500 light-years from Earth. Only nearby Sirius (8.6 light-years away) outshone it.

Stars can be bright because they're close, or hot, or large, or all three. Greater surface area increases luminosity (for a given temperature), and RW Cephei is big, really big. Some estimates put its radius at more than 1,500 times that of our Sun's, and if placed at the Sun's position it would extend beyond Jupiter's orbit. An orange hypergiant, it's a variable star and at its brightest borders on naked-eye visibility — amazing for its distance, which some estimates place at 10,000 light-years or more.

Stepping farther out, the globular cluster NGC 2419 is one of the largest in the Milky Way's halo. It orbits at a distance of 300,000 light-years (5–6 galactic disk radii) from both the center of our galaxy and the solar system. From the perspective of M31 it would be the most visible and prominent Milky Way globular, similar to how we view G1 (Mayall II) in M31. The cluster is 9th magnitude, and its brightest stars may be 17th magnitude, potentially visible in a 16- to 18-inch telescope. Amateur astronomer Paul Alsing reported in 2014 that several dozen stars in NGC 2419 were visible using the 82-inch instrument at McDonald Observatory.

Moving outward, we next see the irregular galaxy NGC 6822, or Barnard's Galaxy, at a distance of 1.7 million light-years in Sagittarius. Many of its nebulae and clusters are visible in amateur equipment, and I have spotted both a supernova remnant and a planetary nebula. An 18.6-magnitude star just off the northwest edge of the Bubble Nebula (Hubble 1925 I) in the northwestern reaches of the galaxy, should be visible in larger reflectors.



▶ **THE FARTHEST STAR?** The author detected these four WR stars using his 32-inch f/4 reflector. They're a challenge, but the satisfaction of snagging them is worth the effort. Each image is approximately 5′ × 5′.

The Andromeda Galaxy, at 2.5 million light-years from us, had long been touted as the most distant object visible to the unaided eye. Edwin Hubble forever changed our understanding of the universe in 1929 with his study of Cepheid variable stars in M31, proving it was an external galaxy and offering the most robust estimates to date of its distance. Two stars are readily visible within our sister spiral to amateurs with medium-size reflectors.

In the 1990s, former *S&T* editor Stephen O'Meara claimed a successor to M31's title in Centaurus A. At a probable distance of around 12 million light-years, its sighting extended our visible universe by more than five times. I was thrilled to duplicate that observation from the mountains of central Chile in the spring of 2017.

Determined Distances

Wolf-Rayet (WR) stars are an intrinsically bright class named after two researchers who identified them in the 19th century (see Steve Gottlieb's article for more detail on WR stars and their nebulae, *S&T:* Aug. 2019, p. 28). Astronomers categorize these stars depending on the relative abundances of carbon (WC), nitrogen (WN), or oxygen (WO), the latter being the rarest type. WR stars are characterized by strong stellar winds that can carve a bubble out of the surrounding medium. Two of the most spectacular WR nebulae in the sky are the Crescent Nebula in Cygnus (NGC 6888) and Thor's Helmet (NGC 2359) in Canis Major. Seen through a large reflector in a dark sky using an O III filter, these magnificently detailed extrusions take one's breath away.

How does all this apply to an amateur seeking the farthest star visible through the eyepiece? I picked WR stars because they can be identified in other galaxies due to their prominent emission lines (and thus their distances are better constrained).

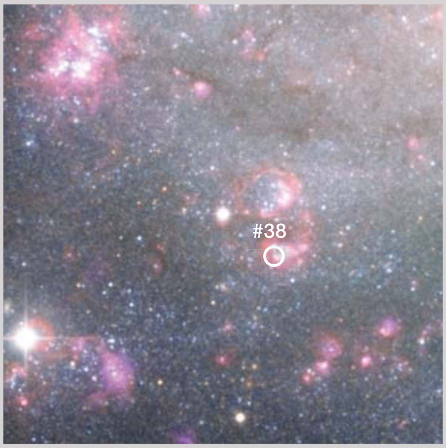
In perfect conditions I can see to at least 20th visual magnitude with my

Wolf-Rayets in NGC 300

Object	Type	Size	Mag(v)	RA	Dec.
NGC 300	Sc	21′ × 13′	8.1	$00^h\ 54.9^m$	–37° 41′
NGC 300 #20	—	—	17.6	$00^h\ 54^m\ 52.6^s$	–37° 41′ 49″
NGC 300 #56	—	—	17.7	$00^h\ 55^m\ 13.5^s$	–37° 41′ 38″
NGC 300 #4	WN	—	—	$00^h\ 54^m\ 42.8^s$	–37° 43′ 02″
NGC 300 #38	WN	—	19.5	$00^h\ 55^m\ 04.1^s$	–37° 43′ 19″

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.

ESO (4)



32-inch reflector. Using the usual formula that correlates magnitude and distance, a very conservative absolute magnitude of –6 places potential WR target stars at a distance of 5.2 million light-years, or just outside the Local Group (with the Milky Way at the center) and significantly more distant than the WR stars in NGC 2359 and NGC 6888. If I were to find a WR star with the absolute magnitude of RW Cephei (–9.4), I could be looking at an object potentially 25 million light-years away, similar to that of M51 (the Whirlpool Galaxy). I studied papers on M51's individual stars and concluded that none are presently visible with my equipment. Face-on spirals away from the plane of our galaxy seem best suited for the search, thus minimizing intragalactic extinction. And that brought me to **NGC 300**.

Digging Deep in NGC 300

NGC 300 is a face-on Sc-type spiral galaxy in Sculptor with many star-forming regions. Previously considered to be a member of the Sculptor Group, it's now thought to be closer than that grouping of galaxies. At a distance of 6.3 million light-years or so, NGC 300 is gravitationally paired with nearby NGC 55 and is often likened to another late-type spiral, M33 (the Triangulum Galaxy), which is known to have an abundance of WR stars. A 2003 paper published by Hans Schild (ETH-Zentrum, Switzerland) and coauthors dealt with 58 stars in NGC 300, of which 22 were confirmed WR stars and the rest were newly identified in their study. The European Southern Observatory Very Large Telescope's 8.2-meter mirrors and associated instruments allowed the team to obtain deeper imaging and spectroscopic data of the targets.

At the 2016 Okie-Tex Star Party, I used my 32-inch f/4 reflector on the night of September 26th to view NGC 300 and its WR stars. With a 9-mm Type 6 Nagler eyepiece yielding 361× and a 14′ field of view, I spent 40–50 minutes scanning the southern half of the galaxy for these stellar beacons from beyond the Local Group and was able to make out four. I use the same numbers as in the Schild paper. The brightest of the new WR candidates, **#20**, appeared as a stellar dot 50″ south-southwest of the galaxy's nucleus. The second brightest candidate was **#56**, located 3.7′ east of the nucleus at a position angle of 97°. It was the most northerly of three objects forming a right triangle and moderately easy at magnitude 17.7.

The two confirmed WR stars I observed were **#4** and **#38**. The former is readily seen in a little clump 45″ east of a 9.6-magnitude star that is 2.6′ southwest of the nucleus. This area also forms a small right triangle of objects, with #4 sitting in the northwest corner. WR star #38 is the faintest of the four on Schild's list, with a magnitude of 19.5. There is a 13.8-magnitude star 3.2′ southeast of the galaxy's nucleus, and it forms a triangle with two slightly fainter objects, each 30″ to the west-northwest and southwest. The southwesternmost of these three objects appears slightly nebulous, and the WR position correlates with a faint *stellaring* (dense, starlike knot) a few arcseconds northeast of the main object. In the eyepiece the feature containing the WR star did appear elongated, if not separated, from the rest of the area. Twenty-inch instruments should snag the candidates of magnitude 17–18, while reflectors in the 25- to 30-inch range may be needed for #38.

Among the targets I didn't attempt this time was #41, a 22.4-magnitude WR star near #56. The 26-solar-mass WR star is most likely in a binary pair with a 20-solar-mass black hole. NGC 300 X-1, as it's known, is only the second such extragalactic pair identified, after IC 10 X-1. Can you make it out?

Most observing projects have a specific, static object in mind, one that can be pursued for as long as needed. We know where it is and how to find it, with only circumstance needed for better insight into its nature. But this one is different. It's an idea dependent on dynamic factors, and finding new stellar candidates for a distance record has been an enriching process. Take a moment to appreciate the present universe where a mere star can be seen so far away.

■ **DAVE TOSTESON** likes to expand the visual limits of the observable universe.

FURTHER READING: To learn more about the observing procedures and results on the WR stars in NGC 300, see the paper by Hans Schild and colleagues published in *Astronomy & Astrophysics* in 2003 at **https://is.gd/NGC300_WR**.

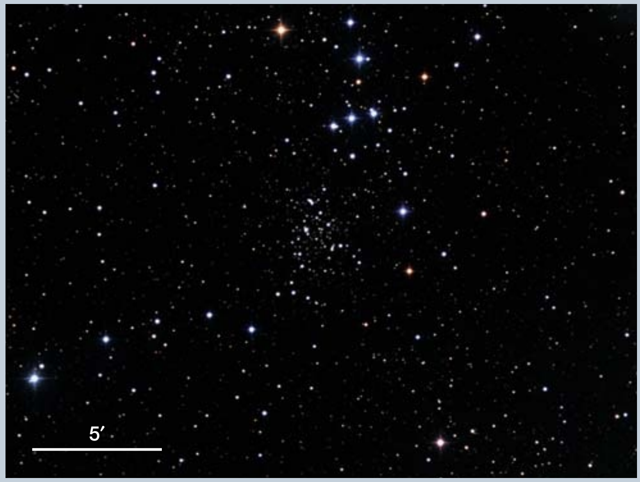
 by Al Lamperti, images by Frank Colosimo

A Full Deck of Kings

Open clusters can be pleasing to behold but tend to be elusive. Join the authors on their foray into the world of King open clusters.

