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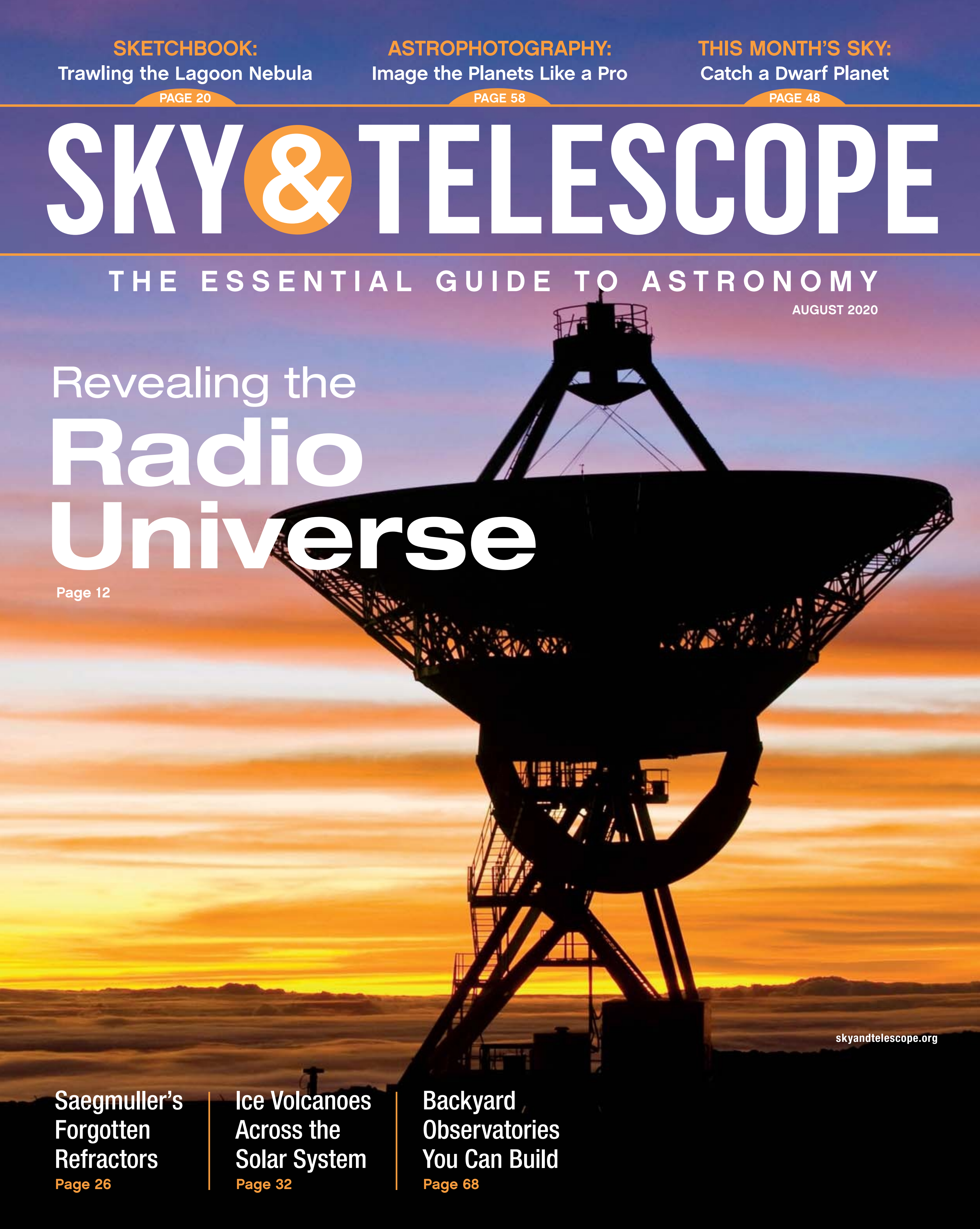
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

AUGUST 2020



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ON THE COVER

A VLBA antenna atop Mauna Kea, Hawai'i

PHOTO: DAVID NUNUK / SCIENCE SOURCE

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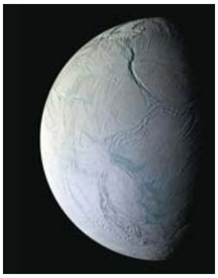
Volcanic Worlds

AS I WRITE THIS IN MID-MAY, I've been recalling the eruption of Mount St. Helens, which occurred 40 years ago this month. For many Americans of a certain age, that eruption, the worst in the contiguous 48 states in generations, remains iconic of volcanism on Earth. Visual memories of its monstrous funnel of superheated ash and tephra, which rose 24 kilometers (15 miles) into an otherwise azure sky, are often the first to appear in our mind's eye when we think of volcanism.

Yet when it comes to volcanic activity in our solar system, St. Helens' eruption is far from typical. In our ongoing three-part series, we look at the surprisingly diverse ways that stuff erupts from below on bodies from the planet Mercury right out to some of the most distant moons we know of.

Last month we focused on Io, the most volcanically active body in the solar system. If the ancient Romans had known of this moon of Jupiter, had seen its sulfur-rich, furiously igneous surface, they would have declared it the forge of Vulcan, their god of fire. For modern scientists, Io demonstrates just how strong a force a body may experience when caught in the gravitational grasp of a giant neighbor.



Saturn's cryovolcanic moon Enceladus, as seen in a Cassini mosaic captured in 2008

NASA / JPL / SPACE SCIENCE INSTITUTE

In this issue, we examine *cryovolcanism* (see planetary scientist Rosaly Lopes's article on page 32). This vaguely oxymoronic term refers to the activity we see on frozen moons like Saturn's Enceladus, where the Cassini spacecraft detected plumes of water vapor spewing from the ice-sheathed surface. Chemical clues in Enceladus's geysers suggest that hydrothermal activity is taking place even now on the floor of this tiny moon's subsurface ocean. On Earth's seabeds, hydrothermal vents engender life forms that need no sunlight. Could the same be true on Enceladus or other moons with hidden seas?

Next month we'll explore volcanism on the inner planets and the Moon. Their origins are similar: Planets and moons start hot, thanks to the accretion process, tidal heating, and the decay of radioactive elements that these bodies incorporate into their interiors when they form. Mercury, Venus, Earth, Mars, and the Moon each have singular volcanic histories, but collectively they tell us an intriguing tale of how rocky planets age.

Beyond the beguiling prospect of life nearby to Earth, the study of our solar system's volcanic bodies will inform the study of eruptive worlds in extrasolar systems, when and if we find definitive evidence of them. Who knows? Maybe in time we'll identify entirely new kinds of volcanism such as we never imagined.

Peter

Editor in Chief

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The Essential Guide to Astronomy

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Eclipse Fun

Herman Heyn's Focal Point (*S&T:* Mar. 2020, p. 84) reminded me of the 2017 total solar eclipse, when my son, Phil, and I traveled to Murphy, North Carolina and set up my 100-mm binoculars in the front yard of a hotel.

Many others had stayed there for the same reason, so Phil and I were among quite a crowd of observers. My binoculars with objective lens filters attracted quite a stream of viewers, and at one point a gentleman asked whether he could get a picture of the partially eclipsed Sun by holding his cell-phone camera up to the eyepiece. Phil, who had some experience with digiscoping, helped him. I was busy taking photos with my DSLR camera when I suddenly heard whoops of delight and amazement: The cell phone had captured a jet in transit across the Sun! The three of us all went home happier than we'd expected.

Howard L. Ritter, Jr.
Perrysburg, Ohio

I'd like to thank Sean Walker for the excellent article (*S&T:* Mar. 2020, p. 30) describing his recommended workflow for extracting a high-quality HDR image from photos taken at different exposures during totality of a solar eclipse. I had just such a set from the 2017 solar eclipse, and previous processing attempts never quite lived up to my expectations. Thanks to *S&T,* I now have an eclipse image of which I am very proud.

Andrew Thomas
Seattle, Washington

▲ Caught by cell through binoculars, a jet flies across the Sun during the 2017 solar eclipse.

▲ This image of 2017's solar eclipse was processed using Sean Walker's technique.

Recycling with John Dobson

I enjoyed Jerry Oltion's article about resurrecting an original Dobsonian (*S&T:* Apr. 2020, p. 36) and thought I'd add an anecdote. My first day job was as an electronic technician at the Lawrence Hall of Science in Berkeley. Computers in those days used huge reel-to-reel tape decks to store data. They came in big aluminum cans 2 feet wide and 2 inches deep. Dobson and his buddies used to come by to collect the empties to use as altitude bearings. His 22-inch that he used for public observing nights at LHS had two of them.

Dave Lusby
Sandia Park, New Mexico

The Dangers of Mercury

As one who has taught chemical safety in the workplace, I was surprised that Govert Schilling's article (*S&T:* Apr. 2020, p. 24) did not include discussion on the health hazards of using mercury in liquid-mirror telescopes. Mercury is a highly toxic substance, and a 4-meter mirror provides a very large evaporating surface. The likelihood of gaseous mercury expanding beyond telescope dome is another problem. I would like to know how these hazards are being controlled.

Bill Wood
Melbourne, Australia

Govert Schilling replies: *According to Paul Hickson (University of British Columbia), mercury evaporation is greatly reduced by a thin layer of mercury oxide that forms on the rotating mirror surface. Moreover, the Mylar cover traps mercury vapor that forms when the mirror is started and stopped. A charcoal filter then sucks out the vapor and removes it from the air. Of course, notes Hickson, mercury vapor levels are continuously monitored and are well below the limit set by the Occupational Safety and Health Administration (OSHA) during regular operations.*

Locating Oneself Without GPS

I was quite interested in Ted Rafferty's article (*S&T:* Mar. 2020, p. 58) about Captain James Cook. Rafferty mentions that the charts of Newfoundland that Cook prepared were used for more than 100 years. Indeed, they were. I used them as a commercial fisherman in the late 1970s. We did have a LORAN-A navigation system, but it was a pain to use and did not work well close to the shore. Cook included drawings of the view of the headlands around the approaches of the bays, which made it easier for sailors to find their bearings on what is (to this day) a rough and undeveloped shoreline.

On the charts themselves, I could see the soundings made in neat rows from when Cook's men painstakingly rowed back and forth while casting the lead line. Sadly, they missed more than a few rocks. Newfoundlanders call these *sunkers*. I have personal experience with one of these, but that's another story.

Sailing in the wake of Cook taught me that it isn't technology that gets us there but the use of our minds.

Ted White
Victoria, British Columbia

I found Ted Rafferty's article fascinating. Although I am somewhat familiar with Harrison's solution of the longitude problem using chronometers, I was intrigued by the descriptions of the lunar and Jupiter-moon methods used to determine longitude. In a somewhat related problem, how did the explorers of Antarctica navigate to the South Pole in 1911–12, and how did they determine their position with just the Sun?

Colin Unsworth
Newtown, Pennsylvania

Ted Rafferty replies: *The navigation Robert Scott and Roald Amundsen used to reach the South Pole in 1911–12 depended on the determination of latitude. Scott employed a theodolite for determining latitude, Amundsen a sextant. Amundsen*

SUN AND PLANE: HOWARD RITTER / PHIL RITTER; ECLIPSE: ANDREW THOMAS *also utilized dead reckoning, relying on a sledge odometer to determine the distance they traveled from a previous location, to calculate his latitude without clear weather. Scott also had a sledge odometer, but it would clog with snow. When both reached the pole, they crisscrossed the area, making determinations of latitude to calculate where each believed the true mathematical pole lay. Both of their best determinations were off from the true pole.*

I enjoyed reading about Captain Cook's use and knowledge of celestial navigation and the accuracy of his measurements. The telescopic quadrant, while providing better accuracy to its users, was an expensive instrument compared to the more basic octant, which was more affordable. This simpler instrument used a small pinhole peepsight, called a sighting pinnula, which would have produced less accurate results.

Aldo Cugnini
Long Valley, New Jersey

Starlink and the Stars

Monica Young (*S&T:* Mar. 2020, p. 14) provides the well-thought-out details on the potential impact of so many satellites at operational altitudes near 340 and 550 km (210 and 340 miles).

While astronomers pay attention to what's in the sky, birds actually need the stars to successfully navigate during nighttime migrations, some of which are thousands of miles long and under skies in which the new interlopers are very visible.

Terry Herlihy
Chicago, Illinois

Compliments on Design

I've been a faithful reader of *S&T* for many years and still have many older issues. My earliest dates back to 1968. I like the changes made, even though I'm still partial to the original sky charts. Anyway, I was really impressed with the cover of the March issue — wow! Beautiful Carina Nebula! Keep up the great work.

Joe Kubovcik
Clayton, Delaware

I really like the new modern look and feel of the *S&T* website. It's easy on the eyes, and I don't need a Telrad to find my way around! The info bar at the top was a nice touch as well. Thank you again for being my absolute go-to place for all things astronomy!

Randall Kayfes
Tucson, Arizona

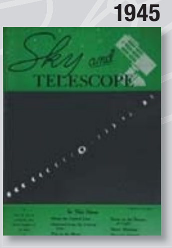
FOR THE RECORD

● On asteroid Ryugu (*S&T:* May 2020, p. 17), the startlingly large crater left by Hayabusa 2's projectile was a result of the rocks' low density and the asteroid's weak gravity.

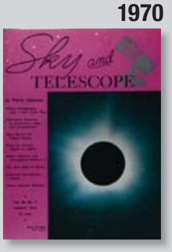
SUBMISSIONS: Write to *Sky & Telescope*, One Alewife Center, Cambridge, MA 02140, USA or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1945



1970



1995

◖ August 1945

Dimmed Moon "[There] was an 87 per cent eclipse of the moon on June 25–26, visible in the Pacific and Indian Oceans, Asia, Australia, and in the regions where most of the fighting now continues. An Associated Press dispatch reports that three American destroyers were being attacked that night by a dozen enemy planes. Bright moonlight made the surface vessels easy targets, but when the partial eclipse darkened the moon's light the attack was successfully repulsed.

"Meanwhile, Pfc. William W. Thorp, of Boston, now on Okinawa, was concerned with sporadic air attacks while observing the partial eclipse. The next day he made a series of sketches from memory, showing that at midnight, Okinawa time, the eclipse reached its maximum, when 'it looked like a dark ball with an icecap directly on top.'. . .

"'Scattered clouds were in evidence, but not heavy enough to obliterate vision. Smoke from screening blew across with varying intensity, but it only gave a foglike effect.'"

◖ August 1970

Oxygen for Life "[A] theoretical discussion by Wallace S. Broecker, Columbia University, . . . considers the balance between oxygen produced by plant photosynthesis and that used up by animals and bacteria, including also what would result if man burned all known reserves of fossil fuels. In this most improbable event, less than three percent of the available O_2 would be used. . . .

"By similar calculations, Dr. Broecker finds that the oceans are also relatively safe from O_2 depletion . . . He concludes: 'If man's existence is to be threatened by pollution of the environment he will succumb to some other fate long before his oxygen supply is seriously depleted. . . . Hopefully the popular press will bury the bogeyman it created.'"