Bright open clusters are quite dazzling to behold: Witness the Perseus Double Cluster. Part of their aesthetic beauty results from the high contrast between the brilliance of the stars and the inky-black background. Many open clusters are bright Messier or NGC objects. A wonderful introduction to the wide variety of open cluster designations, some off the beaten path, can be obtained by participating in the Astronomical League's Open Cluster Observing Program, complete with a downloadable manual (see **https://is.gd/ALopencluster**).

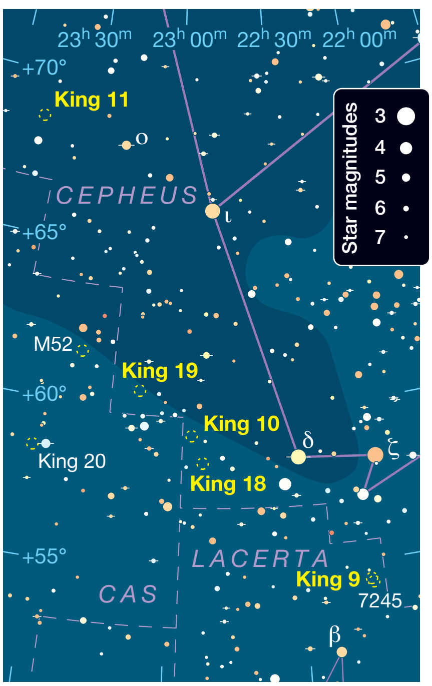
However, as with technology, the aperture of telescopes and persistence of observers have increased over the years, and thus the discoveries of more challenging and perhaps lesser-known (and observed) open clusters have increased. Among the plethora of open cluster designations are those described by American astronomer Ivan King in two papers published in 1949 and 1965. There are 27 King open clusters that range from the obvious to perhaps a couple of bright stars with background haziness perceptible to the eye. Fourteen of the 27 King open clusters whimsically reside in "royal" constellations: Queen Cassiopeia and King Cepheus. *(continued on page 64)*



▼ **KING 9** Let's begin our foray into King open clusters by going to King 9 in Lacerta. Look for this cluster around 5′ northeast of NGC 7245. It's a small, nebulous object with only a handful of stars resolved.
Mv*=18 | S=3′ | No.=40 | Tr=I1m | Mag.=272×

▲ **KING 10** Some stars seem to be resolved in this first cluster that we'll visit in Cepheus, but many are fainter and in the background. There's some milkiness to the cluster.
Mv*=11 | S=4′ | No.=40 | Tr=I1m | Mag.=256×

Cepheus and Lacerta



ALL IMAGES BY FRANK COLOSIMO

Trumpler Classification

All open clusters can be graded using the classification scheme devised by Swiss-American astronomer Robert Trumpler and further described by Swedish astronomer Gösta Lyngå. The scheme is based on three scaled parameters: concentration, range of brightness, and richness. The first parameter describes how well the cluster stands out, or is "detached," from the rest of the star field and whether there is a concentration of stars towards the center. The breakdown of the categories is as follows:

CONCENTRATION

- I Detached clusters, strong central concentration
- II Detached clusters, light central concentration
- III Detached clusters, no central concentration
- IV Clusters that are not well detached from the surrounding star field

RANGE OF BRIGHTNESS

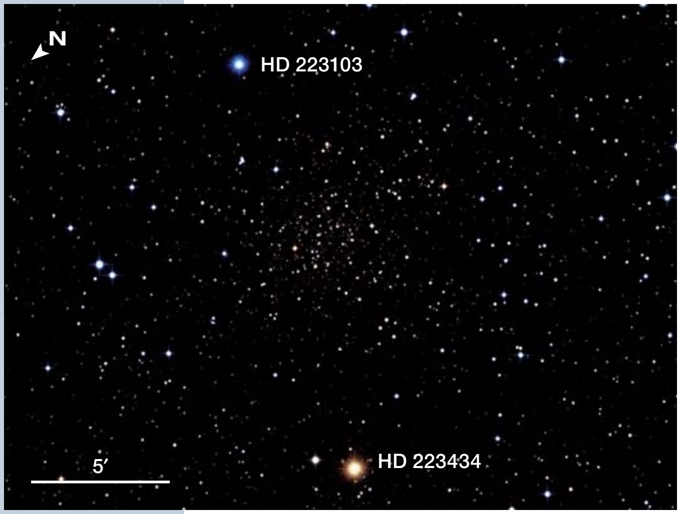
- 1 Most cluster stars are of similar apparent brightness
- 2 Medium range in brightness
- 3 Both bright and faint stars are present in the cluster

RICHNESS

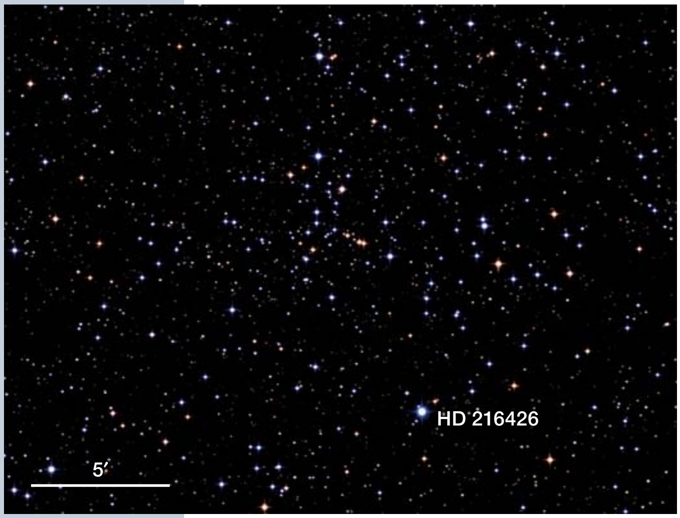
- p Poor: fewer than 50 stars
- m Medium rich: 50–100 stars
- r Rich: more than 100 stars

Clusters can be characterized by the combination of these three parameters. For example, both components of the Double Cluster, NGC 869 and NGC 884, are classified as I3r. Although none of the King clusters is embedded in nebulosity, you may see an "n" added to other Trumpler descriptions.

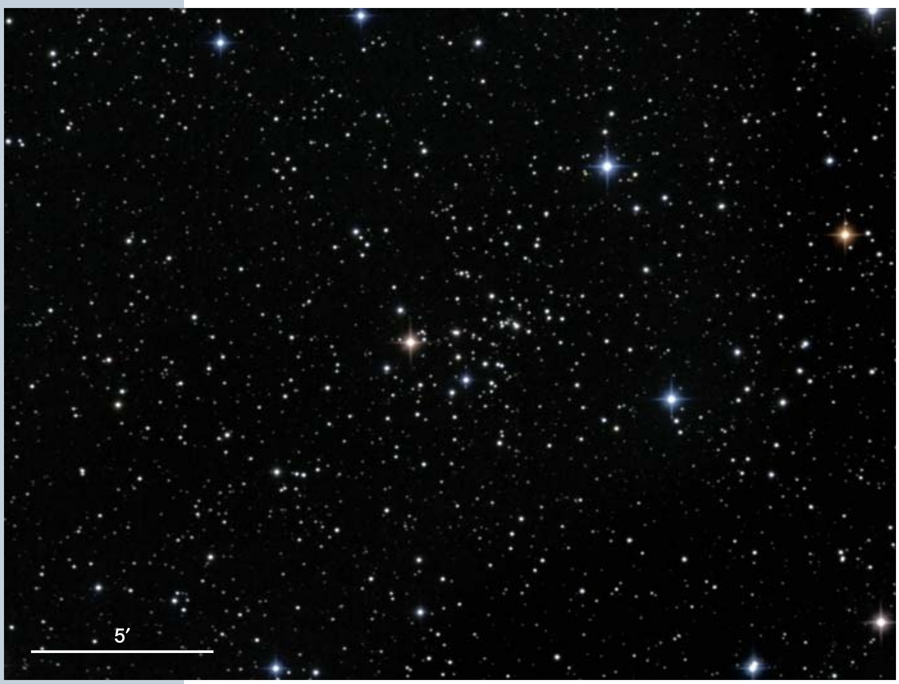
For each of the clusters represented, the visual magnitude (**Mv**) of the cluster is listed. When that wasn't available, the magnitude stated is that of the brightest star in the cluster, indicated by an asterisk (**Mv***). In addition, the size (in arcminutes, **S**), number of stars (**No.**), and Trumpler classification (from Archinal and Hynes, **Tr**) are noted, as is the magnification (**Mag.**) for the visual observations.



◀ **KING 11** Staying in Cepheus, look for this small and very sparse cluster almost exactly halfway between 8th-magnitude HD 223434 and 9th-magnitude HD 223103. Note that north is to the lower left.
Mv*=17 | S=6′ | No.=50 | Tr=I2m | Mag.=337×

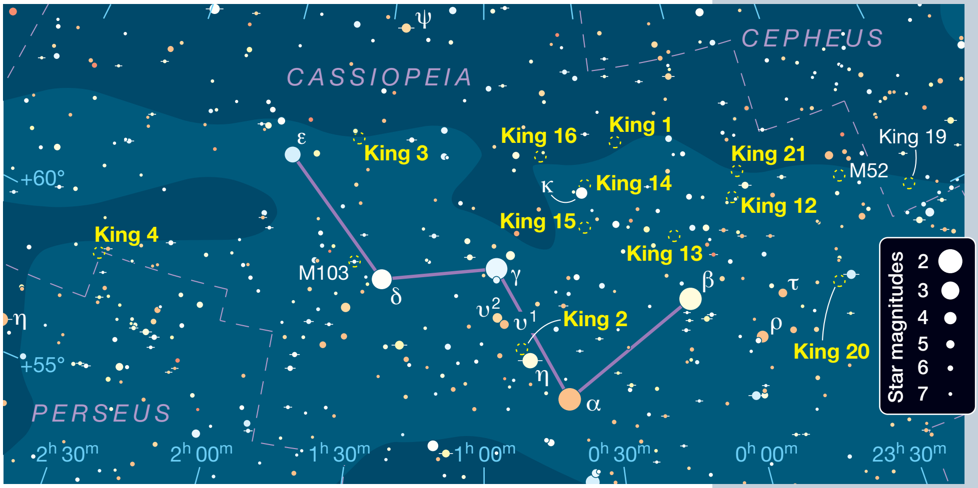


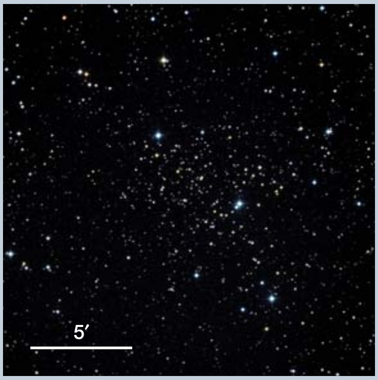
◀ **KING 18** This is an elongated open cluster with no concentration toward its center and milkiness in the background. I'd classify it as III3m (as opposed to the catalog description of II2p). Ninth-magnitude HD 216426 may guide you to the cluster some 5′ north-northeast of the star.
Mv*=12 | S=5′ | No.=20 | Tr=II2p | Mag.=272×



▶ **KING 19** The stars in this cluster are nicely resolved. The brighter members form the vertices of a triangle — it could almost be an asterism.
Mv=9.2 | S=5′ | No.=52 | Tr=III2p | Mag.=66× and 256×

Cassiopeia

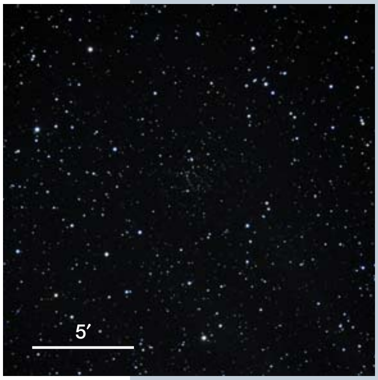


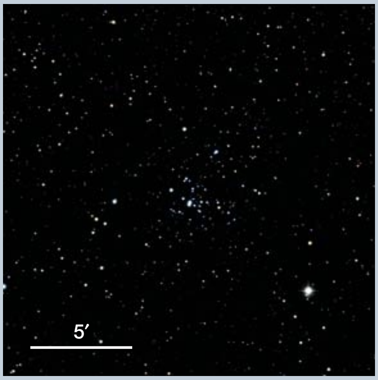


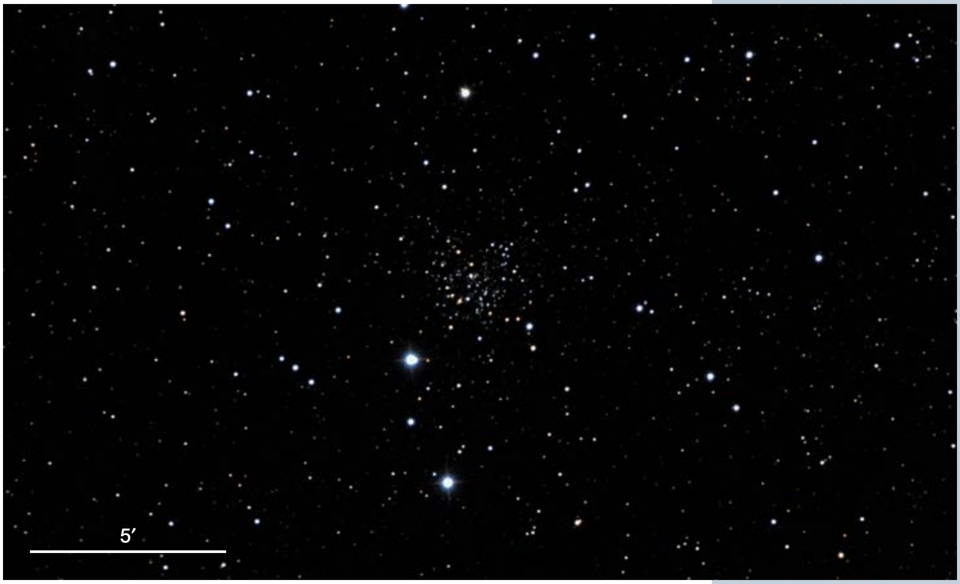
▲ **KING 1** Moving into Cassiopeia, King 1 stands out from the field. The brighter stars in the cluster form a small asterism resembling a kite with a tail — can you see it? — with some haziness among the stars.
Mv=19.3 | S=9′ | No.=100 | Tr=II2r | Mag.=337×

▶ **KING 2** Located some 26′ northeast of Eta (η) Cassiopeiae, King 2 is visibly smaller than King 1 and seems to stand out from the field. I noted only three brighter stars with a hazy glow around them.
Mv=19.8 | S=4′ | No.=40 | Tr=II2m | Mag.=337×

▶▶ **KING 12** I find that this cluster displays a fairly large range of brightnesses, and I would classify it as II3p.
Mv=9 | S=3′ | No.=15 | Tr=II1p | Mag.=73× and 272×

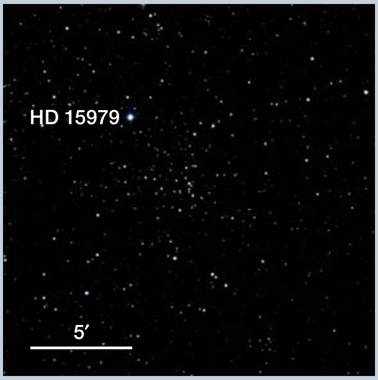


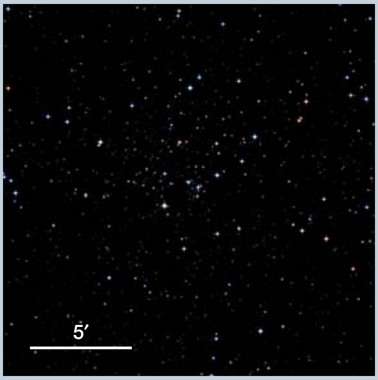




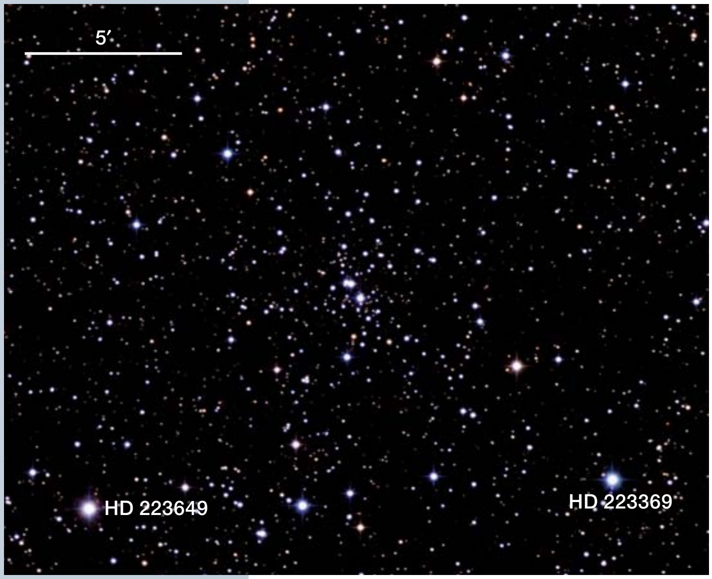
▲ **KING 3** Also known as NGC 609, King 3 is quite faint, adjacent to and slightly northwest of a pair of 9th-magnitude field stars. I can only resolve a few stars.
Mv=11 | S=3′ | No.=77 | Tr=II3r | Mag.=282×

▼ **KING 4** Look for this cluster 2′ to 3′ southwest of 9th-magnitude HD 15979. I caught a hint of it at 77×. With 337×, it was open and spread out, concentrated toward the center with a wide range of star brightnesses, and poor-to-medium in numbers, as per its Trumpler rating.
Mv=10.5 | S=5′ | No.=44 | Tr=III1p | Mag.=77× and 337×