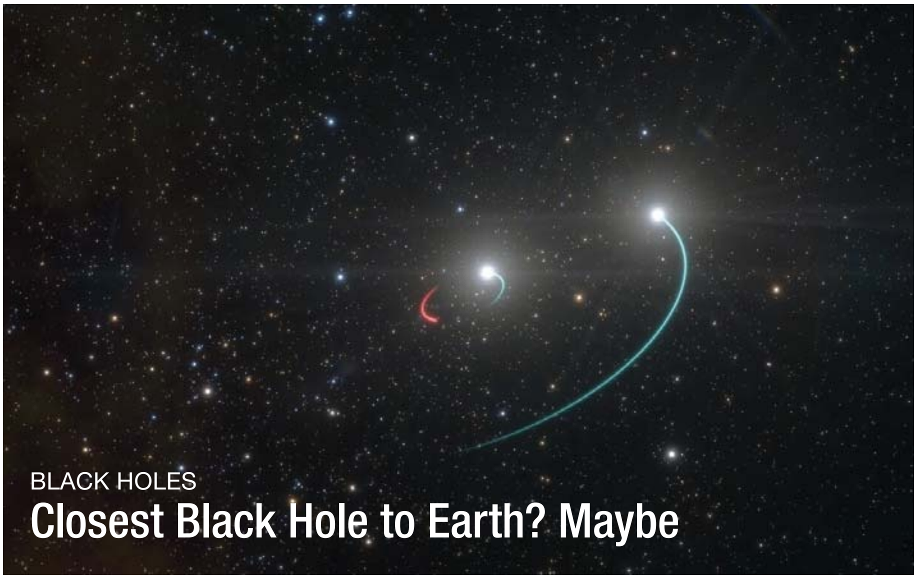
Researchers today are less confident. Global warming makes the oceans less able to absorb atmospheric oxygen. And there are new worries over deforestation.

◖ August 1995

Cosmic Cigar "In August 1994 the asteroid 1620 Geographos cruised 5.1 million kilometers from Earth . . . Eagerly awaiting the flyby was Steven J. Ostro (Jet Propulsion Laboratory), who used the Goldstone 70-meter tracking antenna in California to bounce a 450-kilowatt beam of radio energy off the interplanetary interloper. . . .

"Geographos has indeed proved to be an oddball. 'The silhouette is irregular, nonconvex, and has an aspect ratio of 2.76 ± 0.21,' [Ostro's team reported], 'establishing [Geographos] as the most elongated solar-system object yet imaged.' It is also somewhat larger than expected,"

Even more elongated is the interstellar visitor 'Oumuamua, discovered in 2017.



BLACK HOLES

Closest Black Hole to Earth? Maybe

ASTRONOMERS SAY they've discovered the closest black hole to Earth — an invisible object dancing with two bright stars just over 1,000 light-years away.

Thomas Rivinius (European Southern Observatory, Chile) and colleagues found hints of the object in spectra of the star HR 6819 in the constellation Telescopium. HR 6819 is a *Be* star, a bluish star that spins so fast, material whips off its equator to form a disk around the star. Previous work had revealed a blue, *B*-type giant star hidden in HR 6819's glare, detectable thanks to the fingerprints it leaves in the *Be* star's spectra. After disentangling the stars' spectra, the researchers found that the giant is wobbling back and forth as it circles a third, unseen object every 40 days or so.

▲ This artist's impression shows the orbits of the three objects in the HR 6819 system: two stars (cyan) and one putative black hole (red).

ESO / L. CALÇADA

Based on shifts in the giant star's spectra and the average mass for such stars, the astronomers estimate that the unseen object contains more than 4 Suns' worth of mass. With that heft, the object would leave its own fingerprints in the spectra if it were a star. The team therefore concludes that the object is a black hole. The researchers report the result in the May issue of *Astronomy & Astrophysics*.

If real, HR 6819's black hole would take first place as the closest black hole to Earth, knocking from the pedestal the accreting black hole in V616 Monocerotis, which lies about 3,300 light-years away.

However, Hugues Sana (KU Leuven, Belgium) expresses misgivings, as the team didn't include the disentangling analysis in the paper (it'll be published later). Although Sana agrees there are clearly two stars in the system — the *Be* star with wide spectral lines and the giant star with narrower ones — he suggests that if the giant star is in some way atypical, its calculated mass could be wrong. That would throw off the mass estimate for the third object.

Both Sana and Rivinius emphasize parallels between HR 6819 and another system dubbed LB-1. LB-1 made the news a few months ago (*S&T:* Mar. 2020, p. 8) when a different team announced that its *B*-type star appeared to pair with a black hole so massive that it violated rules for how these objects form. Quick rebuttals by other astronomers (including Sana) led to the black hole's downsizing. There's now an ongoing debate about what's really in the LB-1 system.

A preliminary analysis by Sana's team suggests that LB-1 contains both a *B*-type star and a *Be* star — but no black hole. Rivinius's team, on the other hand, has done its own observations of the LB-1 system, and he says they have evidence of an architecture exactly like what they're proposing for HR 6819: a *Be* star, a *B*-type star, and a third, nonstellar object.

Whatever is going on in LB-1, both Sana and Rivinius say, HR 6819 could be its twin.

■ CAMILLE M. CARLISLE

JETS

Vast Magnetic "Strings" Puzzle Astronomers

NEW OBSERVATIONS have revealed magnetic "strings" crossing vast distances outside the large, bright galaxy at the center of the Norma galaxy cluster.

A supermassive black hole at the galaxy's core powers two well-studied jets that plow into thin gas surrounding the galaxy. Now, the MeerKAT radio telescope array in South Africa has revealed three lengths of plasma, strung like hand-pulled Chinese noodles between the jets across 260,000 light-years of extragalactic space. Mpati Ramatsoku (Rhodes University, South Africa) and colleagues published the observations in the April *Astronomy & Astrophysics*.

MeerKAT imaged the galaxy ESO 137-006 at radio frequencies of 1 GHz and 1.4 GHz, showing unprecedented detail in a phenomenon that previous radio instruments have only hinted at. Gregory Taylor (University of New Mexico), who was not involved in the study, says these features appear to be real: "I don't see any way for typical errors that we encounter in interferometry (such as radio frequency interference or calibration errors) to generate these features," he explains. Supporting the features' credibility, he adds, are the number and variety of filaments within both lobes, both straight and curved.

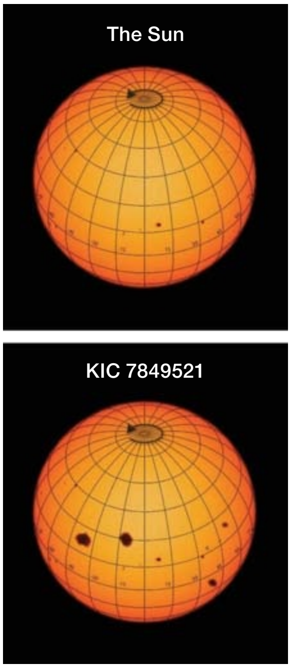
Ramatsoku and colleagues' analysis

SUN

The Sun Is Less Active Than Stars Like It

WHILE THE SUN'S occasional spots and flares don't alter its energy output by more than 0.3%, that's not the case for other Sun-like stars. According to a new study in the May 1st *Science*, the brightness of most solar twins varies more than the Sun's.

Timo Reinhold (Max Planck Institute for Solar System Research, Germany) and colleagues searched data sets amassed by NASA's Kepler space telescope and the European Space Agency's Gaia mission to find stars with Sun-like temperature, surface gravity, composition, and age. Using the Kepler data to study the stars' tiny periodic brightness variations (probably due to large sunspots rotating in and out of view), the team found 369 Sun-like stars with rotation rates between 20 and 30 days, comparable to our own Sun's 24.5-day period. To the researchers' surprise, the brightness of these stars varies on average five times more than the Sun's does.



◀ The Sun's brightness doesn't vary as much as that of other Sun-like stars, such as KIC 7849521.

The researchers also looked at a larger sample of 2,529 Sun-like stars for which they couldn't derive rotation rates but which is expected to contain many stars rotating at rates similar to the Sun. The brightness fluctuations of these stars are comparable to the Sun's.

"[The result] fits in with ideas that the current solar dynamo is near a transition point between one dynamo type and another," says David Hathaway (Stanford University).

It's also possible there is no fundamental difference between the Sun and other Sun-like stars — maybe the Sun just hasn't exhibited its full possible range of activity for quite a while. Studies of radioactive isotopes produced by cosmic ray particles reveal that our star hasn't been substantially more active for the past 9,000 years or so than it is now. But, according to Reinhold, "compared to the entire lifespan of the Sun, 9,000 years is like the blink of an eye."

"[The study] leaves a number of open questions," says Frederic Clette (Royal Observatory Belgium), "calling for a broader and finer study to firmly establish that the Sun is truly an anomaly."

■ GOVERT SCHILLING

IN BRIEF

Mismatched Black Holes Merge

For the first time, the LIGO and Virgo gravitational-wave observatories have detected gravitational waves from an unequal pair of black holes. The event, called GW190412, involved objects of 8 and 30 solar masses, an asymmetry that made the "hum" of gravitational-wave overtones clear for the first time. Before the two black holes came together, the larger one was spinning fairly slowly — roughly 40% the maximum permitted by gravity. Collaboration members announced the result April 18th at the American Physical Society's virtual meeting.

■ CAMILLE M. CARLISLE

Read more at https://is.gd/GW190412.

Supernova Suggests Extreme Scenarios

One of the most luminous supernovae discovered suggests that some extremely bright explosions require exotic energy sources. Matt Nicholl (University of Birmingham, UK) and colleagues published years of follow-up observations of the supernova, designated SN 2016aps, in the April 13th *Nature Astronomy*. According to Nicholl's team, the blast radiated 500 times the energy of an average supernova. The engines of typical supernovae, such as radioactive decay and neutrino transport, can't explain its extreme luminosity, says Stan Woosley (University of California, Santa Cruz), who was not involved in the study. Instead, super-strong magnetic fields or a pair-instability supernova could account for the total radiated energy.

■ GOVERT SCHILLING

Read more at https://is.gd/SN2016aps.

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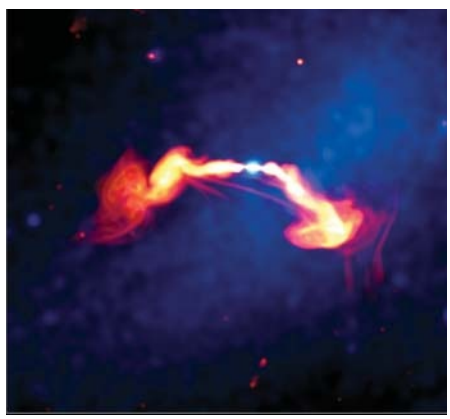
of the radio data determined that the radio waves that these lengths of plasma give off come from electrons spiraling along magnetic field lines, which is a common type of jet emission called *synchrotron radiation*. The electrons slow down as they radiate energy, which changes the nature of their emission; based on the MeerKAT data, the astronomers think all three plasma strings formed around the same time.

These results invite speculation as to the strings' origin, and the researchers suggest some possible scenarios. For example, as the central galaxy pushes through the thin gas that permeates the cluster, its blooming jet lobes might interact somehow with this gas, trailing magnetic field lines and plasma behind them. But the researchers say these scenarios need further study.

■ MONICA YOUNG


▶ Plasma glows along magnetic threads that connect two jet lobes, crossing hundreds of thousands of light-years. (The galaxy itself is a speck at the center.)

SUN COMPARISON: MPS / HORMESDESIGN.DE;
MAGNETIC STRINGS: M. MURGIA (INAF) / SARAO

SOLAR SYSTEM
The Origins of Interstellar Objects

▲ An artist's impression of the interstellar object Comet 2I/Borisov

STUDIES OF THE FIRST TWO interstellar visitors to the solar system — 1I/'Oumuamua and 2I/Borisov — are shedding light on the objects' origins. An abundance of primordial carbon monoxide from Comet Borisov suggests that it formed in the frosty outer fringes of its parent star's planetary disk. Separately, a new theoretical model shows that the fragmentation of a larger body could have formed 'Oumuamua.

Two studies published April 20th in *Nature Astronomy* measured Comet Borisov's composition soon after perihelion last December and found an unexpected overabundance of carbon monoxide (CO) compared to water molecules. Dennis Bodewits (Auburn University) and colleagues observed Comet Borisov using Hubble and the Neil Gehrels Swift Observatory, while Martin Cordiner (NASA Goddard Space Flight Center) and colleagues employed the Atacama Large Millimeter/submillimeter Array (ALMA). Both studies showed the ratio of CO to water to be higher than in any comet observed in the inner solar system. The high CO levels indicate that Comet Borisov likely formed beyond the *snow line,* where CO turns to ice, in the outer part of a planetary disk.

The origins of 1I/'Oumuamua are more difficult to explain (*S&T:* Oct. 2018, p. 20). This object, now out of view, was elongated, porous, and tumbled erratically. Not only that, it didn't slow down as much as expected as it moved away from the Sun, yet it released only wisps of gas.

Now, Yun Zhang (Chinese Academy of Sciences) thinks she has a model that can explain 'Oumuamua's odd properties. Zhang and Douglas Lin (Tsinghua University, China) describe their idea April 13th in *Nature Astronomy.*

During planet formation, a rubble-pile comet or asteroid might pass very near its young host star, close enough for strong gravitational effects to stretch the rubble pile until it disrupts. The star's heat vaporizes volatile ices on the surface of the elongated fragments, accounting for 'Oumuamua's lack of comet-like activity. However, volatiles stored deeper down, such as water, wouldn't vaporize until the object reached the inner solar system, accounting for 'Oumuamua's non-gravitational acceleration.

Not only could this scenario explain 'Oumuamua's odd properties, the researchers say the escape of such fragments could be a common occurrence in our galaxy.

■ JEFF HECHT

MILKY WAY
Is Our Galaxy Throwing Out Star-Making Material?

A SUBSTANTIAL FRACTION of the smattering of stars dwelling in the Milky Way's halo may have an unexpected origin: the galaxy itself. Sijie Yu (University of California, Irvine) and colleagues published remarkably realistic simulations supporting this scenario in the *Monthly Notices of the Royal Astronomical Society.*

Most of the Milky Way's stars circle within the disk and central bulge that make up the most visible portion of our galaxy. All around this disk, halo stars also orbit the center within a roughly sphere-shape volume, traveling on highly elongated orbits toward or away from the galactic center.

Astronomers have long thought that most of these stars come from dwarf galaxies falling into the Milky Way (*S&T:* Apr. 2017, p. 22). Stars may also form within the halo as infalling gas clouds compress. What Yu and colleagues propose, though, is the opposite: They suggest stars are forming in gas clouds thrown *out* of the Milky Way.

Yu studied six simulated Milky Way–like galaxies, part of the so-called "Latte Suite" from the Feedback in Realistic Environments 2 simulation. FIRE-2 reproduces the growth and evolution of galaxies in unprecedented detail, accounting for both cosmology and local feedback effects.

Tracking the six simulated galaxies, the researchers traced individual stars back in time, finding that between 5% and 40% of the halo stars originated in gas flung out of the galaxy's center. In the simulations, large outflows arising from rounds of supernova explosions collapse into stars on their way out to a galaxy's periphery.

While astronomers have seen clear evidence of galactic winds in numerous other galaxies, such as M82, similar signatures in the Milky Way remain ambiguous (*S&T:* Apr. 2014, p. 26). Yu sees subtler evidence of star-forming outflows in data from the European Space Agency's Gaia satellite combined with maps of stellar chemical abundances. But there's no smoking gun yet.

Amina Helmi (University of Groningen, The Netherlands), who was not involved in this study, says, "I think we need more data to be able to identify such stars, particularly chemical abundances of distant halo stars." Nevertheless, with predictive simulations such as these in hand, astronomers will know what to look for.

■ MONICA YOUNG

NRAO / AUI / NSF / S. DAGNELLO

EXOPLANETS

Fomalhaut b: Enshrouded Exoplanet or Puff of Dust?

DEBATE OVER THE NATURE of Fomalhaut b ensued not long after its 2008 discovery. Now, armed with previously unpublished observations and computer simulations, András Gáspár and George Rieke (both at University of Arizona) make the case in the May 5th *Proceedings of the National Academy of Sciences* that Fomalhaut b instead marks the fast-disappearing remains of a giant asteroid collision.

The discovery images that Paul Kalas (University of California, Berkeley) and colleagues took revealed a spot of visible light moving about 115 astronomical units (a.u.) from its star. But the spot didn't appear at infrared wavelengths, suggesting its mass was small, perhaps too small to be a planet at all.

Gáspár and Rieke analyzed previously unpublished Hubble images obtained in 2013 and 2014, finding that Fomalhaut b appears to be moving out of the system, elongating slightly as it does so. They also find that the object had faded out of view by 2014.

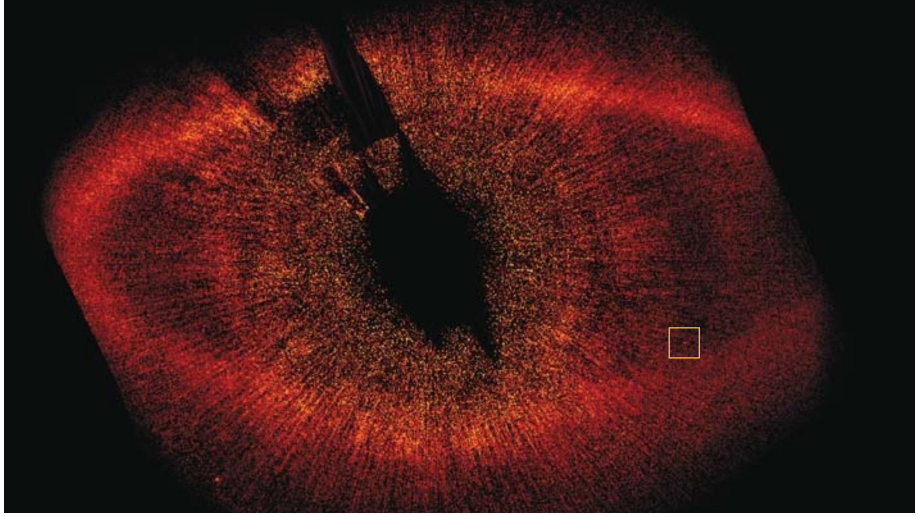
Gáspár and Rieke propose that the spot marks a spectacular crash between two large asteroids, both bigger than 200 kilometers (125 miles) across. This scenario would explain the object's trajectory better than if it were a dust-enshrouded planet, though the difference between the two scenarios' predictions is small.

However, such collisions are rare even in systems as young as 440 million-year-old Fomalhaut. "The planetesimal collision that could create a Fomalhaut b dust cloud would happen once every 100,000 years, and the dust cloud can only be seen for 10 years," Kalas points out. Indeed, Gáspár and Rieke calculate the collision happened just 39 days before the first observations. "Was I really the luckiest astronomer in the world when I pointed the Hubble Space Telescope at Fomalhaut?" Kalas asks.

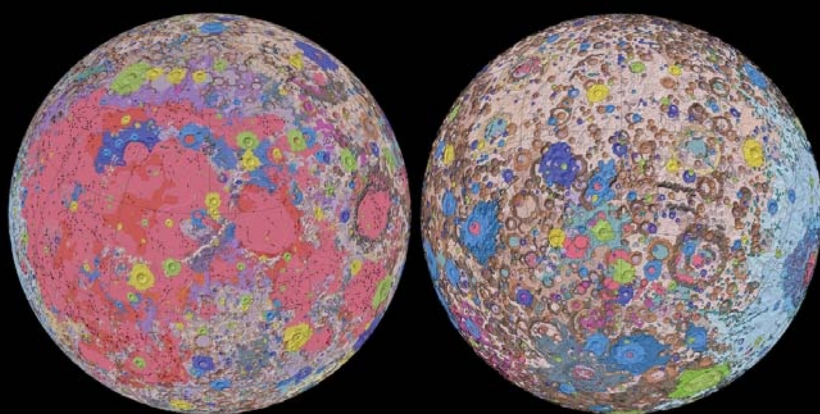
"Sometimes you do get lucky and observe a rare event," Gáspár counters. And some factors, such as migrating giant planets in the system, could make massive collisions more common. Scott Kenyon (Center for Astrophysics, Harvard & Smithsonian), who was not involved in the study, says the scenario is plausible.

Kalas and Gáspár are planning to follow-up with Hubble and the James Webb Space Telescope, respectively. "I certainly wouldn't mind our model being proven wrong," Gáspár says.

■ MONICA YOUNG



▲ The position of Fomalhaut b is marked in this Hubble image from 2008, where the star itself is blacked out. A thin oval dust ring is also clearly visible around the star.

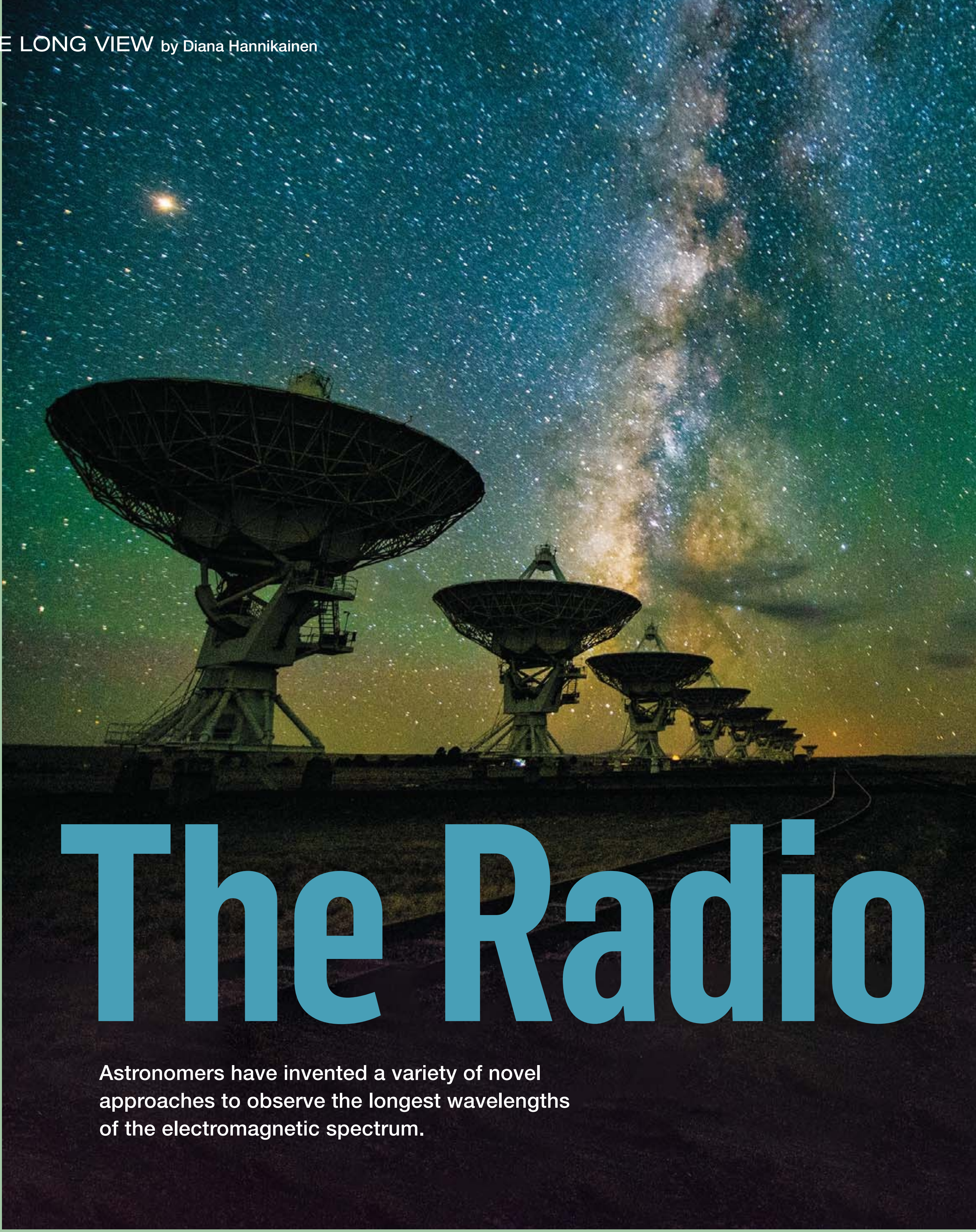


New Geologic Map of the Moon

The U.S. Geological Survey (USGS) has released a new geologic map of the Moon (1:5,000,000 scale). To code geologic areas, USGS scientists used information from six Apollo-era regional maps along with topographical data from Japan's Selene mission and NASA's Lunar Reconnaissance Orbiter. Historical maps were aligned with modern data sets to preserve previous observations. In addition to merging new and old data, USGS researchers also developed a unified description of the *stratigraphy*, or rock layers, of the Moon, depicted as 48 colors on the map. This image only hints at the map's riches. To see the map in full detail, and with a full legend showing what each color indicates, visit the agency's website at https://is.gd/USGSMoonMap.

■ MONICA YOUNG

FOMALHAUT: NASA / ESA / P. KALAS & J. GRAHAM (UNIVERSITY OF CALIFORNIA, BERKELEY) AND M. CLAMPIN (NASA / GSFC); MAP OF THE MOON: NASA / GSFC / USGS



The Radio

Astronomers have invented a variety of novel approaches to observe the longest wavelengths of the electromagnetic spectrum.

LISTENING TO THE UNIVERSE Our galaxy's plane arcs over antennas in the Karl G. Jansky Very Large Array in New Mexico. The telescopes can move along rails into different configurations, depending on the observing goals.

Sky

Cable upon cable upon tangled cable . . . Never had I seen such a convoluted jumble of wires, screws, pliers, and other whatnots in such a small space. It was like a hardware store had imploded. In imploding, the mayhem had become strangely alive. I could feel the thrumming of the correlators in the pit of my stomach. A fan oscillated in the corner, whooshing breaths of air over the back panels of monoliths that looked like they belonged in the opening scene of *2001: A Space Odyssey*.

But I was nowhere near a film set. I was in a radio telescope's control room, an operations central reminiscent of the deck of the starship *Enterprise*. And mind you, this was a *single-dish* radio telescope, nowhere near the elaborate, multiple-dish setups of instruments such as the Very Large Array. However, this telescope — the 14-meter radio dish of Metsähovi Radio Observatory in Finland — was one element in a global network that unites radio dishes across the planet into one behemoth of a receiver, poised to capture signals from the farthest reaches of the cosmos.

Today, we're familiar with discoveries based on radio observations, from the silhouette of a distant galaxy's black hole to hints of aurorae on failed stars called brown dwarfs. But radio astronomy is a relatively new science. A century ago, the only electromagnetic window wide open to astronomers was the visual band. Early forays had been made into

▼ **JANSKY'S MERRY-GO-ROUND** This replica of Karl Jansky's original antenna uses the same materials as the original, down to the Model T tires on the rotation axis. The turntable design enabled Jansky to determine the direction of any signal he detected at 20.5 MHz.

VLA WITH MILKY WAY: NRAO / AUI / NSF; JEFF HELLERMAN; REPLICA OF JANSKY'S ANTENNA: NRAO / AUI / NSF

Long Waves and Longer Waves

Observers on Earth are poised to receive radio waves from cosmic sources in two ways. The first is by recording the source's *flux density*, which is the power received per unit area at a specific frequency. The unit of flux density is the Jansky, in honor of Karl. One Jansky = 10^{-26} watt per square meter per hertz. In some sources, such as quasars, the emitted radiation can vary with time. Astronomers can combine flux densities from multiple frequencies to better model the emission mechanisms, which in turn reveal the physical processes that contribute to the observed radiation.

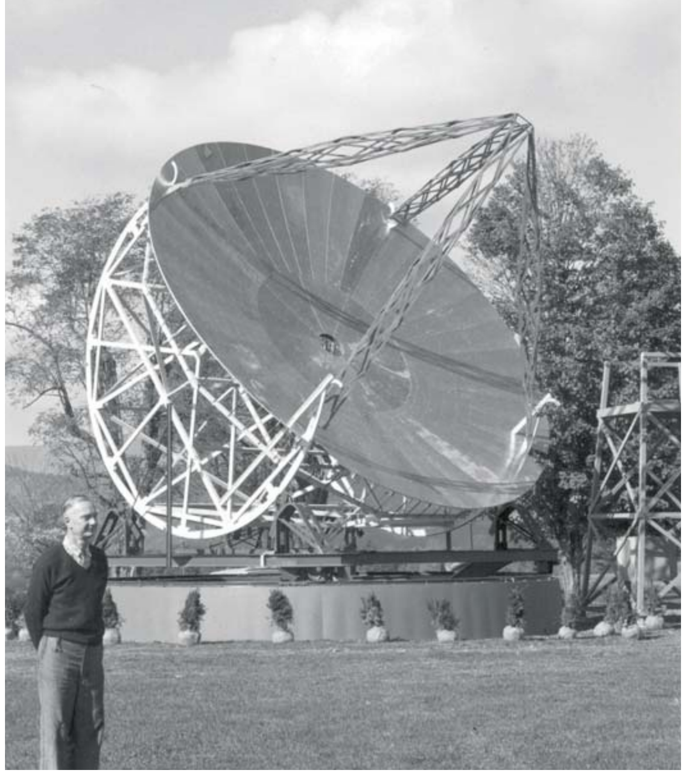
The second way astronomers study radio sources is by generating a map of the spatial distribution of the emitted radio frequencies. Flux densities are used in conjunction with point sources, while maps are useful for extended sources.

infrared astronomy, but challenges posed by Earth's atmosphere limited observations. The sounding rockets that would give us our first glimpses of the gamma-ray, X-ray, and ultraviolet universe were still more than two decades away. And the longest wavelengths we know of, radio waves, were about to become a surprising and mesmerizing window onto the cosmos — one that has gone from revealing our Sun's magnetic nature to tracing super-fast streams of matter gushing out of distant galaxies and the buzz that echoes back to us from the Big Bang.