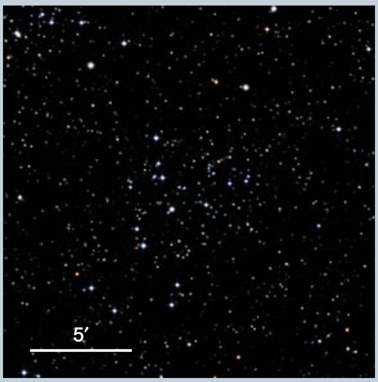


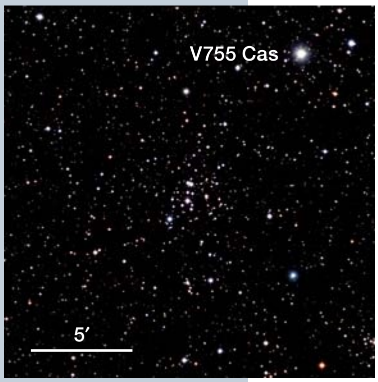


▲ **KING 13** There's a grouping of stars on the edge of a lopsided trapezoid asterism. I see it as III1p.
Mv*=12 | S=5′ | No.=30 | Tr=II2m | Mag.=272×



◀ **KING 21** Look for an arc of four stars: two brighter ones similar in magnitude and two others that are dimmer. Small compared to other King clusters, you'll find King 21 about 7′ above and about halfway along a line connecting 8th-magnitude HD 223649 and 9th-magnitude HD 223369.
Mv=9.6 | S=4′ | No.=20 | Tr=I2p | Mag.=282×

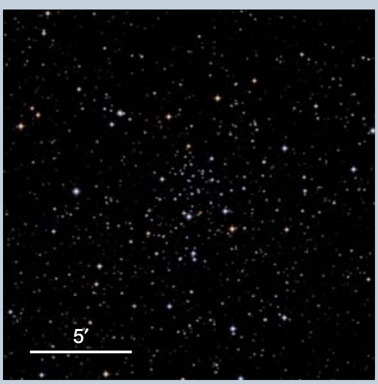


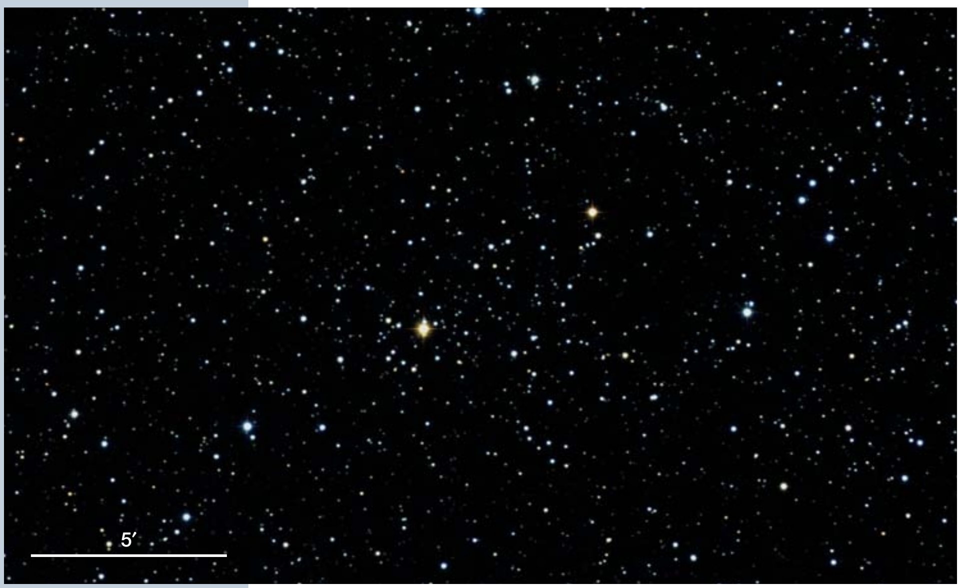


◀◀ **KING 14** Easy to find about ¼° northwest of Kappa (κ) Cassiopeiae, King 14 is an open grouping that's separate from the background.
Mv=8.5 | S=7′ | No.=186 | Tr=III1p | Mag.=73×

◀ **KING 16** This is a tight grouping that stands out nicely around 8′ southeast of the eclipsing binary V755 Cassiopeiae.
Mv=10.3 | S=5′ | No.=71 | Tr=I2m | Mag.=73× and 272×

▼ **KING 20** Easier to find than King 11 (which I had just observed earlier that night), King 20 appears quite open — look for it a little less than ½° east-southeast of the eclipsing binary AR Cas. It displays a moderate range of magnitudes and no concentration to the center.
Mv*=13 | S=5′ | No.=20 | Tr=II2p | Mag.=337×





▲ **KING 15** Visually, King 15 looks like it could be the "Bull's-eye Cluster" to me. It's quite an unusual open cluster in that there is a bright star in the center encircled by a half dozen other stars.
Mv*=18 | S=3′ | No.=12 | Tr=IV2p | Mag.=337×

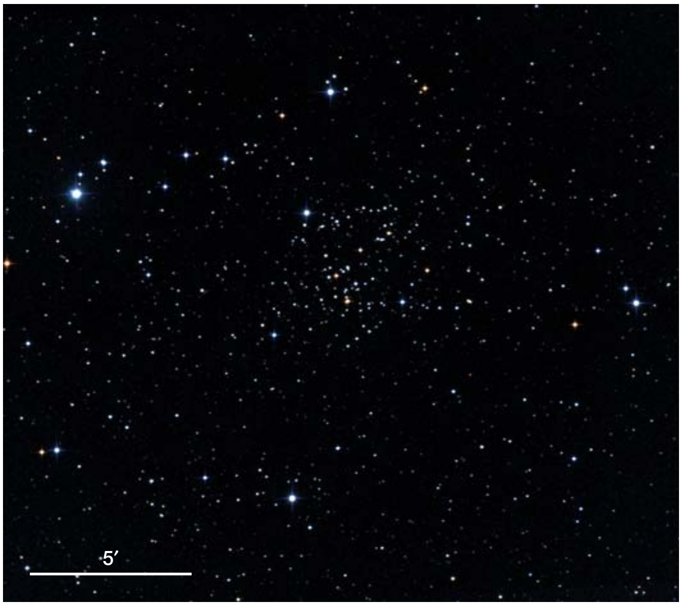
(continued from page 60)

Visually tackling the King list requires dark skies, increased aperture, and high magnification. Over the years, I have observed each of the King open clusters with reflector telescopes ranging from 18 to 22 inches. The more recent observations were made with a 22-inch reflector. The challenge in finding, observing, and resolving the clusters is due, in part, to their intrinsic brightness, their age, and their greater distance from us. For example, the average distance to the two members of the Double Cluster is 7,200 light-years, whereas that of the King open clusters is almost 10,000 light-years. Interestingly, the average age of the Double Cluster, which is composed of "young" bright stars, is 11.3 million years, whereas the King clusters average 1.1 billion years, or nearly 100 times older!

The observer shouldn't automatically dismiss a King open cluster even if its magnitude appears to be beyond the capability of their telescope. Sky conditions, position in the sky, magnification, experience, and persistence may prove the numbers deceiving.

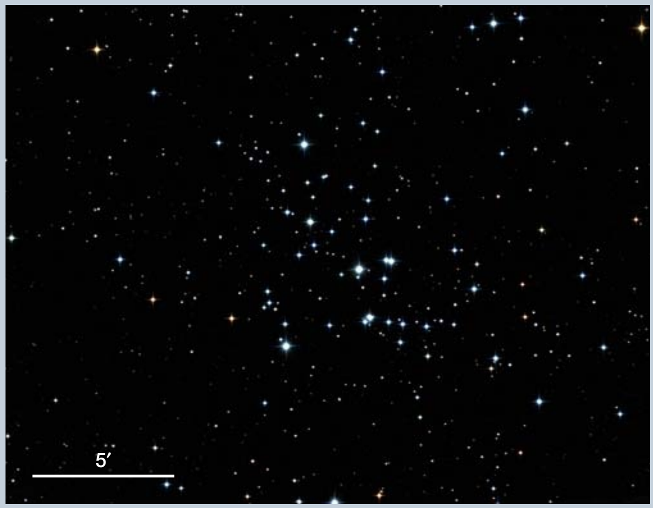
Within these pages are images provided by Frank Colosimo accompanied by my observing notes. Frank obtained

▼ **KING 5** In the northern reaches of Perseus, King 5 is a faint yet resolvable open cluster.
Mv*=13 | S=6′ | No.=40 | Tr=I2m | Mag.=98×

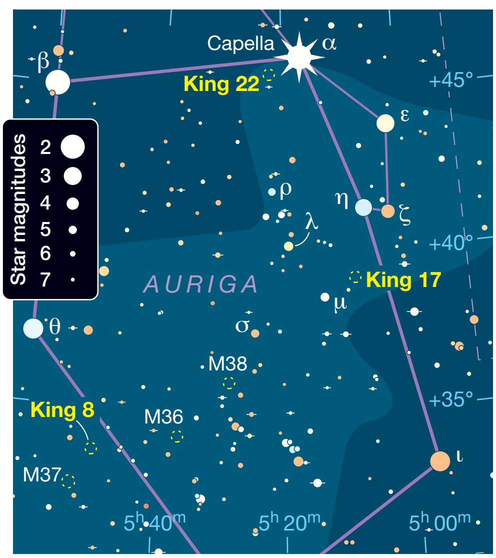


▼ **KING 6** Across the border in Camelopardalis, King 6 is a scattering of bright stars along with many faint stars, and elongated in shape.
Mv*=10 | S=10′ | No.=35 | Tr=II2m | Mag.=208×

▼▼ **KING 7** This is a very dim open cluster, with one bright star surrounded by haze, making it hard to classify.
Mv*=16 | S=8′ | No.=80 | Tr=I2r | Mag.=272×



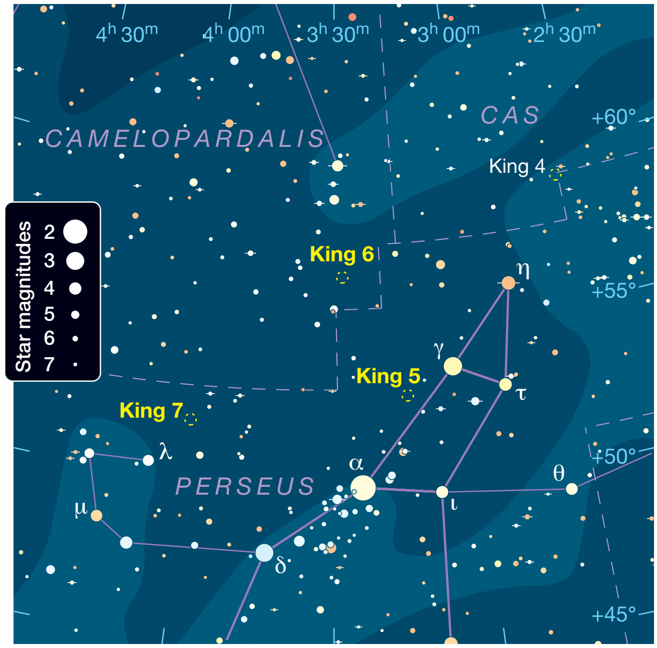
Auriga



▲▲ **KING 8** The first of three targets in Auriga, King 8 is a very easy open cluster with no concentration toward its center. Made up of a moderate population of mostly bright stars, the range of magnitudes in the cluster is small, as per its Trumpler classification.
Mv=11.2 | S=4′ | No.=198 | Tr=II2m | Mag.=77×

▲ **KING 17** The star field can be found easily, though this open cluster is very small and very faint.
Mv*=14 | S=5′ | No.=25 | Tr=II2m | Mag.=337×

Perseus and Camelopardalis



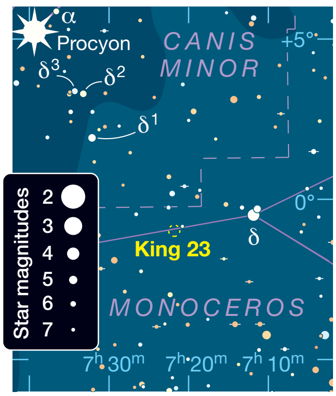
▼ **KING 22** A very open cluster that is easily missed, King 22 (also known as Berkeley 18) is around 1° southeast of Capella. I only noted bright members, but maybe poor transparency made it difficult to separate the fainter stars.
Mv*=16 | S=12′ | No.=300 | Tr=III1r | Mag.=66× and 256×

the images in July and September 2018 and March 2019, all from New Ringgold, Pennsylvania. He used two telescopes, an 11- and a 12.5-inch, and applied 60-second exposures to acquire the images via a CCD camera. For each image, 20 or more exposures were collected and stacked to reduce noise, and luminance, red, green, and blue filters were applied to reproduce color. The short exposure time was chosen to simulate what a visual observer would see. Each image has a bar representing 5 arcminutes superposed.

One thing to bear in mind is that it's obvious that the camera is much more capable of recording fainter stars and resolving the cluster than the observer's eye. The camera can integrate light and make objects stand out better than large-aperture telescopes. However, as experienced visual observers have learned, increasing the magnification can increase the contrast of the fainter objects, and the eye is better able to distinguish them from the background. As planetary scientist and imaging-instrument developer Roger Clark states: "The eye is more sensitive to fainter, lower contrast objects when they appear larger to your eye." Cells in the visual system respond to sudden changes of brightness but do so poorly when the illumination is gradual.

Although the aesthetics of most of the King open clusters may not overwhelm the observer, the challenge of finding them and sepa-

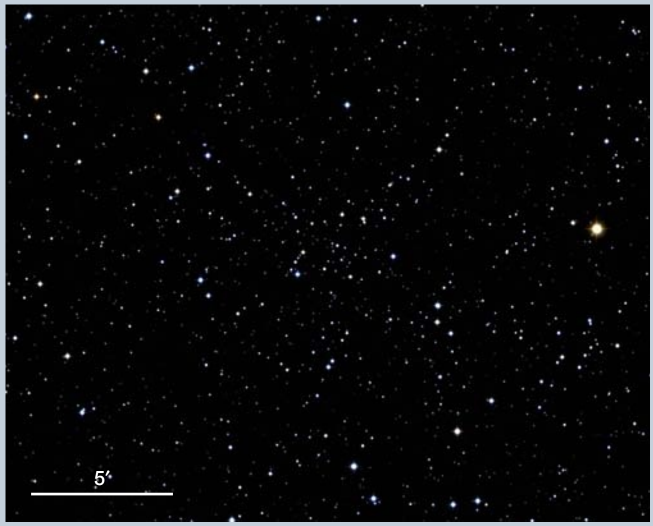
Monoceros



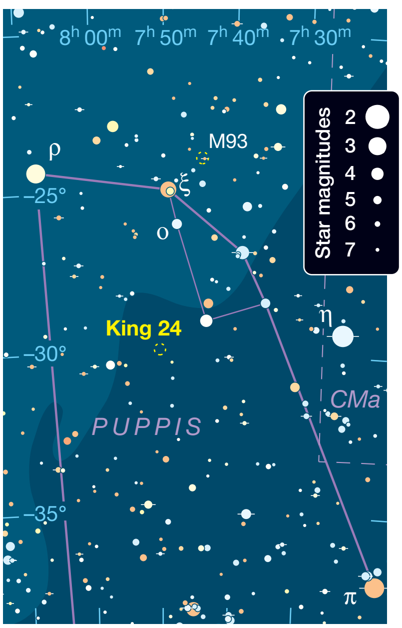
▶ **KING 25** In northern Aquila, King 25 is fairly faint, and I can just about see it. I can possibly snag three stars with averted vision. I find it hard to reconcile the numbers and brightness of its Trumpler classification; I would probably consider it to be more like II1p.
Mv = unavailable | S=5′ | No.=40 | Tr=III2m | Mag.=272×

▼ **KING 23** We head into Monoceros for this cluster, also called Czernik 28, which appears as a gentle arc of about 5 stars that seem to cup some haziness. King 23 is in the same low-power field as Berkeley 37, a slightly more obvious open cluster visually.
Mv = unavailable | S=5′ | No.=20 | Tr=III2p | Mag.=337×

▼▼ **KING 24** In Puppis, this cluster — another that also has a Czernik designation, Czernik 32 — comprises two "bright" stars with a faint hazy glow near a delicate string of stars.
Mv = unavailable | S=3′ | No.=30 | Tr=II1m | Mag.=337×

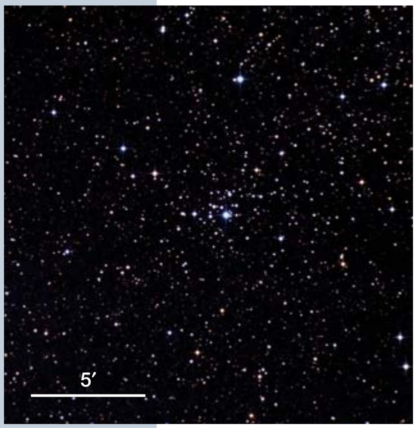


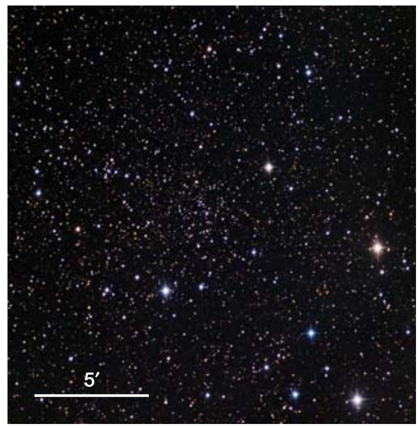
Puppis



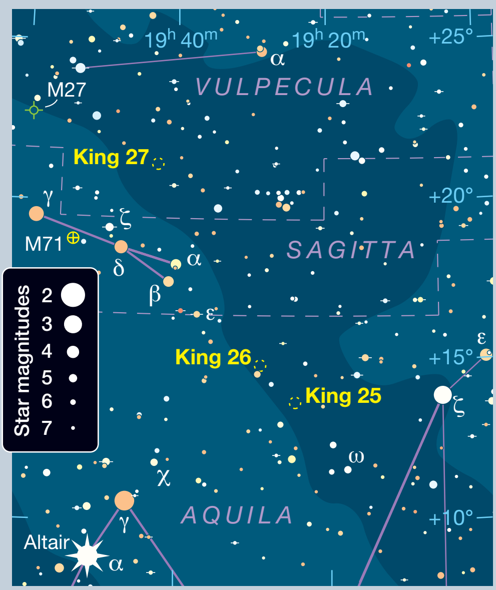
▶ **KING 26** I note one fairly bright star on the western edge. The cluster seems a bit elongated, almost triangular in shape with about 8 fainter stars. I detect no concentration toward the center, a small population of stars, and a wide range of magnitudes, all consistent with the cluster's Trumpler classification.
Mv = unavailable | S=2′ | No.=15 | Tr=II1p | Mag.=337×

▶▶ **KING 27** We appropriately conclude our tour of open clusters in Vulpecula, with the last cluster identified by King, better known as Czernik 40. It's a fairly faint cluster and wide open. There was haziness among the brighter, 10th-magnitude stars on the periphery. The cluster stands out from the field, even with a poor number of stars.
Mv = unavailable | S=4′ | No.=30 | Tr=II2m | Mag.=337×





Aquila and Vulpecula



rating them from the background is quite satisfying and fulfilling. For those who enjoy both the aesthetics and scientific aspects of open clusters, several references listed under "Further Reading" are highly recommended. After all, having an appreciation of the scientific characteristics of open clusters, such as their formation, age, size, mass, structure, composition, photometric analysis, proper motion, and location in the Milky Way Galaxy, adds to your enjoyment of their role in our local neighborhood. With more than 41 different open cluster designations — the King clusters among them — the observer/imager will be kept busy for many pleasurable sessions.