The First Signals

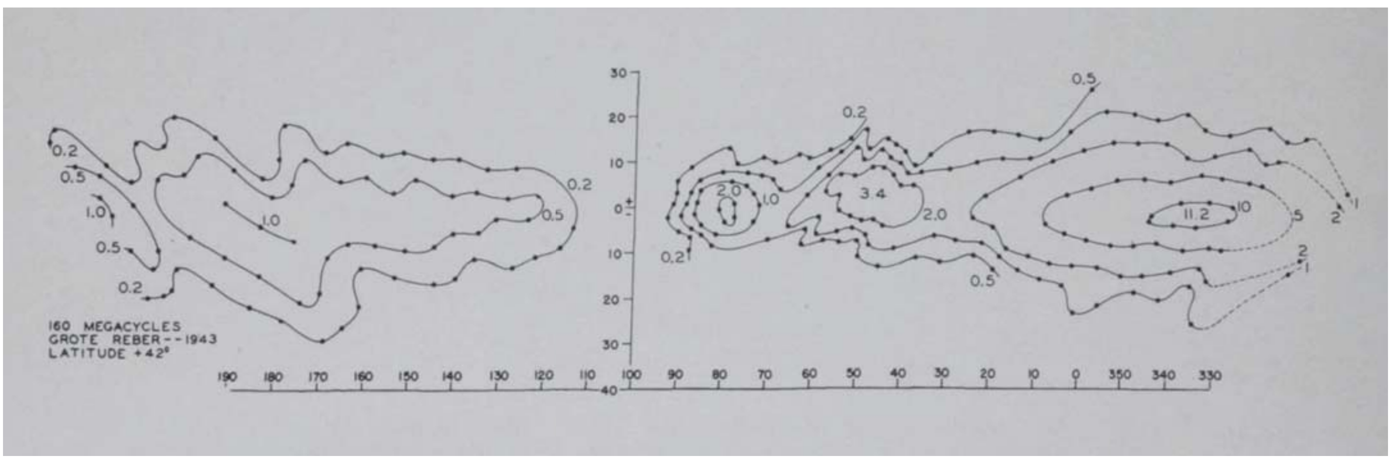
It all began thanks to the work of a young physicist and engineer by the name of Karl Jansky. Employed by Bell Telephone Laboratories in the late 1920s and early 1930s to work in the nascent field of radio communications, Jansky's job was to investigate sporadic static that could interfere with transmissions. In his quest to discover the origin of this nuisance, he built a telescope — basically a glorified antenna of brass piping and timber, some 30 meters across and 6 meters high (about 100 feet by 20 feet). He mounted this contraption on the wheels of a Model T Ford, which allowed it to rotate in any direction and inevitably earned it the nickname "Jansky's merry-go-round."

Jansky distinguished three kinds of interference, readily dismissing two that originated in thunderstorms. But the third kind was a steady hiss that periodically reached maximum intensity every 23 hours and 56 minutes (you might recognize this as Earth's sidereal period). Jansky initially attributed this hiss to the Sun, but when its intensity failed to decrease during the solar eclipse of August 31, 1932, he had to rustle up another explanation. He found that the signal was strongest in the direction of the galactic plane, specifically at a right ascension of 18^h, somewhere in Sagittarius. This location, Jansky noted with cautious excitement in a 1933 paper, coincided with the center of the Milky Way. We now know the radio signals that Jansky captured originate from a 4-million-solar-mass black hole called Sagittarius A*. But since astronomers at the time didn't know black holes existed — or, for that matter, that celestial objects emit radio waves — scientists did not grasp the full significance of Jansky's finding.



▲ **REBER'S BACKYARD SCULPTURE** Grote Reber stands at Green Bank in the 1960s after reassembling his radio telescope there. Reber originally built the instrument in 1937.

Enter Grote Reber, American pioneer of radio astronomy. Reber, an electrical engineer by training, was an amateur radio operator. When he heard of Jansky's discovery, he designed and built an instrument in his own backyard — a



▼ **EMISSION FROM THE MILKY WAY** *Left:* Reber gathered these radio maps' data in 1943, observing the sky at 160 MHz. The Milky Way's disk lies along a line intersecting 0 on the *y*-axis, and the galactic center is in the contour marked 11.2 on the far right. (The maps are plotted in an older version of galactic coordinates, so you may notice the *x*-axis doesn't quite match today's coordinates.) Contour lines are in terms of 10^{-22} watts per square centimeter, circular degree, megahertz. *Right:* This 2018 image, made with the MeerKAT radio telescope in South Africa, is one of our clearest images of the galactic center. The image spans about 2° by 1° — only a small segment of Reber's map.

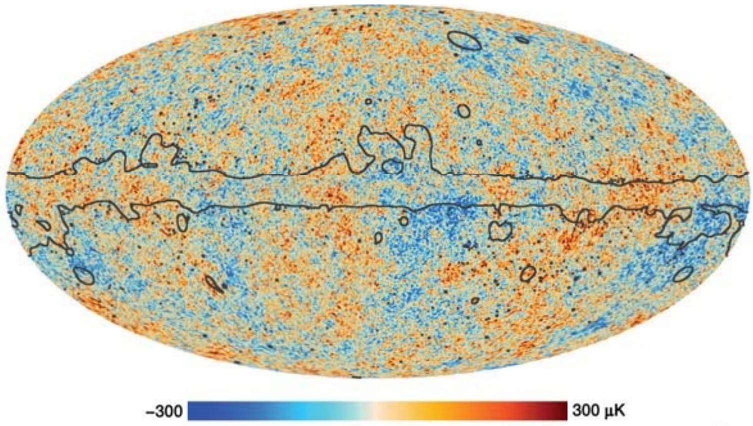
REBER WITH HIS SCOPE: NRAO / AUI / NSF; CONTOURS: G. REBER / *S&T* 1949; MODERN VIEW OF GALACTIC CENTER: SARAO / MEERKAT parabolic dish some 9 meters in diameter — in order to investigate this new phenomenon. Reber ultimately mapped the radio emission from broad sections of the Milky Way, including the galactic center as well as Cygnus and Cassiopeia. It was the spark that lit radio astronomy's engine.

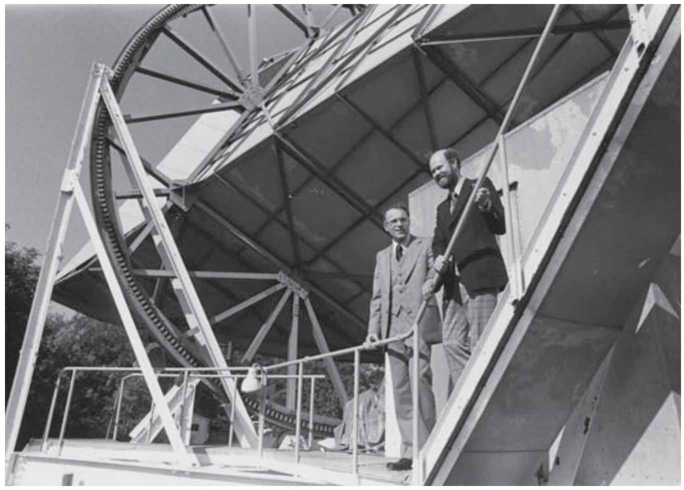
But sources much closer to home than the galactic center also emit radio waves. In 1942 James Hey, English physicist and later radio astronomer, was the first to find that radio signals come from the Sun (*S&T:* Oct. 2014, p. 30). He observed radio emission from electrons gyrating around the concentrated magnetic fields associated with sunspots. Solar flares also emit bursts of radio waves.

After World War II, accelerated by advances in radar technology, radio astronomy as a discipline took off. Observers discovered a host of sources in subsequent decades, including objects that astronomers had never known existed. Jocelyn Bell (later Bell Burnell), a graduate student at the University of Cambridge (UK), caused quite a stir when, in 1967, she discovered evenly timed radio signals emanating from one spot in the sky that astronomers later realized come from a rapidly rotating and highly magnetized neutron star, or *pulsar.* At that time, neutron stars were largely theoretical concepts. She famously filed the signal under the label LGM — shorthand for "Little Green Men." But the 1974 Nobel Prize in Physics for this discovery omitted Bell Burnell. Instead, it went to her supervisor, Antony Hewish, as well as to Sir Martin Ryle, a trailblazer in radio observing techniques and founding director of the Mullard Radio Astronomy Observatory.

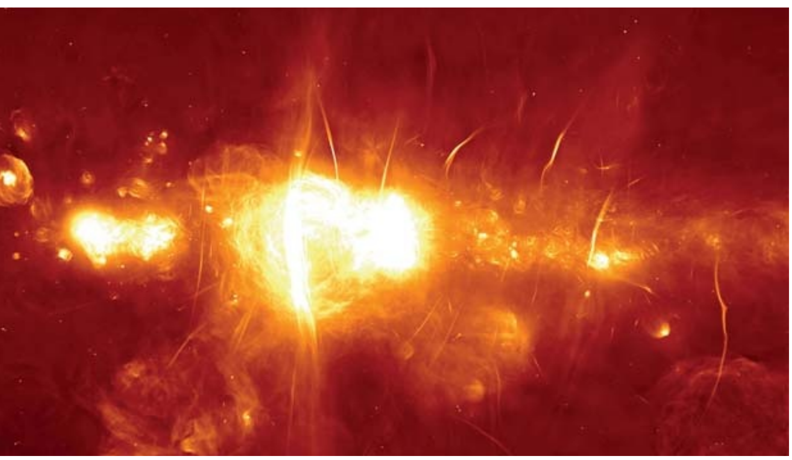
The discovery of quasars was another paradigm-shifting milestone in the history of radio astronomy. In 1956, Geoffrey Burbidge demonstrated that *synchrotron* radio radiation — photons from charged particles whirling at relativistic speeds along magnetic field lines — could account for the emission from the jet of M87, confirming earlier predictions and reports of synchrotron emission detected in the optical. But it wasn't until 1963, when the combined efforts of Cyril Hazard, Maarten Schmidt, and Bev Oke (and their collaborators) demonstrated that a starlike pinpoint of light, 3C 273, was in fact more than a billion light-years away, that astronomers realized something fantastic was afoot.

PLANCK MAP: ESA AND THE PLANCK COLLABORATION; PENZIAS AND WILSON: AIP EMILIO SEGRÈ VISUAL ARCHIVES, PHYSICS TODAY COLLECTION



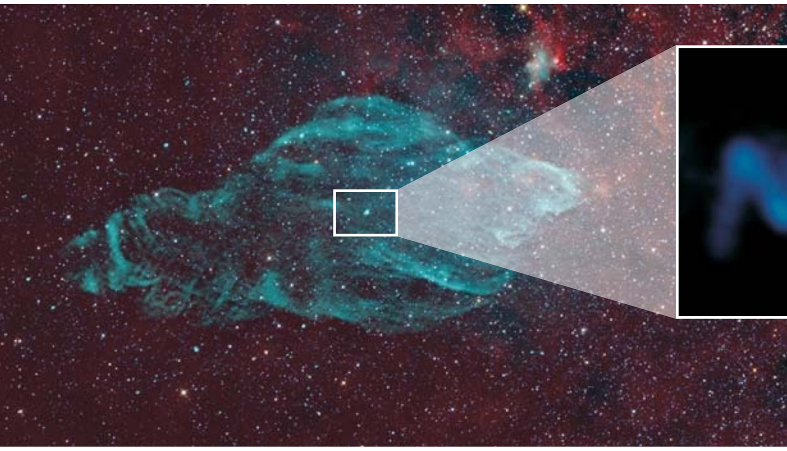


▲ **COSMIC HISS** Using a horn antenna, Arno Penzias and Robert Wilson *(above, with antenna)* detected a hiss at 4 GHz that proved to be the afterglow of the universe's Big Bang phase. Several instruments have mapped that *cosmic microwave background*, including the recent Planck spacecraft *(top)*. The contour outlines our galaxy's plane and some other nearby sources.



These *quasi-stellar radio sources*, or quasars for short, are supermassive black holes accreting matter from large disks of hot gas around them and then spewing much of this matter out in narrow but powerful relativistic jets from their poles. Quasars' extensive and variegated jets are the source of the synchrotron radiation, which arises from electrons spiraling along magnetic field lines in the jets. The exact mechanism for accelerating these particles is still unclear, but it's likely associated with the sudden release of magnetic field lines normally anchored in the accretion disk.

More recently, astronomers have discovered miniature counterparts to these extragalactic colossi. Instead of a supermassive black hole gobbling up vast amounts of gas, we have a stellar-mass black hole accreting matter from a companion star. In lieu of jets extending for up to hundreds of thousands of light-years, the outflows in *microquasars*, as these objects are known, are mere light-years in length. In microquasars we witness changes in the accretion disk and jet on human-friendly terms, i.e., minutes to days instead of the years to centuries required for quasars.



▲ **MICROQUASAR** Wobbling jets emanate from the black hole SS 433, the remnant of a star that exploded and created the Manatee Nebula (W50), visible only at radio wavelengths. Gas stolen from a companion star fuels the black hole's jets.

All Shapes and Sizes

Radio wavelengths range in length from about a millimeter to 100 kilometers (about 0.04 inch to 60 miles). Earth's atmosphere absorbs wavelengths shorter than a few centimeters, while the ionosphere bounces wavelengths longer than 30 meters back into space. So the radio "window" that ground astronomers have access to consists of cosmic waves typically a few centimeters to about 30 meters long. Radio astronomers like to dabble in frequencies, not wavelengths, though; this range corresponds to several tens of gigahertz (GHz) to 10 megahertz (MHz).

Since the radio window is so wide — spanning several orders of magnitude — radio telescopes come in all sizes and shapes. Parabolic dish antennas are the most efficient and versatile. The parabolic shape of the dish bounces incoming radio waves toward a detector or a subreflector situated at the focal point, just as the primary mirror in optical telescopes redirects incoming light to the secondary mirror. Oftentimes astronomers can tune the detectors to receive different frequencies simultaneously. But unlike mirrors in optical telescopes (which reflect wavelengths a millionth as long as radio telescopes do), these dishes needn't have a solid surface in order to catch radio waves. Usually a wire mesh akin to chicken wire does the job.

To detect fine detail in the objects we observe, we obviously want the dish to be big — really big. But physics (read "gravity") and weather ("high winds") limit dish sizes. Clever engineers have sidestepped these problems by constructing dishes in natural depressions in the earth. The most iconic is the Arecibo Observatory in Puerto Rico, where a dish 305 meters wide nestles in a natural cavity formed by a sinkhole. Arecibo was the largest sinkhole telescope until China completed FAST in 2016, which, as its name — the Five-hundred-meter Aperture Spherical Telescope — suggests, is 500 meters across (*S&T:* Feb. 2017, p. 26).

Even as they dazzle with their size, however, these dishes are immobile. Their gaze is fixed, and they can only observe transiting celestial objects at zenith as Earth rotates. Moving the feed antenna suspended at the focal point provides some maneuverability; FAST's dish also comprises deformable panels, moved by more than 2,000 actuators to alter the shape of the reflecting surface and place off-zenith targets within reach. But even so, targets near the horizon are out of range.

THEY COME IN MANY FORMS *Left:* This behemoth in Green Bank, West Virginia, is the largest fully steerable radio telescope in the world. As with other radio observatories, a radio quiet zone exists around the Green Bank site — visitors navigate using bicycles and diesel autos. *Right:* The Molonglo Observatory Synthesis Telescope covers 18,000 square meters outside of Canberra, Australia. Astronomers originally built it as a giant cross in the 1960s, but they shut down the north-south arm in 1978.

MICROQUASAR: MANATEE NEBULA: B. SAXTON (NRAO / AUI / NSF), M. GOSS ET AL.; SS 433: B. SAXTON (NRAO / AUI / NSF), R. M. HJELLMING AND K. J. JOHNSTON; GREEN BANK: NRAO / AUI / NSF; MOST: DIANA HANNIKAINEN

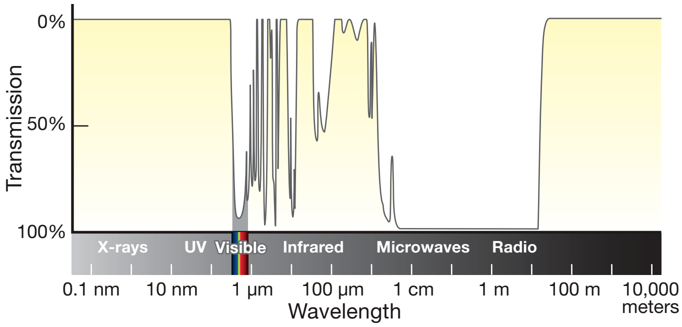
If one is willing to compromise in size, then fully steerable radio dishes are feasible. The largest of these is the Robert C. Byrd Green Bank Telescope in West Virginia, with its 100-by-110-meter dish. The 100-meter Effelsberg Radio Telescope near Bonn, Germany, is a smidgen smaller since it's not elliptical.

Not all radio telescopes are dishes, though. Take the Molonglo Observatory Synthesis Telescope, for example. MOST, situated outside of Canberra in Australia, consists of two cylindrical paraboloids, each 778 meters in length and 12 meters wide. The paraboloids are aligned east-west and can swivel about their long axes, allowing for up to 12 hours of continuous observation as Earth rotates. CHIME (the Canadian Hydrogen Intensity Mapping Experiment), another non-dish antenna array, consists of four side-by-side cylindrical reflectors, each 20 by 100 meters. They look like enormous unwieldy fishnets, poised to receive their daily cosmic catch.

A Telescope as Big as Earth

Resolution improves with increasing telescope size. But if there are structural limitations to dish size, what can astronomers do to improve the resolution of radio telescopes? An ingenious, albeit rather tricky, technique is that of linking individual radio telescopes together: *interferometry*.

The simplest type of interferometer consists of two radio telescopes set a certain distance apart, observing at the same frequency. Radio waves from a celestial source will arrive at the two telescopes at slightly different times, depending on the source's location in the sky. The difference in arrival



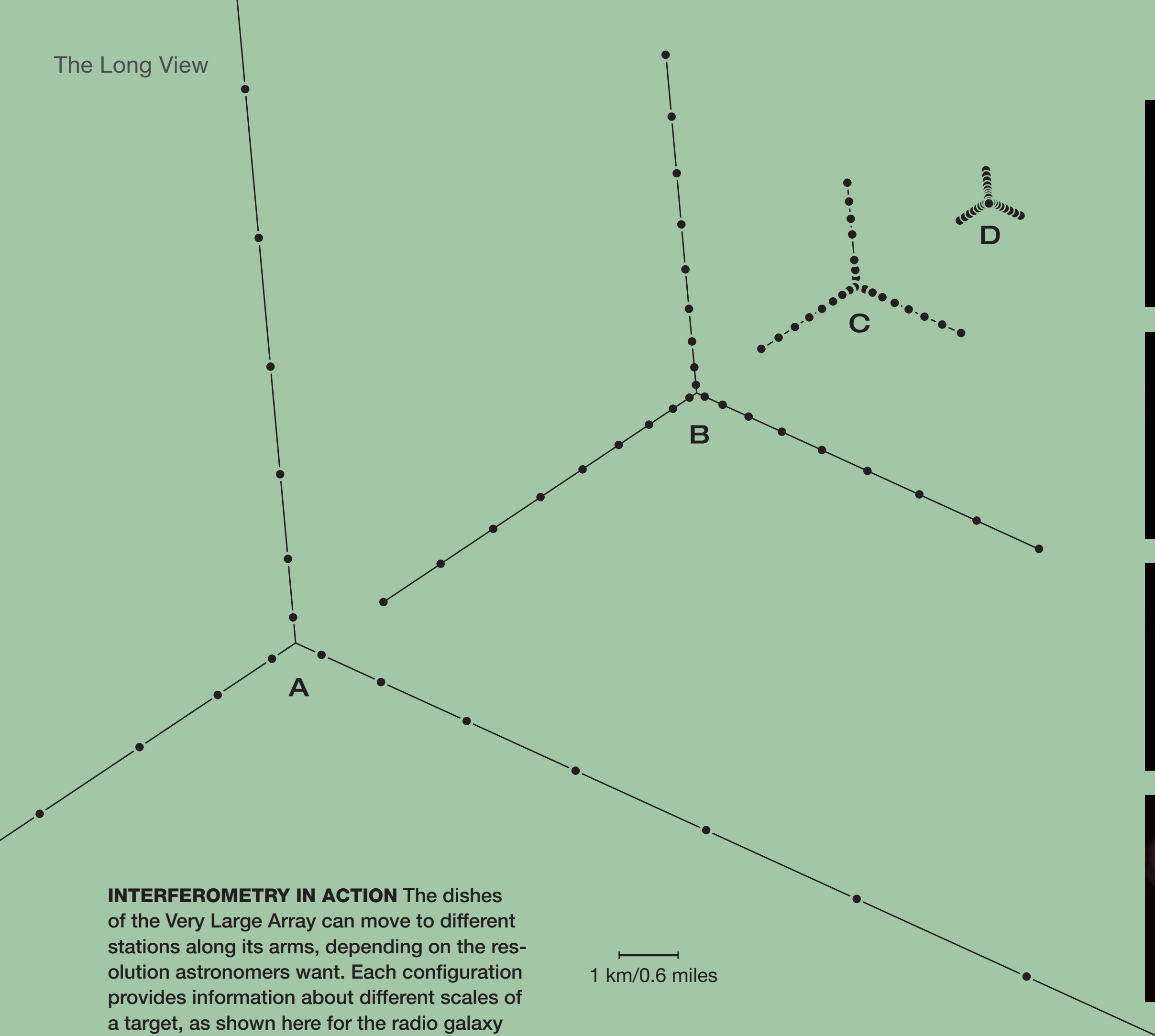
▲ **ATMOSPHERIC WINDOWS** Earth's atmosphere blocks many wavelengths of light, but visible light and parts of the ultraviolet, infrared, microwave, and radio bands make it through. (Astronomers often lump microwaves in with radio.) Opacities and wavelengths are approximate.

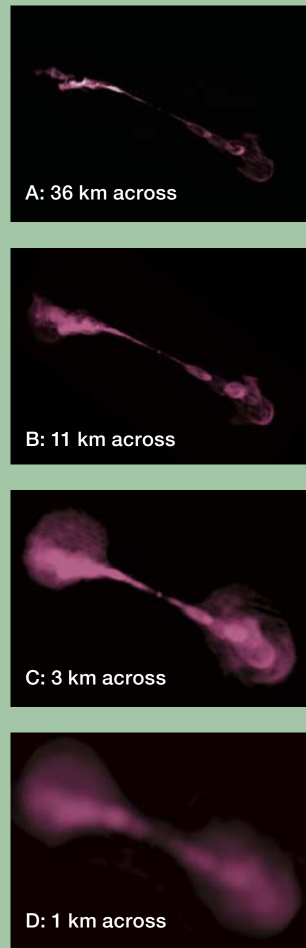
times translates to a time delay in the phase of the wave: The peaks and troughs of the waves each antenna receives will not overlap perfectly but will instead combine to create a more complexly rippled wave, known as an interference pattern. It's the job of a digital device called a correlator to combine the signals and work backwards to figure out the incoming angle of the radio waves. As Earth turns and the telescopes continue observing, the correlator has to keep up with the constantly changing angles, and in so doing reconstructs ever-more-detailed images.

Australian radio scientists Ruby Payne-Scott and Joe Pawsey, with their colleague Lindsay McCready, pioneered the interferometric technique alongside Ryle in the UK (and later groups in the Netherlands). Shortly after the end of World

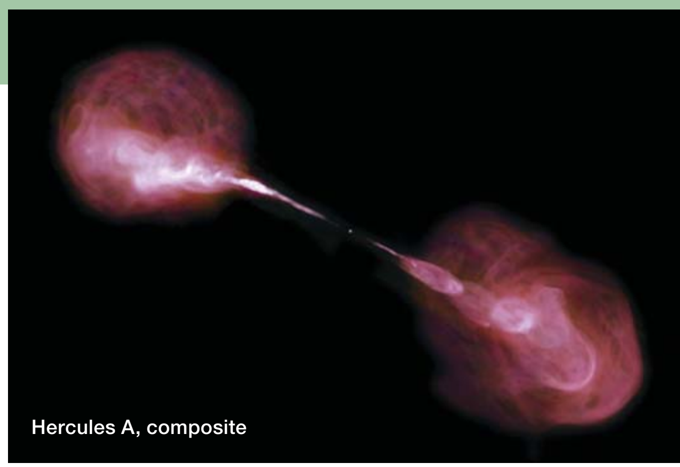
ATMOSPHERIC OPACITY: GREGG DINDERMAN / S&T; CHIME: ANDRE RENARD / DUNLAP INSTITUTE FOR ASTRONOMY & ASTROPHYSICS

CHIME The CHIME radio array in British Columbia combines four cylindrical reflectors to look for brief, mysterious flashes called fast radio bursts.





INTERFEROMETRY IN ACTION The dishes of the Very Large Array can move to different stations along its arms, depending on the resolution astronomers want. Each configuration provides information about different scales of a target, as shown here for the radio galaxy Hercules A. The combined image contains information from multiple scales.



War II, they used converted wartime radar dishes near Sydney, Australia, to observe the rising Sun. Each radar station sat atop a cliff and captured both the direct radio signal from the Sun as well as that reflected off the surface of the sea. This ingenious method yielded a baseline at each station of roughly 100 meters, enabling the trio to determine the position and angular size of bursts of radio emission as the Sun moved across the sky.

The researchers localized the origin of a series of giant bursts in February 1946 to a group of sunspots, demonstrating that the burst originated from an area much smaller than the solar disk. They published their results in a 1947 paper in the *Proceedings of the Royal Society of London*.

Since those early, heady days of the sea-cliff experiment, interferometers have grown to multiple-element arrays. The principle is the same: Link telescopes together, and you effectively get a baseline as long as the distance between the two farthest elements. One caveat is that the telescopes have to operate at the same frequency for this *very long baseline interferometry* (VLBI) to work.

The most iconic interferometer is the Karl G. Jansky Very Large Array (VLA), near Socorro, New Mexico, operated by the National Radio Astronomy Observatory. It was built in the 1970s and began operations in 1980. Twenty-seven dishes, each 25 meters in diameter, are set on rail tracks in a Y-shape and can be maneuvered into four principal configurations, depending on the scientific goal. The widest configuration yields a baseline of some 36 km.

However, these days the heavy hitter in interferometer-enabled science is the Atacama Large Millimeter/submillimeter Array (ALMA), perched high in the northern Chilean

ARRAY CONFIGURATIONS: GREGG DINDERMAN / *S&T*; HERCULES A IMAGES: NRAO / AUI / NSF desert. ALMA uses 66 movable antennas to peer deep into stars' natal clouds and other normally inaccessible locations. Among its successes, the array is helping transform what we know about planet formation (*S&T:* May 2020, p. 34).

Yielding an even larger distance between elements is the Very Long Baseline Array (VLBA), its ten 25-meter radio dishes spanning the U.S. from the Virgin Islands in the Caribbean to Hawai'i in the Pacific. Astronomers record data with these elements and ship them to Socorro, where a correlator combines them into what one humongous telescope would have seen. European scientists have forged another large array, the European VLBI Network (EVN), with 22 antennas spread across Europe to places beyond, including Puerto Rico, South Africa, and South Korea. And finally, the VLBA and EVN can operate together — and *voilà* we have a radio telescope with a diameter almost as big as Earth's.

But why confine oneself to Earth? Wouldn't lobbing an antenna into orbit provide that much longer a baseline? In fact, there have already been several ambitious experiments using space-based antennas, dating back to 1979 when the Soviets shuttled a 10-meter telescope to Salyut 6. The first standalone orbiting radio telescope was Japan's 8-meter antenna of the VLBI Space Observatory Program (VSOP), which operated from 1997 to 2003. The latest in this line was Russia's 10-meter Spektr-R, which operated from 2011 to 2019 and provided a baseline of around 350,000 km.

Building on these early space-based forays, radio astronomers hope to extend their reach even farther. The Event Horizon Telescope (EHT) team, for example, is contemplating launching an antenna into Earth orbit or placing one on the Moon. Those with big dreams are targeting the second Lagrangian point, a location some 1.5 million km "behind" Earth as viewed from the Sun where spacecraft can hover with minimal effort. It boggles the mind to think of what a virtual radio receiver of that size could reveal about supermassive black holes residing in distant galaxies.

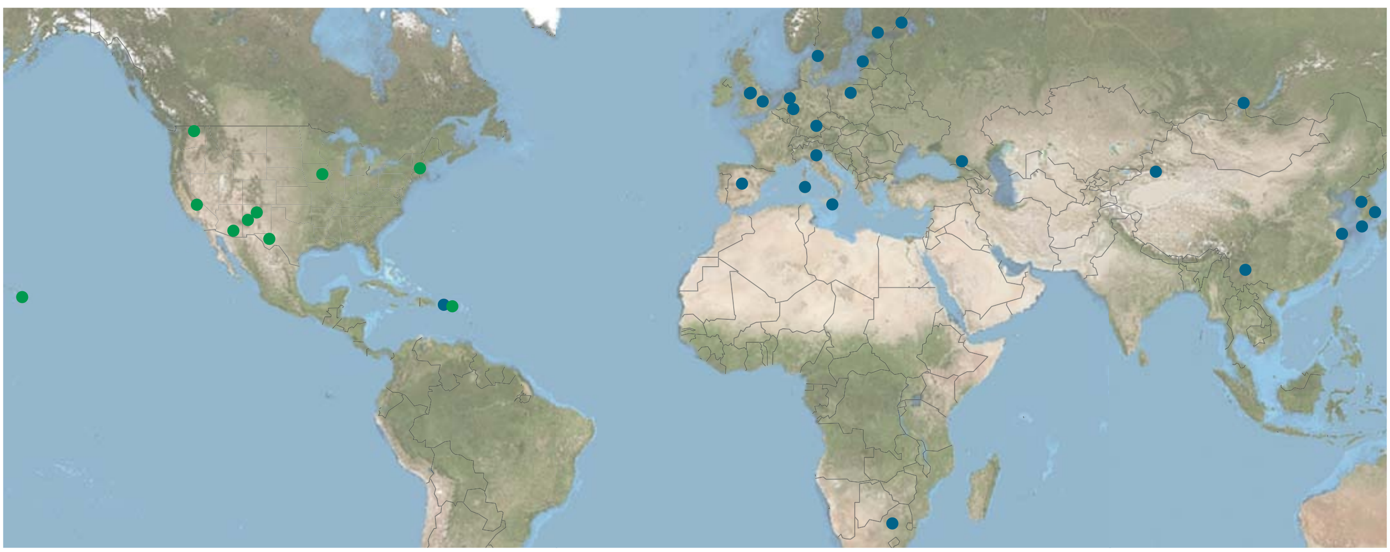
Dial in to the Future

The EHT and ALMA technically work at frequencies beyond the upper edge of what astronomers consider radio. Monster arrays at lower frequencies are also currently in development. The Square Kilometre Array (SKA), for example, will straddle two continents, with antennas located in South Africa and Western Australia. When completed it will include thousands of antennas.