■ When obsessed with various observing projects, **AL LAMPERTI** is rumored not to be playing with a full deck! **FRANK COLOSIMO** has been observing at the Blue Mountain Vista Observatory (**star-watcher.org**) for 12 years, which is where he obtains his images. Both Al and Frank are members of the Delaware Valley Amateur Astronomers.

FURTHER READING: For more information and specific details on open clusters, see *Star Clusters* by Brent A. Archinal and Steven J. Hynes (Willmann-Bell, Inc., 2003) and *Star Clusters and How to Observe Them* by Mark Allison (Springer-Verlag, Ltd., 2006). For a table of parameters of the King clusters in this paper, go to **https://is.gd/KingClusters**.

S&T Test Report by Richard S. Wright, Jr.

Celestron's RASA 8 Schmidt Astrograph

Lightning-fast imaging now comes in a popular-size package.

▲ Celestron's 8-inch Rowe-Ackermann Schmidt Astrograph (RASA 8) optical tube assembly packs a blazing-fast f/2 imaging speed into a lightweight package.

8 Rowe-Ackermann Schmidt Astrograph

U.S. Price: $1,699

celestron.com

What We Like

Fast photographic speed

Lightweight

Integrated cooling fan

What We Don't Like

No provision for standard filters

Short back focus limits camera options

FAST OPTICS ARE LIKE FAST CARS: Both are a thrill to experience first-hand. I have some previous experience with fast astrographs and thus was very enthusiastic when the opportunity arose for me to try out Celestron's new f/2 8-inch Rowe-Ackermann Schmidt Astrograph (RASA 8). Just as with a fast automobile, though, there's little tolerance for sloppy driving when it comes to operating this instrument.

The RASA 8 is an optical design inspired by the classic Schmidt camera, in which a piece of film is placed at the prime focus of the primary mirror. While Schmidt cameras produced well-corrected stars across a piece of film using a custom film holder that curved the film to match the curved focal plane of the instrument, the RASA design flattens the focal plane with a set of corrective optics located near the camera's focus point. From a distance, the RASA 8 looks a lot like one of Celestron's Schmidt-Cassegrain telescopes (SCTs), but as you get closer you'll notice some significant differences. The most obvious one is that a camera attaches to the RASA 8's front corrector plate — there is no visual back to connect a star diagonal or eyepiece. The telescope is also slightly longer than a standard 8-inch SCT, measuring 24.7 inches.

The optical design of the RASA 8 is a tradeoff between focal length and photographic speed. The RASA 8 has a focal length of 400 mm, approximately one-fifth that of a standard 8-inch f/10 SCT. While this translates to an amazingly fast focal ratio of f/2, it also means a much lower resolution. For comparison, an 8-inch f/10 SCT paired with a camera having 9-micron-square pixels produces an image scale of 0.93 arcsecond per pixel, whereas the same camera attached to the RASA 8 produces 4.64-arcsecond resolution. This instrument should perform best with cameras having very small pixels.

Being fast is nice, and there are some great benefits that make imaging easier. One is short exposures. You can take pleasing photos of many astronomical targets with exposures of just a few minutes, or you can spend a lot of time on an object to pick up really faint details, such as the extended dust or nebulosity that exists around some popular objects. Short exposures stacked together also mean less rigorous demands on your mount's tracking

ALL IMAGES BY THE AUTHOR

▲ Attached to the RASA 8's corrector plate is an additional set of corrective optics and the camera mount, seen here with its threaded M42 adapter in place. Three push-pull screws and smaller lock-down screws used to adjust the camera's squareness are visible through three curved slots.

abilities, and they are also very forgiving of polar alignment error. A very fast telescope combined with an accurate tracking mount can even eliminate the need for autoguiding.

Overall, a fast focal ratio can make imaging a lot of fun and in many ways easier. The road ahead can be slippery, though, so you'll need to take some care.

Cool It

Any telescope will perform poorly until it has acclimated to the ambient air temperature, and unassisted acclimation can take hours with a closed-tube system such as this. The RASA 8 comes with an integrated fan system ready to go. A 12V DC plug on the back accepts the included battery pack requiring eight AA batteries to power the fan. I usually started the fan as soon as I set up in the field, and by the time twilight ended the RASA 8 was ready to go.

Focusing at f/2

The range of focuser positions providing sharp focus is called the *critical focus zone* (CFZ). The CFZ gets smaller at faster focal ratios, and at f/2 it is tiny — only several microns wide. Achieving focus by hand is extremely difficult, and with the RASA 8 the focus position shifts as the temperature changes throughout the night. You'll need to refocus a few times per evening in most circumstances. A focus motor, paired with the software of your choice, is strongly recommended. My first few efforts with the RASA 8 were manually focused, and the results weren't quite perfect. I then ordered and installed the Celestron Focus Motor for SCT and EdgeHD telescopes ($199.95), which produced consistently better results.

While I'm not the most mechanically inclined person, installing the focus motor was quick and easy. It can be powered via a USB cable attached to a powered USB hub, though I recommend using an external 12V power supply, as I did. Like most focusing systems, this one has a slight amount of mechanical backlash. Fortunately, most focusing software allows for manually input backlash compensation, and it was relatively easy to find the right value to produce sharp focus every time.

Connecting the Camera

While proper cooling and focus are important, the interface between the camera and the RASA 8 is perhaps most key to producing good images. There's a threaded assembly for connecting your camera at the front of the telescope's corrector plate. Within this port is a removable clear-glass optical window that can be replaced with Celestron's dedicated Light Pollution Imaging Filter ($219.95). Having quite a collection of 2-inch filters for fast astrographs, I was overjoyed when I saw this, until I realized that the thread in the RASA 8 is not an industry-standard 2-inch filter thread but instead one that only accepts Celestron's proprietary filters.

Connecting a camera is fairly easy with the M42 adapter that was included in my evaluation package, as most of my spacers are M42 threaded. But here's where you need to choose your camera carefully. The RASA 8 has a fixed 29-mm distance requirement from its front corrector element to your camera's sensor, and that drops to 25 mm if you use an M42 adapter.

▼ The rear of the RASA 8 includes the focusing knob at right and its integrated cooling system fan. Its 12V DC MagLev fan draws outside air in through three filtered ports (one is seen clearly at left) to quickly bring the scope to ambient temperature.

▲ Focusing the RASA 8 by hand is a challenge. Adding Celestron's optional Focus Motor for SCT and EdgeHD telescopes, along with the author's favorite focusing program, made the task quick and repeatable.

This leaves DSLR users out of the RASA 8 game, as no current DSLR will work with this little back focus, though Celestron makes this very clear. However, mirrorless cameras shouldn't have problems being set at the right distance to reach focus. Celestron recommends mirrorless cameras as well as smaller astronomical CCD and CMOS cameras, with the detector mounted close to the front flange of the camera housing. One-shot color cameras are the best match for this instrument, though a monochrome camera with a very thin third-party filter tray could work; you'll need to look carefully at the total back focus for your particular combination of equipment.

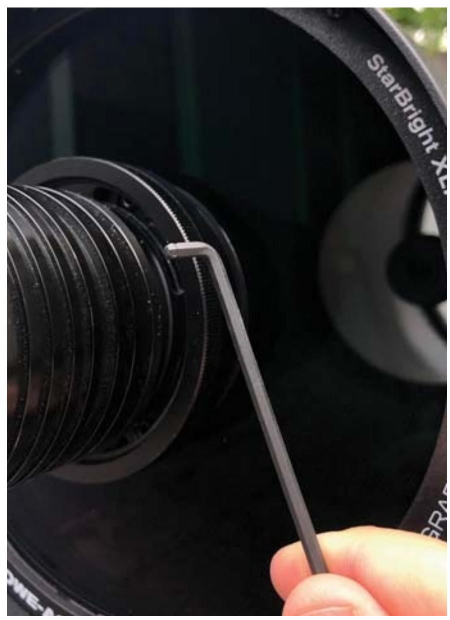
For my own tests, I used an engineering-grade Starlight Xpress Trius-SX814C one-shot-color camera. Its round body introduced no additional obstruction in the optical path, particularly when I removed its side fan. The camera's 3.39-micron-square pixels offered a resolution of 1.9 arcseconds per pixel when combined with the RASA 8.