Astronomers also have plans to upgrade the VLA. The Next-Generation VLA (ngVLA) will consist of 244 dishes each 18 meters in diameter, spread across a baseline more than 200 times longer than the current setup. The new network will combine a tight spiral of dishes in the U.S. Southwest with remote stations across the country.

We may well ask what radio telescopes in the making and new technologies hold in store for us. What will we learn about the formation of the first stars and galaxies right after the Big Bang? Or how planetary systems arise? Will we gain insight into black holes . . . and ultimately understand gravity better? From the magnetism that bathes the universe to the growing number of distant cosmic flashes called fast radio bursts, the heavens are awash in mysteries that radio telescopes will help us solve. Stay tuned.

■ After umpteen years of pointing X-ray and radio telescopes at the universe, Observing Editor **DIANA HANNIKAINEN** has switched to commanding backyard light buckets. She dedicates this article to the memory of Richard Hunstead (1943–2020), her beloved mentor in radio astronomy.



GREGG DINDERMAN / *S&T*

▲ **WORLDWIDE WEB OF DISHES** The two largest VLBI networks are the U.S.-based VLBA (green) and the European VLBI Network (blue). Stations participate in the network but also belong to other projects or organizations — for example, Arecibo Observatory in Puerto Rico is part of the European network but is operated by the U.S. National Science Foundation and the University of Central Florida.

Swimmin' in the Lagoon

The Lagoon Nebula harbors a wealth of cosmic treasures.

COSMIC POOL You can see the Lagoon Nebula, M8, just by looking up. It's in the Great Rift of the Milky Way and looks like a small puff of steam coming from the spout of the Sagittarius Teapot. North is up in all images unless otherwise noted.

The old black-and-white photo of the **Lagoon Nebula** (M8) that first sparked my interest in this beautiful object also mystified me. Even though it was gorgeous, it didn't look like a lagoon at all. But what did I know as a 14-year-old kid? Not much, of course, but aside from the puzzling name I was entranced and wondered if I could observe it for myself with my homemade 8-inch f/4 Newtonian.

I was thrilled that I could see the Lagoon from my suburban yard, even though only the brightest parts of the nebula and the open cluster residing within it showed up. Once I began sketching at the eyepiece in the summer of 1974, I drew several renderings of M8. The star cluster stood out more than the nebulosity, but I thought they looked pretty awesome together.

◀ **FIRST SKETCH** The author made this early sketch of the Lagoon Nebula on July 19, 1974, using his 8-inch f/4 Newtonian telescope.

When I saw the Lagoon Nebula the following summer from a much darker site with the same scope, the nebulosity appeared much more extensive and totally stole the show from the cluster. I was blown away! That was the first time I'd observed under a dark rural sky, and I remember the view like it was last night.

A few decades later, the **Hourglass** region at the heart of the Lagoon — a small, bright butterfly of nebulosity named by John Herschel — was on the Oregon Star Party (OSP) Advanced Observing List. For the first time I dove into the Lagoon to sketch what to me was an unfamiliar section of my old favorite. I'd never observed the Lagoon at high power, and I fell in love with it all over again. After spending an hour or so sketching this area at 408× with my 28-inch f/4 Newtonian, I promised myself I'd return and sketch the entire nebula and cluster with the same care in the future. Not being in a hurry I kept putting it off — there's just so much other stuff to see in the universe.

About the Drawings

In the summer of 2019 I finally started sketching the Lagoon in detail — four nights at the Golden State Star Party and

LAGOON NEBULA: NASA / ESA / DIGITIZED SKY SURVEY 2; EARLY SKETCH: HOWARD BANICH eight nights at the Oregon Star Party, for a total of about ten hours. Most of this was done during the OSP, which had some exceptionally clear and dark skies even by its high standards. Sometimes it pays to procrastinate.

I used my 28-inch scope for these observations. I had two goals in mind: First, draw the Lagoon with my lowest-power eyepiece and record the entire object without nebula filters. Second, zoom in on the Hourglass region (again without nebula filters) and sketch every detail visible. They were equally challenging sketches, but oh so much fun. Based on these rough sketches, I created finished drawings with more accurate proportions to realistically portray how I saw the entire object. For the low-power drawing of the Lagoon as a whole I used magnifications of 131× and 155×, and for the close-up of the Hourglass I used 253× and 408×.

The Wide View

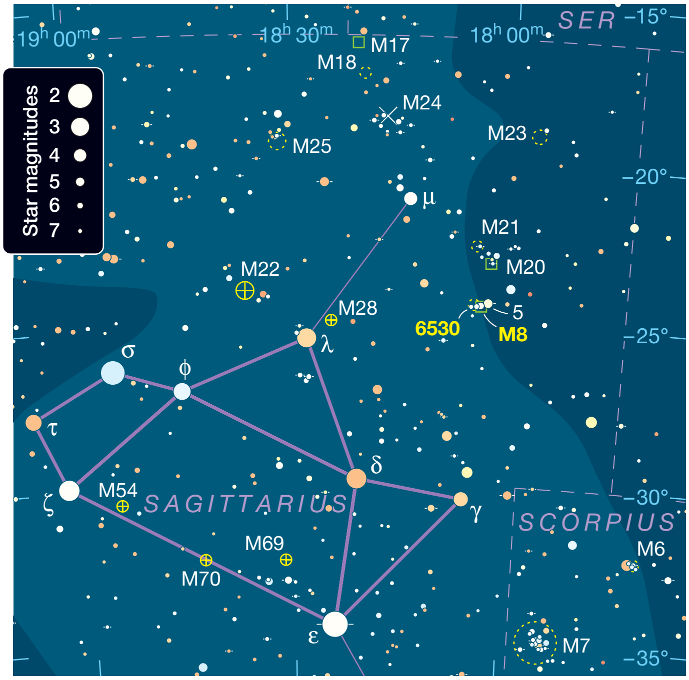
The Lagoon Nebula (also cataloged as NGC 6523) lies in the Sagittarius–Carina spiral arm of the Milky Way, around 4,000 light-years toward the galactic center from our vantage point. It's an H II region also classified as an emission nebula with an associated star cluster, **NGC 6530**. The Lagoon's dimensions are roughly 54 light-years in the east-to-west direction and 36 light-years north to south.

Although the Italian astronomer Giovanni Battista Hodierna is credited with discovering the Lagoon sometime before 1654 with a 20-power Galilean-type refractor, this misty naked-eye patch must have been known to humans since they first started looking at the sky. On a dark night M8 and M20, the Trifid Nebula, look like little puffs of steam just north of the brightest part of the Milky Way as they rise out of the Sagittarius Teapot's spout.

Because it's so bright, smaller scopes do well on the Lagoon. My 8-inch nicely frames both M8 and M20 in a low-power view along with an uncountable number of Milky Way stars. Although there's a wealth of nebular detail to see in this incredibly rich field without a filter — even under a suburban sky — the view is instantly transformed into a "nebulapalooza" with an ultra-high contrast (UHC) or O III nebula filter. Nebulosity becomes brighter and rich with detail, and the outer fringes of the fainter stuff become visible.

Despite being M8's signature feature, the dark, curved nebula cutting the Lagoon in half doesn't have a Barnard designation. However, three much smaller and less prominent dark blotches within the Lagoon do — **B88**, **B89**, and **B296**. Perhaps Barnard's photographic plate overexposed the dark lane, but this feature doesn't have a Lynds Dark Nebula designation, either. No matter, this highly distinctive but anonymous channel seems to flow northeast before going due north. Or maybe it's flowing in the opposite direction — how does it look to you? For now, let's refer to it unofficially as the *dark channel*.

The dark channel gives the Lagoon its personality. Where else can you easily see a long, curved, dark cloud that looks like an interstellar stream? Look closely on a good night and

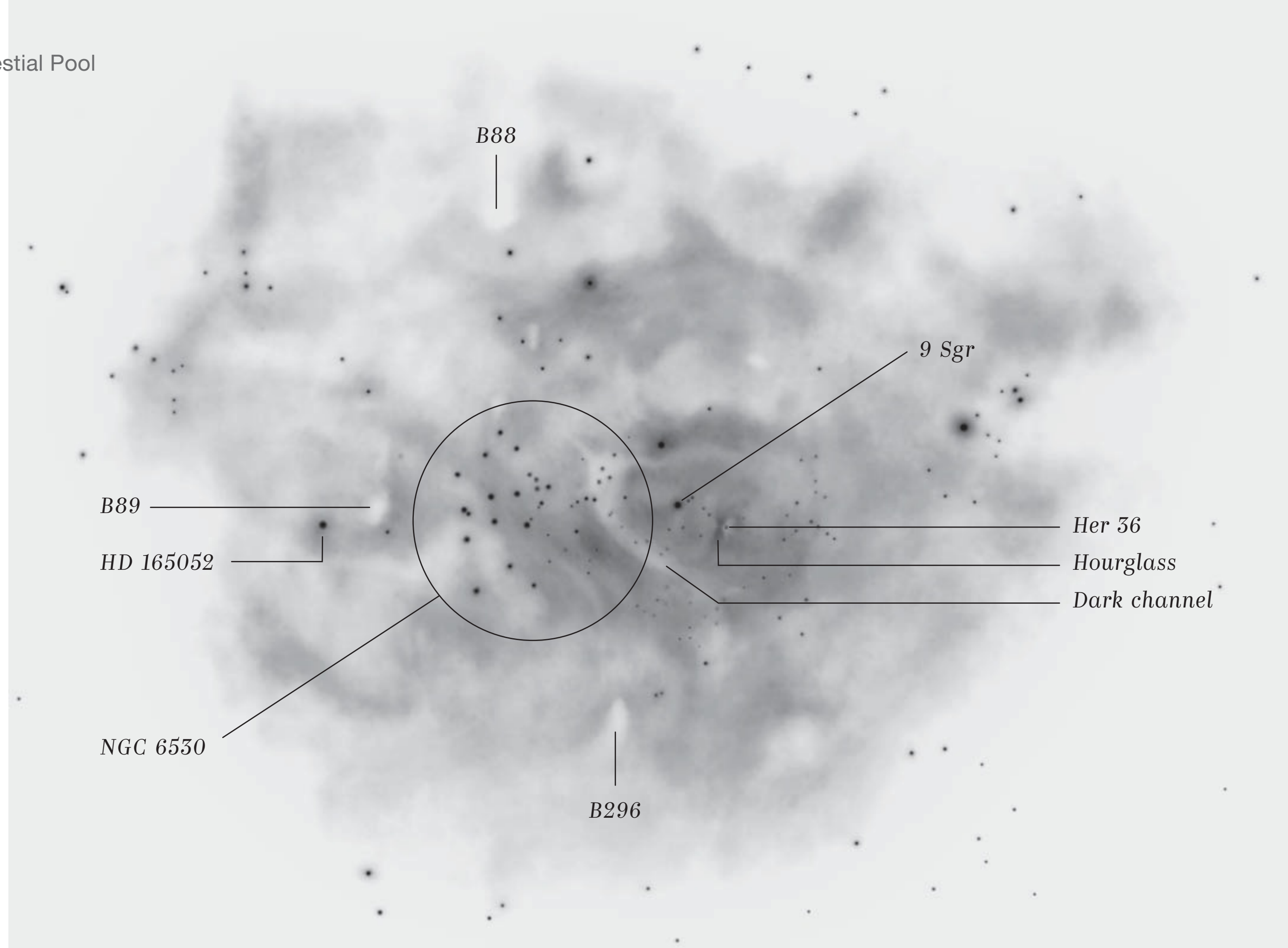


it even seems to have small alluvial features along its length to enhance the impression. The faint stars within the dark channel glitter like sunlight reflecting off smooth, shiny river rocks, completing the illusion. No matter how you see it, the dark channel is a unique dark nebula and is not to be missed.

If you have access to an unspoiled sky, you may find that nebula filters don't improve the view as much as you might expect. I prefer the unfiltered view on a great night because almost all the nebulosity remains visible and it's so much easier to appreciate the stars within and superimposed on the Lagoon — not to mention the surrounding richness of the

▼ **SWIMMIN' AUTHOR SKETCHIN'** The author's good friend Jimi Lowrey was on his first visit to the Oregon Star Party in 2019. Every evening, as the author prepared to observe and sketch M8, Lowrey would saunter by and ask "Swimmin' in the Lagoon?" in his distinctive Floridian accent.

JIMI LOWREY



▲ **A PLETHORA OF OBJECTS** A labeled version (above) and inverted version (opposite page) of the author's low-power drawings of the Lagoon Nebula show the multitude and variety of observable targets.

Milky Way star fields. And with the open cluster NGC 6530 being a major component of M8, I prefer seeing its lovely stars in their unfiltered glory.

NGC 6530 is a beauty. Consisting of more than 100 suns, around two dozen of the brightest members (ranging from about 7th to 10th magnitude) are arrayed in an eye-catching pattern that would be a sensational sight even without their beautiful nebulous environment. These are young stars, only 2 to 4 million years old, and research suggests that the cluster is currently gravitationally unbound (making it more of a stellar association rather than an open cluster), although it may not always have been in its past.

What could be better than soaking up the low-power view of the lovely Lagoon and its cluster together? As it turns out, one can see even more magnificence by bumping up the magnification.