The spacing of the camera from the front corrective elements is absolutely critical to achieve Celestron's stated usable image circle of 32 mm. In fact, my first few attempts were quite disappointing because of spacing issues. The SX814C has a back focus of 17 mm, which meant I needed exactly 8 mm of spacers on top of the M42 adapter. Initially I was off by quite a bit and this caused a couple of effects. Although I could still achieve good focus in the middle of the field (or any part of the field where I wanted to focus), stars appeared progressively worse as you looked farther from this point. Even being 1 mm off in the camera spacing produced distorted stars around the outer edge of my already small chip. To further complicate things, the chip in my camera was not quite square to the camera housing, so I needed to adjust the tip/tilt of the camera mounting. Fortunately, very few users will have to deal with this kind of scenario.

In general, you should never need to collimate the RASA 8, as everything inside is pretty locked down. However, the tip/tilt of the camera might still need to be tweaked if your chip is not 100% perpendicular to the RASA 8's optical axis. There are three push/pull screws that require 2-mm and 3-mm hex key (or Allen) wrenches to adjust. I found some cameras had just enough room to make these adjustments, but with my Starlight Xpress, there wasn't enough room to fit standard hex key wrenches. Fine-tuning the tip/tilt by removing the camera, making an adjustment, replacing the camera, taking an image, then repeating the operation was frustrating and took quite some time. I eventually found a set of L-shaped hex key wrenches with a shorter arm that fit. It would be great if Celestron provided these with the scope, as I suspect many users may encounter the same issue.

▼ In most cases you won't need to adjust the tilt of your camera to get round stars across the RASA 8's entire 32-mm image circle. But in the event that you do, look for short L-shaped hex key wrenches.

▲▶ A removable clear optical window located just in front of the corrective optics can be replaced with an optional Light Pollution Imaging Filter. Both use a proprietary thread rather than a standard 2-inch filter thread.



▲ *Left:* Once everything is dialed in, shooting at f/2 makes short work of many bright Messier objects. This image of M16 in Serpens consists of 31 unguided 1-minute exposures using the Starlight Xpress Trius-SX814C CCD camera. *Right:* With proper spacing, the RASA 8 delivers a reasonably wide and well-corrected field. This image of globular cluster M13 in Hercules consists of 74 stacked 30-second exposures using the Trius-X814C camera at the Texas Star Party.

Flat-Field Challenges

Proper image-calibration is essential for good astrophotography results. This includes not just darks, but also quality flat-field calibration frames. The RASA 8 has a large central obstruction, which produces a "doughnut" of illumination on larger detectors that cannot be corrected by using post-processing tricks. Quality flat-field calibration will reliably correct this odd illumination, but flats can be tricky to shoot with the RASA 8 for two reasons.

First, at f/2 it's difficult to shoot twilight flats because it's very easy to overexpose the sky. A more reliable option is to shoot flats using an electroluminescent panel or even T-shirt flats, but the camera itself is jutting out past the front corrector plate, and there's no way to seat the panel or stretch a T-shirt on the front of the tube assembly. A practical solution is to place a dew shield on the RASA 8. The scope really requires a dew shield anyway, and even in dry climates, stray light from the side can very easily enter the telescope, creating unwanted glare and gradients.

Celestron's optional Dew Shield for C6 and C8 Tubes ($26.95) provides a very handy mechanical means to cover the front of the scope with a flat-fielding accessory, or even to completely cover the scope in order to shoot dark or bias frames with cameras that don't have a mechanical shutter.

Recommendations

There are no shortcuts to good results. Shooting with a fast instrument makes some things easier, including tracking and guiding, but you still need a compatible camera, sharp focus, and precise spacing of your camera and sensor. You also need to properly calibrate your images, and this includes flat fields. Without the integrated cooling fan, the scope cools down very slowly, so don't forget to run it for about a half hour. It's really such a good idea that Celestron should figure out how to add the option to all of its SCT telescopes.

With the 8-inch Rowe-Ackermann Schmidt Astrograph, Celestron has delivered a scaled-down version of its premier 14- and 11-inch astrographs that can work well for amateur astrophotographers who are primarily interested in wide-field, one-shot color imaging of deep-sky objects. Once you get it all dialed in for your equipment, the sky is literally the limit.

■ Software Bisque software engineer **RICHARD S. WRIGHT, JR.** can often be found managing a small fleet of equipment at most major star parties.

▼ An additional accessory that should be purchased with the RASA 8 is a firm dew shield *(left)*, such as Celestron's Dew Shield for C6 and C8 Tubes. This ensures the corrector plate stays dew-free but also allows a firm seating to place an electroluminescent panel *(right)*.


When Kit actually used his scope, he remembered to remove the lens cap!

Kit Schweitzer's 35-Year Dream

Some projects take a while but are well worth the wait.

THE MOMENT I OPENED Kit Schweitzer's submission letter and saw the photo of him with his big brass telescope, I knew I was going to write about it. Kit's opening words were the clincher: "I think most amateurs would agree that there is nothing more beautiful in the field of astronomical equipment than a brass telescope."

I absolutely concur. No matter how fancy we make the Dobsonian or the Schmidt-Cassegrain or any other kind of scope, there's something primal about the brass refractor. As Kit said, "It evokes visions of a time when we could probe the cosmos with the eye and discover much just by careful observation." I've seen a few at star parties, and there's always a circle of people around them simply admiring the scope itself as much as the view through it.

Kit's scope was a long-term project. It started in 1984 in Taos, New Mexico, where he frequented the weekly Los Alamos National Laboratory salvage yard sale. On one such occasion he purchased a 5-inch-diameter, five-foot-long brass tube, and thus the dream of an all-brass telescope was born.

Over the next 35 years he moved to Tucson and joined the Tucson Amateur Astronomy Association, and he collected and made parts as happenstance would have it. A friend gave him a beautiful antique bronze rack-and-pinion focuser and brass finderscope that was in a box of unrelated telescope parts. Also in the box was a 12½-inch f/5 primary mirror. Kit said, "So I made him a Dobsonian out of the primary mirror in trade for the brass parts to use in my scope."

The focuser was from a much bigger instrument, which meant Kit had to fabricate an adapter to join it to the tube. The focuser had four bolt holes, so Kit machined a back plate and brazed a flange on the back plate to fit into the tube, then added four additional threaded holes to make a push-pull alignment system for collimation.

Several years later Kit bought the glass for a doublet objective lens. Having made several mirrors, he felt he was up to the task, but after months of struggle he finally set it aside. He did cast a bronze lens cell and counter-cell in his home foundry, but when he found a factory-made objective (an iStar Optical R30 f/12 doublet) that came in its own aluminum cell, he kept the aluminum inner cell and modified the cast counter-cell to fit.

The project lay dormant for several more years until another friend gave Kit an antique, very heavy steel alt-azimuth tripod with a rack-and-pinion lifting fork that once held a similar scope.

Making a cradle to hold the scope to the mount proved more difficult than Kit expected. He tried casting and he tried fabricating one out of heavy sheet brass, but neither option proved satisfactory. So Kit turned toward the future and


◀ The finder and focuser were a fortuitous discovery in a box of old scope parts.

ALL PHOTOS BY SKYLAR SHERBROOKE

taught himself how to make printable 3D models on a computer. The result is a large black cradle that was printed with high-impact plastic yet looks like it could be part of the original tripod.

Buoyed by that success, Kit designed the finder brackets on his computer and had them cut out of ⅝-inch sheet brass using a commercial CNC water jet.

The result is a beautiful telescope that combines telescope-making techniques from the very beginning of metalworking to the current day. As Kit said, "To have constructed an antique-looking replica — yet with state-of-the-art modern optics — is a dream come true. I learned many skills along the way. The final touch was spinning the brass lens caps, another process I had never tried before."

▲ The 3D-printed mounting cradle fits in beautifully with the rest of the scope.

As you might suspect from the photos, the scope and mount are heavy. The scope weighs 38 pounds, and the mount 63. Kit reports that "Even separating the tripod and the optical tube assembly is really a two-person job."

Sadly, Kit didn't get to use the scope much after he completed it. He died just days after sending me his submission letter. But in that letter he said something that still makes me smile, for it's true of every ATM project I've ever done and sums up so well why we build our own telescopes. Kit said, "The project was a long time coming, but the fun was in the journey."

Indeed it is. Many thanks, Kit, for taking this journey and sharing it with the rest of us.

■ Contributing Editor **JERRY OLTION** also has a few (dozen) long-term projects in various stages of completion.

▷ DUSTY ORION

Peter Ward

The famous Orion Nebula complex, comprising M42 and M43 (top), displays an intricate mix of emission and reflection nebulosity, with thick streams of dust delineating the two main nebulae.

DETAILS: *Alluna RC16 Ritchey-Chrétien telescope with SBIG STX-16803 CCD camera. Total exposure: 7 hours through hydrogen-alpha and color filters.*

▽ GUARDIANS OF THE NIGHT

Jeff Dai

The center of the Milky Way rises above a row of sentinel-like moai at Ahu Akivi, Easter Island. Jupiter is the brightest object seen above center, while fainter Saturn appears below the galactic center.

DETAILS: *Canon EOS 6D Mark II DSLR camera with 14-mm lens. Total exposure: 15 seconds at ISO 12,800, f/1.8.*

SHIMMERING STARS

Amirreza Kamkar

Saturn (middle left), the Lagoon Nebula (M8), and Jupiter (right), as well as the brighter stars of Sagittarius, are reflected on the surface of a small lake in the Alborz Mountains in northern Iran.

DETAILS: *Canon EOS 6D with Sigma 24-mm f/1.4 lens. Total exposure: 13 seconds at ISO 4000.*

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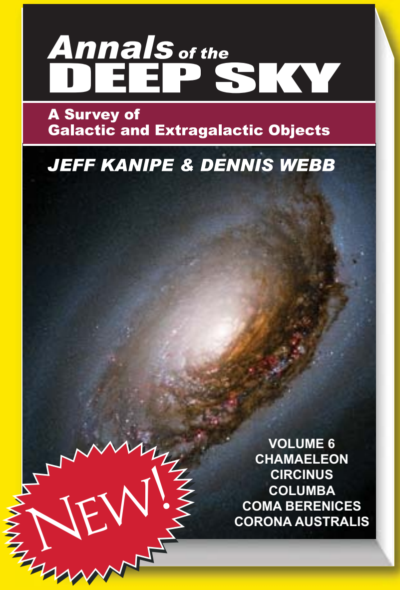

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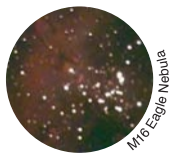

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EYEPIECES

MISCELLANEOUS

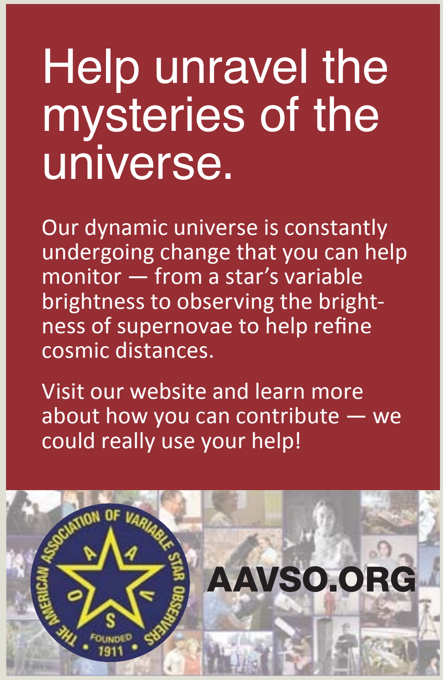
MOUNTS

OBSERVATORIES/DOMES

OBSERVATORIES/DOMES (cont.)

OPTICS

ORGANIZATIONS



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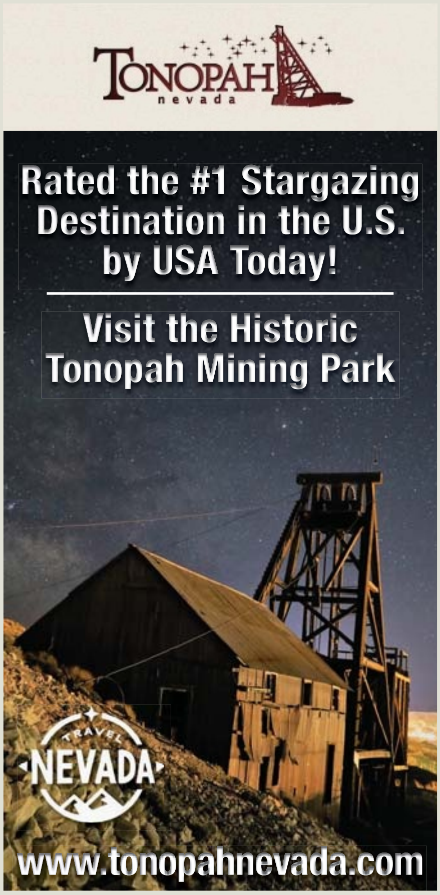

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FOR RENT: 3BR/2BA furnished home in ARIZONA SKY VILLAGE PORTAL, AZ. Spectacular observing/birding! irkitzman@gmail.com www.arizona-dreaming.com 520-203-8500

FOR SALE: 2 Building Lots in Portal, AZ next to Arizona Sky Village. Spectacular views and and night. https://www.landandfarm.com/property/7_6_Acres_in_Cochise_County-9630605/
and https://www.landandfarm.com/property/8_45_Acres_in_Cochise_County-9630608/
Contact Joan: 520-203-0459
joangalanis@tierraantigua.com

Classified ads are for the sale of noncommercial merchandise or for job offerings. The rate is $1.75 per word; minimum charge of $28.00; payment must accompany order. Closing date is 10th of third month before publication date. Send ads to: Ad Dept., Sky & Telescope, 90 Sherman Street, Cambridge, MA 02140.

INSIDE This Issue

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

Product Locator

AD INDEX

Event Calendar

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

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

September 21–29
OKIE-TEX STAR PARTY
Kenton, OK
okie-tex.com

September 25–29
ACADIA NIGHT SKY FESTIVAL
Bar Harbor, ME
acadianightskyfestival.com

September 26–29
GREAT LAKES STAR GAZE
Gladwin, MI
greatlakesstargaze.com

September 27–29
EASTERN IOWA STAR PARTY
Dixon, IA
https://is.gd/EIowa

September 27–29
BLACK FOREST STAR PARTY
Cherry Springs State Park, PA
bfsp.org

September 27–29
CONNECTICUT STAR PARTY
Goshen, CT
https://is.gd/CSP2019

September 27–29
HIDDEN HOLLOW STAR PARTY
Mansfield, OH
wro.org/hidden-hollow-star-party

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

October 5
NOVAC STAR GAZE
C. M. Crockett Park, VA
novac.com/wp/outreach

October 20–27
PEACH STATE STAR GAZE
Deerlick Astronomy Village, GA
atlantaastronomy.org/pssg

October 21–26
ELDORADO STAR PARTY
Eldorado, TX
eldoradostarparty.org

October 21–27
STAUNTON RIVER STAR PARTY
Staunton River State Park, VA
chaosastro.org/starparty

October 22–26
ENCHANTED SKIES STAR PARTY
Magdalena, NM
enchantedskies.org/essp

October 22–27
DEEP SOUTH STAR GAZE
Sandy Hook, MS
stargazing.net/DSRSG

October 24–27
SJAC FALL STAR PARTY
Belleplain State Forest, NJ
sjac.us/starparty.html

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

Who Ya Gonna Call?

One summer night, the author saw a huge explosion in the sky. He had to tell somebody, but whom?

IT STARTED INNOCENTLY ENOUGH. I was home alone about 8 p.m. on a warm September 1, 1987. The family was at the mall collecting last-minute items for the impending school year. The Moon, just past first quarter, hung in the southwest sky, so I decided to do some viewing with my new 10-power binoculars.

I mounted them on a tripod and climbed onto a flat section of our roof. I extended the tripod legs to the max so I could remain standing, and I began observing the bright lunar surface. When the Moon began to set below the treeline, I decided to pack it up.

Just then my eye caught a fast-moving orange object in the northwest sky. At first I thought it was a satellite, but it was moving way too fast. I struggled to get it into view in the binocs, but the tripod kept interfering. When, down on one knee, I finally caught it in the lens, it was high overhead, and it was trailing a long, orange tail of sparks.

That's when it exploded in a spectacular display of fire and smoke and debris. It reminded me of the tragic explosion the year before of the Space Shuttle *Challenger*, with pieces flying off in all directions. I braced for the sound but then thought, *No, shock wave first!*

Four very bright objects had darted out from the fireball, and they continued moving to the south-southeast very slowly and all in a vertical line. I watched them for about two minutes until they blinked out over the horizon. There had been no shock wave, no sound, no debris.

What the hell did I just see?

My heart racing, I looked at my watch. It was 8:40 p.m. Feeling I just had to tell someone, I called our local paper in Springfield, Massachusetts. The voice on the other end snickered when I asked if anyone had reported an incident in the sky. No, they hadn't. The next day I called the Minor Planet Center in Cambridge and spoke with its director Brian Marsden. He directed me to the Smithsonian's Scientific Event Alert Network. When I phoned them, they suggested I call the North American Aerospace Defense Command.

"Are you kidding? Isn't NORAD top secret?"

"No, it's not. Here's the number."

When I called NORAD, a male voice asked, "What time did this happen?" About 8:30 p.m., I told him. "What direction did it come from?" I described it as best I could. I could hear his keyboard clicking. After a few moments of silence he said, "You saw the re-entry of the Soviet launch vehicle that carried Kosmos-1873 into orbit on August 28th. We've been tracking it." It was projected to re-enter the atmosphere over eastern Canada on the 1st, he said, and any solid remains would splash down in the Caribbean Sea east of Puerto Rico at 8:38 p.m. "You are the only confirmed sighting. Thanks for calling in."

I was stunned. I called the Springfield newspaper again, repeated my story, and gave them NORAD's number. "You can call NORAD?" I assured the reporter she could. The paper printed the story the next day.

The day after the piece appeared I received a call from a guy in Springfield. He said he and some friends had just finished a night softball game on the 1st and were in the parking lot having a few beers. They saw something in the sky but didn't want to say anything because they'd been drinking. Besides, they didn't know whom to call. I'm glad they called me. At least someone else saw it!

■ **BILL SIMMONS** is a retired professional firefighter/EMT and U.S. Army veteran who served in Korea and Greenland. He and his wife Kathleen live in Easthampton, Massachusetts, and have eight children.

LEAH TISCIONE / *S&T*