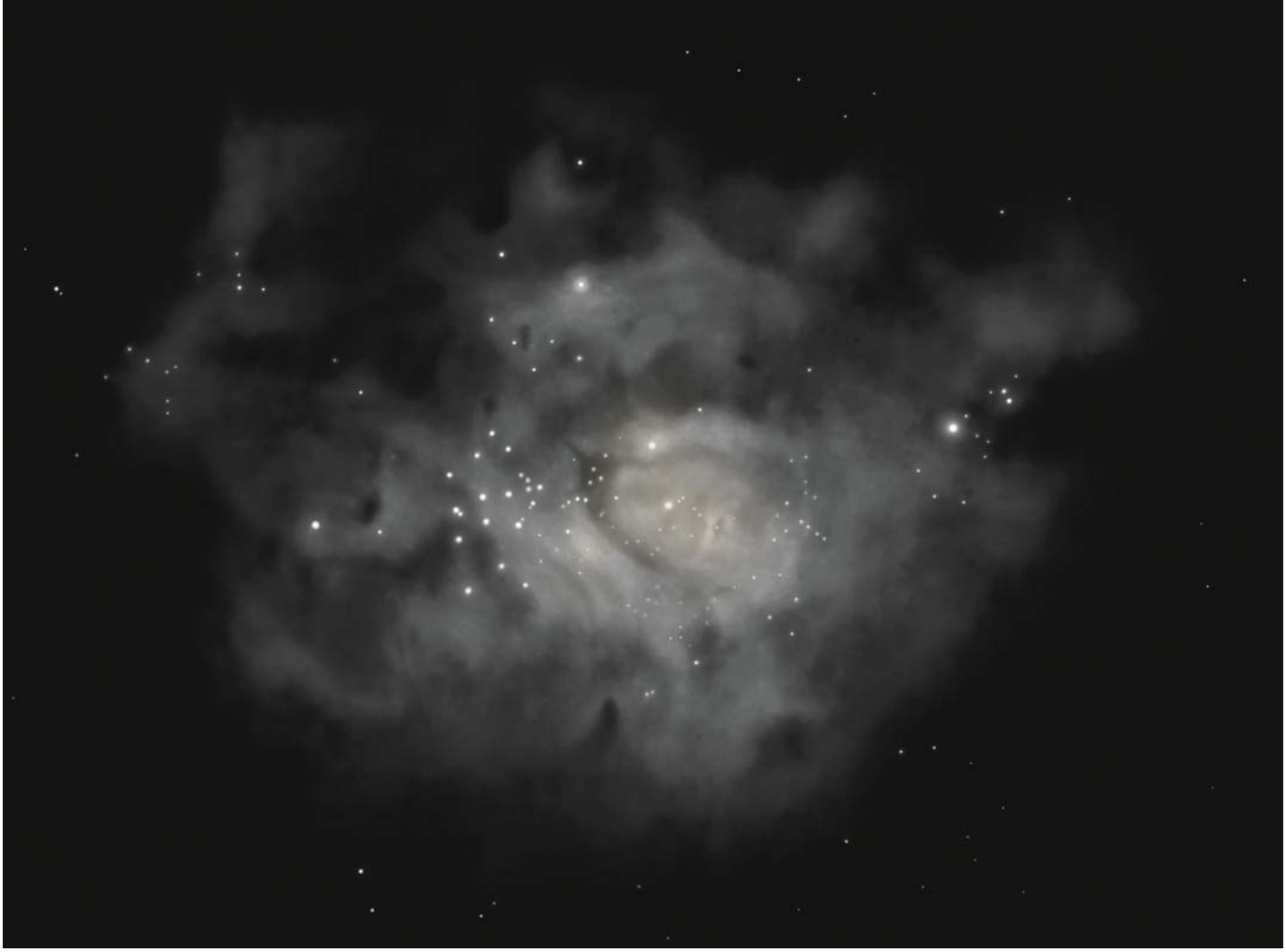
A Little Closer

We've all seen amazing images of the Lagoon festooned with a series of dark globs of matter spread across its bright nebulosity. Many of these are *Bok globules* — collapsing protostellar clouds — essentially, the birthplaces of stars. Some of the globules are visible if you bump up the magnification. These relatively compact dark clouds lie in front of the bright

What's in a name?

How did M8 come to be called the Lagoon Nebula? My guess is that the smooth, curved silhouette of the dark channel splitting the brightest regions of the nebula in half was the inspiration even though it didn't look like a lagoon. Yes, but. This distinctive feature wasn't always seen this way. John Herschel performed a detailed study of M8 from the Southern Hemisphere in the 1830s, and his monograph published in 1847 shows an oval pool where I see a flowing streak. Agnes M. Clerke suggested in her book *The System of the Stars*, published in 1890, that M8 "might be designated the 'Lagoon' nebula" based on Herschel's description of "a number of oval dark vacancies" in the nebula (see **https://is.gd/clerke** for Clerke's comments). I now officially know more than when I was 14.

HOWARD BANICH



▲ **GLORIOUS LAGOON** The author's logbook from the second night at the OSP reads: "Lots of contrast for the nebulosity, and even with the soft seeing this is a wonderful view! The SQM is reading 21.95 now and the sky in general is awesome — the Milky Way is wide and granular. Anyway, the Hourglass area in the Lagoon is a wonderland of soft nebulosity shading from bright to barely visible, great stuff. I've worked on both sketches for the past hour and a half — I've had a great time!" The author carefully recorded stars within the boundaries of the nebulosity and omitted the vast majority of the rich Milky Way star fields surrounding the Lagoon. There were subtle hints of a warm hue in the bright central areas, but no definite reddish tones. Note the prominent dark channel running through the central region of the nebula.

HOWARD BANICH

nebulosity of the Lagoon, which is really the only way we can detect them, especially the smaller ones. Usually not much more than about 1 light-year across, Bok globules commonly give rise to multiple star systems.

Experiment with different magnifications on your scope to find the best view of these dark blobs. Be sure to use a UHC or O III filter if you observe under a less-than-pristine sky. I found a magnification of around 100× works best on my 8-inch, which also excludes the Trifid Nebula from the field of view, making the Lagoon easier to concentrate on. For my 28-inch scope I like to use a magnification of 408×. Take your time at the eyepiece and see how many of these dark cloudlets you can detect.

Looking Around

Nebulosity in the faint outer reaches of the Lagoon was the most surprising feature I saw, especially since I didn't use a nebula filter. Filters greatly increase the visual size of the nebula and show much the same detail as the image on page 20 fairly well, but that doesn't mean the fainter nebulosity was an easy catch. I clearly saw it on only the best nights while I was purposely scanning the extreme edges of M8.

The low-power drawing also illustrates the overall texture and structure of the Lagoon. The bright central area west of the dark channel shows a circular flowing pattern, while the surrounding outer areas are more of a patchwork of soft glows and dark areas. Interestingly, studies have shown the Lagoon is generally expanding from the Hourglass region outward in all directions and that a thin sheet of warm gas is moving toward us from its near edge. The thinner areas allow for a less obstructed view of this brightest part of the Lagoon.

Perhaps this implies that radial pressure is pushing gas and dust outward from the two main stars that power the glowing nebula — **9 Sagittarii (9 Sgr)** and **Herschel 36 (Her 36)**. If so, it seems the dark channel is really more of a compression feature.

The Close-up View

Let's move to the detailed drawing showing the region west of the dark channel, and the area around the Hourglass, where

▲ **THE HOURGLASS** Seen here is the inverted version of the author's high-power finished drawing portraying the Hourglass region. This view shows how much dark nebulosity attenuates the light of Her 36 — the relatively faint star immediately west of the Hourglass — as compared to 9 Sgr, left of center. These two multiple stars supply most of the energy that ionizes the Lagoon Nebula. Both this and the low-power drawing started as pencil sketches, and the author subsequently photographed and adjusted them in GIMP to more closely portray what he saw in the eyepiece.

HOWARD BANICH

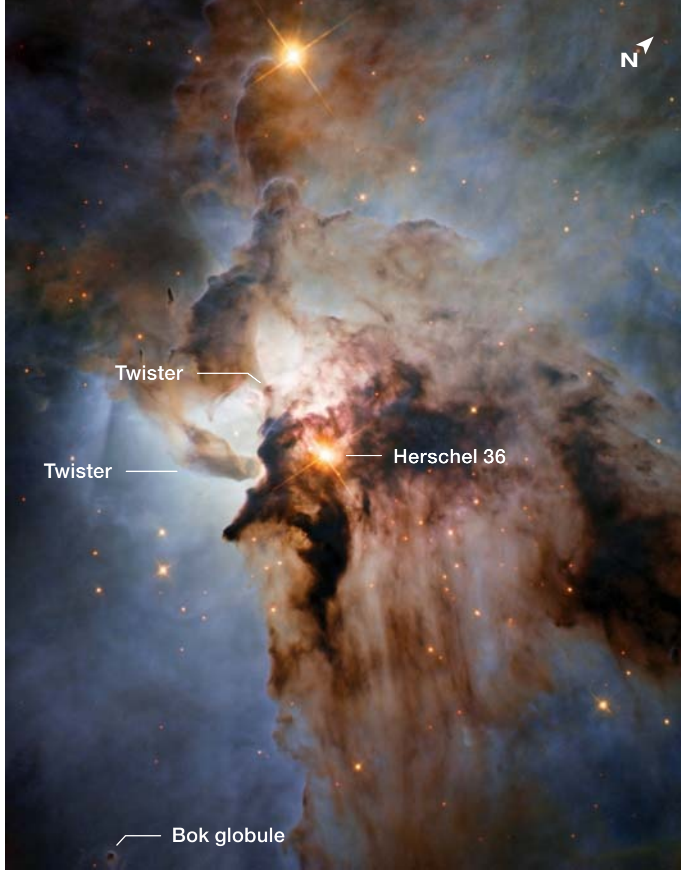
the seemingly unremarkable star Herschel 36 resides. But don't let looks deceive you: Her 36 is a triple star comprising a spectroscopic binary with *O*9 and *B*0.5 components and a more distant *O*7.5 companion. Although we see their combined glow shining only at magnitude 10.3, Her 36 is considerably reddened by nebulosity. Make no mistake, this young, monster stellar system is pumping out blistering torrents of ultraviolet light that ionize not only the nearby Hourglass, but also the entire western portion of the Lagoon.

The other powerhouse in the nebula, 9 Sagittarii, looks much brighter at magnitude 6.0 and is a spectroscopic double, with an *O*3.5 primary star and an *O*5–5.5 secondary. This energetic pair, located just northeast of the Hourglass and Her 36, fluoresces the eastern part of the Lagoon. A third star, **HD 165052**, is also a massive binary, with *O*6.5 and *O*7.5 components, and it adds to the ionization of the eastern part of the Lagoon. But its overall contribution is fairly minor compared to 9 Sgr and Her 36. There are other bright stars in and near the Lagoon, but these three are the ones most responsible for sculpting and ionizing the nebulosity with their intense ultraviolet output. *O*-stars such as these are the rarest of main sequence stars, and their energetic stellar winds are the engines that light up H II regions like the Lagoon.

Divin' into the Hourglass

Despite its brightness, the Hourglass is frequently overlooked — fellow observers are often surprised at the amount of detail here when I share the view of this wondrous area. Although not as rich as the Huygens Region in M42, it's just as much fun to explore. But as bright as this area is, I can barely detect a warm hue in places. No definite reddish tint like in the Trifid Nebula or M42.

The Hourglass is actually a window into the interior of an ultra-compact H II region, cataloged as **G5.97–1.17**, where the nearby star Her 36 is furiously ionizing atomic hydrogen. It's also well-defined, with its two narrow ends nearly touching. In fact, only in moments of steady seeing at 408× could I tell they weren't in contact, but now that has me rarin' to observe this area again. The bright north and south wings of the Hourglass have fainter extensions, with the northern wing



▶ **CELESTIAL TWISTERS** This Hubble image probes the Hourglass region in the Lagoon. One "interstellar tornado" bisects the Hourglass at its waist, and the other constitutes its southern border. The author saw only the central tornado. Note how nebulosity heavily obscures Her 36. A Bok globule peeks out from the lower left corner.

flowing north then curving west. The southern extension is somewhat more chaotic in appearance but generally proceeds south then west. This all comes together in a faint loop surrounding the dark nebula that's trying to hide Her 36.

Two "interstellar twisters," one forming the Hourglass's southern edge and the other pinching it at the waist, are veritable cosmic tornadoes. They appear to be physically twisting due to temperature differences between their cores and surfaces. That's insanely awesome and seeing even one of them has me all fired up — knowing the incredible nature of an obscure object like this makes observing deeply gratifying.

I had every expectation the Hourglass was a bipolar nebula. Nope, not even close — it's merely a random shape created by several overlapping layers of dark nebulae as seen from our vantage point. These cosmic tornadoes even play a role in creating the deceptively regular contours.

This interplay between bright and dark nebulosity in and around the Hourglass is hypnotic: subtle shading, gentle contours, almost imperceptibly morphing edges are everywhere. A few big and bright stars join dozens of fainter suns.

No matter their brightness, these points of brilliance highlight the soft glow of surrounding nebulosity and are a reminder of the slow but staggering process of star creation. Shock waves and gravitation ever so gradually compress extraordinarily rarified wisps of interstellar gas and dust to the point of nuclear fusion, resulting in monster stellar furnaces like Her 36 and 9 Sgr that ionize 54 by 36 light-years of atomic hydrogen, and making it fluoresce brightly enough that we can see it without a telescope from 4,000 light-years away.

Absolutely stupendous, and you don't even need a telescope to start swimmin'.

■ Contributing Editor **HOWARD BANICH** could be going for a dip right now and can be reached upon his return at **hbanich@gmail.com**.

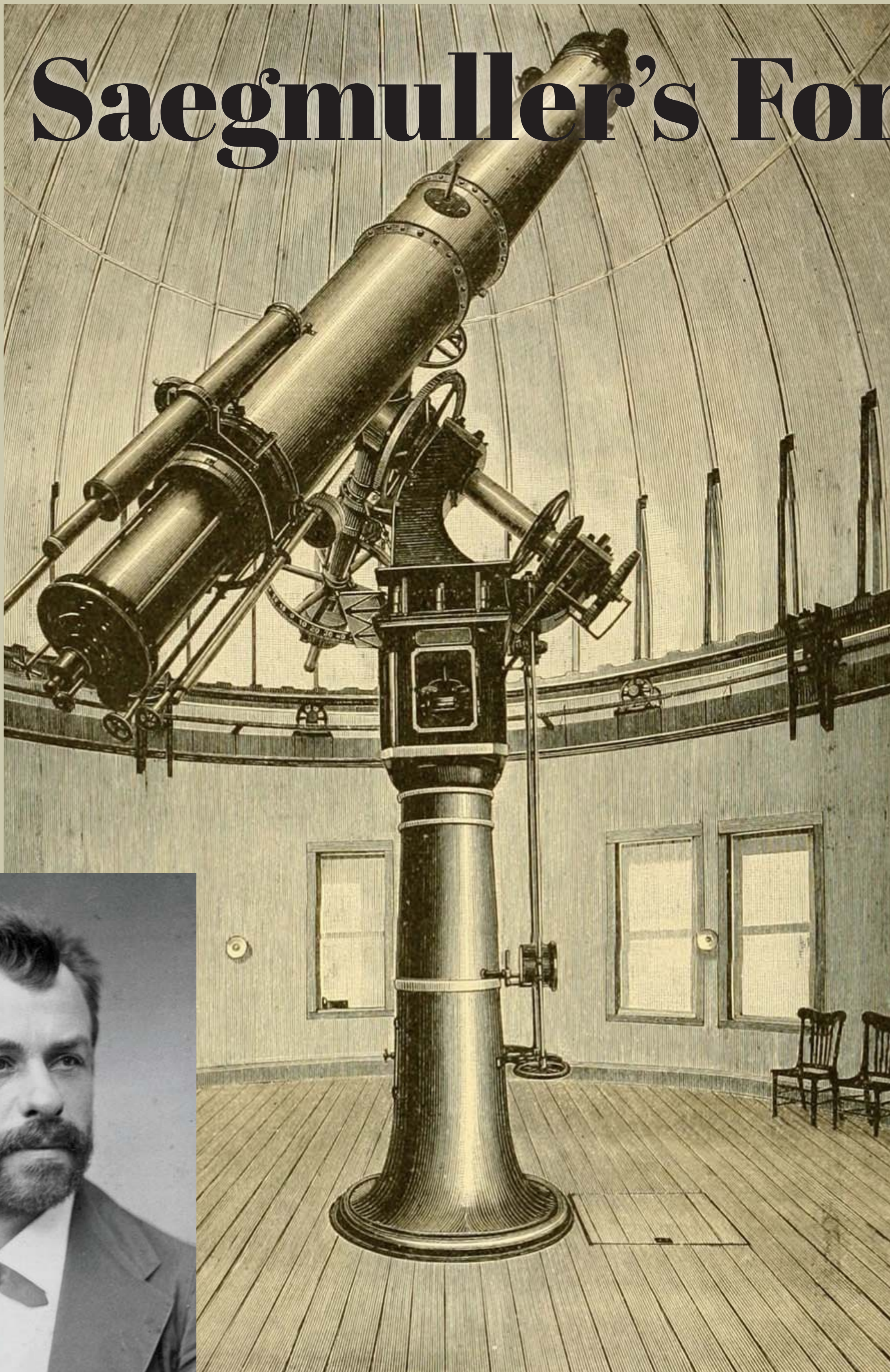
FURTHER MATERIAL: Go to **https://is.gd/3Dhourglass** to see a remarkable 3D flythrough showing how the landscape of the Hourglass is arrayed.

Gems in the Lagoon

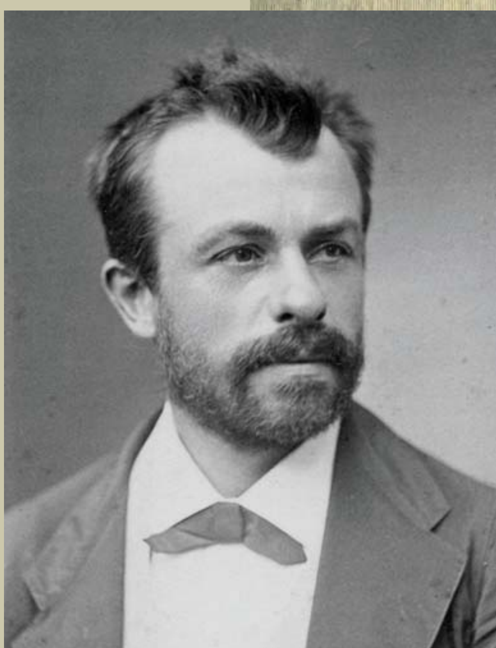
Object	Type	Mag(v)	Size/Sep	RA	Dec.
Messier 8	Em. nebula / H II region	6.0	45′ × 30′	$18^h\ 03.8^m$	–24° 23′
Hourglass	H II region	—	30″	$18^h\ 03.7^m$	–24° 23′
NGC 6530	Open cluster	4.6	15′	$18^h\ 04.4^m$	–24° 23′
Barnard 88	Dark nebula	—	2.0′ × 0.5′	$18^h\ 04.6^m$	–24° 07′
Barnard 89	Dark nebula	—	0.5′ × 0.5′	$18^h\ 05.0^m$	–24° 22′
Barnard 296	Dark nebula	—	6′ × 1′	$18^h\ 04.1^m$	–24° 32′
9 Sagittarii	Double star	6.3, 6.8	0.02″	$18^h\ 03.9^m$	–24° 22′
Herschel 36	Multiple star	7.6, 7.7, 10.3	0.0″, 3.5″	$18^h\ 03.7^m$	–24° 23′
HD 165052	Double star	6.9	0.0″	$18^h\ 05.2^m$	–24° 24′
G5.97–1.17	H II region	—	0.4″	$18^h\ 03.7^m$	–24° 23′

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.

Saegmuller's Forg



▶ **CROWNING GLORY** This engraving from the 1899 publication *Handbuch der Astronomischen Instrumentenkunde* portrays the Saegmuller 20-inch refractor installed at Chamberlin Observatory in Denver, Colorado. Featuring an objective lens by the legendary optical firm of Alvan Clark & Sons, the telescope was the largest instrument Saegmuller ever made. The scope's mount cost $10,000 — slightly less than the $11,000 price of the objective.



▼ **ENTREPRENEURIAL GAZE** George Saegmuller was 32 years old when this portrait was captured in 1879. After immigrating to the United States nine years earlier, he eventually found himself working with instrument maker Camill Fauth.

PORTRAIT: DAVID F. BURNS; ENGRAVING: L. AMBRONN / HANDBUCH DER ASTRONOMISCHEN INSTRUMENTENKUNDE VOL 2, COURTESY INTERNET ARCHIVE

otten Refractors

The legacy of one 19th-century telescope maker's short but productive career survives in the instruments he created.

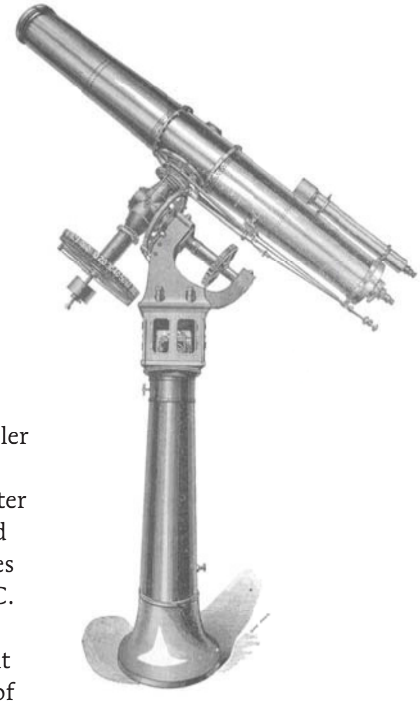
To enter the dome, Victor Blanco had to move a dead soldier blocking the door. The observatory was seriously damaged by fire and then by shelling. The 19-inch telescope inside was the second largest made by George Saegmuller and the second to be destroyed by fire; the first accidentally and the second intentionally.

The latter half of the 19th century was the golden age of refractor telescopes, the pinnacle represented by instruments made with optics by Alvan Clark & Sons and mounts manufactured by the Warner & Swasey Company. These legendary firms overshadowed most other instrument makers of the era, including a small company in Washington, DC, that produced several large refractors, many of which utilized mounts with unique and innovative features. That operation was headed by an engineer named George Nicholas Saegmuller.

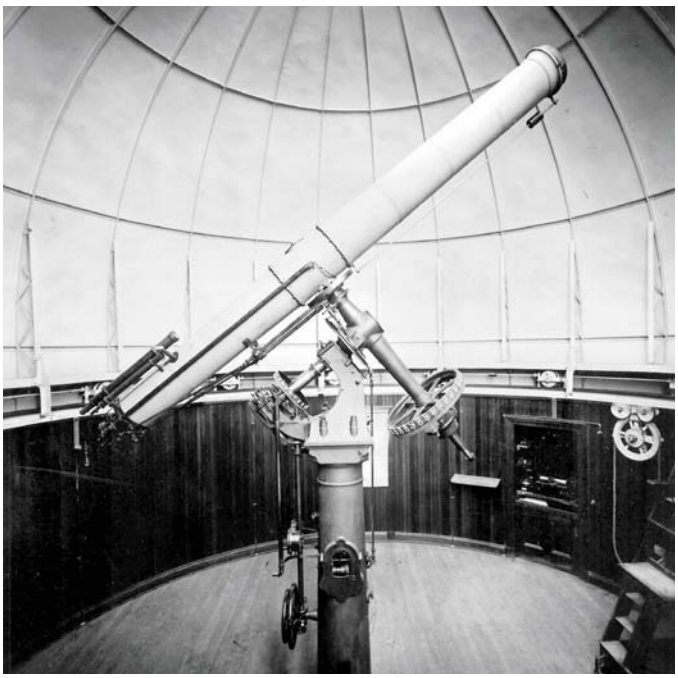
Saegmuller was born on February 12, 1847, in Neustadt, Germany. Trained as a mechanical engineer, he moved to York, England, to work for T. Cooke & Sons, maker of scientific instruments, including clocks and telescopes. Saegmuller then returned to Germany for mandatory military service, after which, in 1870, the 23-year-old immigrated to the United States and settled in Washington, DC. He soon took a position in a workshop that made equipment for the Coast Survey, a maker of nautical charts.

A Good Start

While working for the Coast Survey, Saegmuller met Camill Fauth, another German immigrant, with whom he'd later form Fauth & Company. After Fauth moved back to Germany in 1890,



▲ **CATALOG SHOPPING** This engraving from Saegmuller's 1892 catalog shows the Catholic University of America's 9-inch refractor. That same catalog listed the price of a 9-inch refractor as $2,800 to $3,250, though it's not clear if that figure included the objective lens.



▲ **NAVY GAZING** The U.S. Naval Observatory's 12-inch refractor is shown here as it appeared in 1895, three years after its completion. This is the only large Saegmuller refractor that didn't have its clock drive located in a glass enclosure at the top of the pier.

▲ **CLACEY OPTICS** This 1948 photograph shows Georgetown University's 12-inch instrument, which notably bears an f/13.5 objective lens figured by John Clacey. The observatory's director, Father Francis Heyden, poses at the controls of the telescope.

CATHOLIC UNIVERSITY REFRACTOR: CATHOLIC UNIVERSITY LIBRARY; USNO REFRACTOR: RICH SCHMIDT / U.S. NAVAL OBSERVATORY LIBRARY; GEORGETOWN REFRACTOR: COURTESY GEORGETOWN UNIV. LIBRARY

Saegmuller took control of the company and began making large refractor telescopes.

In my research, I inventoried a total of nine Saegmuller refractors with objective lenses 9 inches in diameter or larger. Remarkably, eight of these were built between 1890 and 1897 — a span of just eight years. Since most large telescopes from this era are referred to either by the observatory that housed them or by the maker of the objective lens, my list may not be complete. Regardless, I've been able to verify that Saegmuller indeed built all the instruments described in this article.

A FRIEND IN A HIGH PLACE While director of the Georgetown Observatory, Father John Hagen helped acquire Saegmuller telescopes for the facility as well as for Jesuit colleges in the Netherlands and the Philippines. This photo was taken in 1914 when he served as director of the Vatican Observatory.

Early Instruments

In 1890 Saegmuller built his first large refractor, for the Catholic University of America in Washington, DC. The 9-inch objective was produced by local optician John Clacey, who would subsequently make objectives for several Saegmuller telescopes. Clacey specialized in lenses with focal ratios somewhat shorter than what was typical at the time. This yielded a significant advantage since a telescope fitted with a short-focus objective can fit into a smaller dome, thus reducing the overall cost of the observatory. The clock drive for this instrument's mount sat in a windowed cube structure situated between the pier and the support for the right ascension axis. This distinctive configuration was common to nearly all of Saegmuller's mounts.

The next three refractors that Saegmuller built utilized 12-inch objective lenses. One went to the Ladd Observatory at Brown University in Providence, Rhode Island, the other two to the U.S. Naval Observatory and to Georgetown University, both in Washington, DC.

All three telescopes featured Saegmuller's patented "hand wheels" for slewing in both right ascension and declination. Because electric motors were not yet available, these controls were purely mechanical, utilizing an innovative combination of shafts and gears to link the hand wheels to the axes of motion. One particular challenge was the linkage for the declination control, which had to pass through the center of the right ascension axis without being affected by its rotation. The hand wheels made controlling the aim of the telescopes much easier.

DIALING IN THE UNIVERSE Two defining characteristics of a Saegmuller mount are its star dials and hand controls, both visible in the author's 1986 photo of the newly restored Georgetown University refractor.

Two conflicting anecdotes surround Clacey's role in the Georgetown University instrument. The first purports that Clacey provided an f/13.5 lens because the Clarks declined to make one with a focal ratio lower than f/15. This would have been a problem, because the telescope was to be housed in an existing dome that was too small to accommodate such a long optical tube. The second story holds that originally the Clarks supplied the objective, but it was found to be of poor quality and so Clacey had to rework it.

Both the Naval Observatory and Georgetown instruments featured innovative "star dials" (also called "finder circles") that were mounted on the side of the pier and conveniently displayed the right ascension and declination position of the telescope. Although there's been some debate as to who conceived the idea, the star dials wouldn't have been feasible without the linkages that Saegmuller used for the mount's hand wheels.

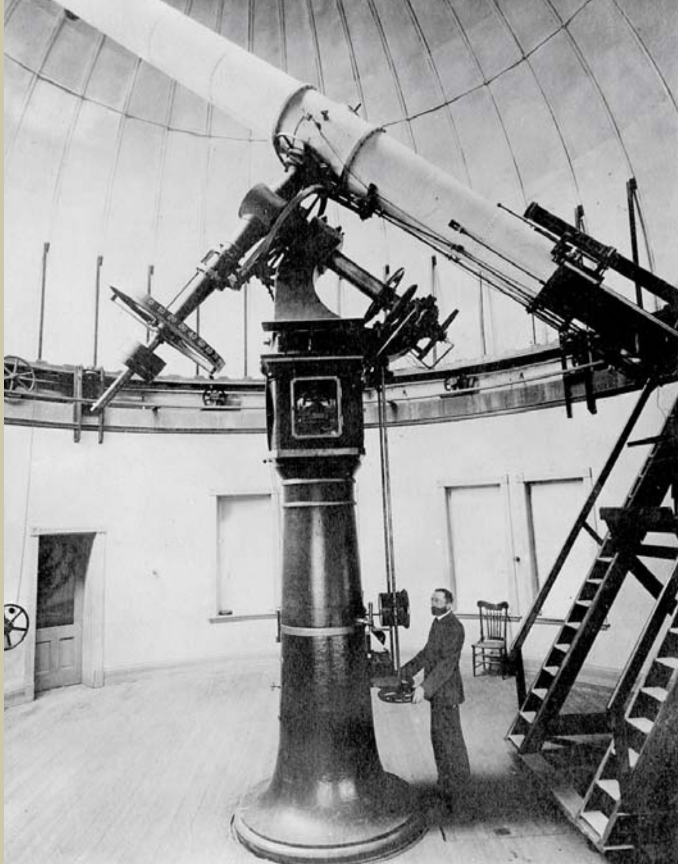
Going Big and Going Abroad

The two refractors that Saegmuller built next were also his largest. He designed them for the Chamberlin Observatory in Denver, Colorado, and the Manila Observatory in the Philippines. Saegmuller always considered the Chamberlin scope, which employed a 20-inch Clark objective, to be a financial failure as payment came in the form of land in the Denver area. Unfortunately, the lots awarded to Saegmuller lay in a poor section of town, so even as their value didn't increase, he had to pay taxes on them.

Work on the Georgetown instrument brought Saegmuller into contact with Father John G. Hagen, director of the university's observatory. Hagen played an important role in acquiring Saegmuller refractors for other Jesuit observatories, including the Manila Observatory's 19-inch refractor. Not long after the telescope was installed, it survived the Battle of Manila Bay in 1898, shortly after the outbreak of the Spanish-American War.

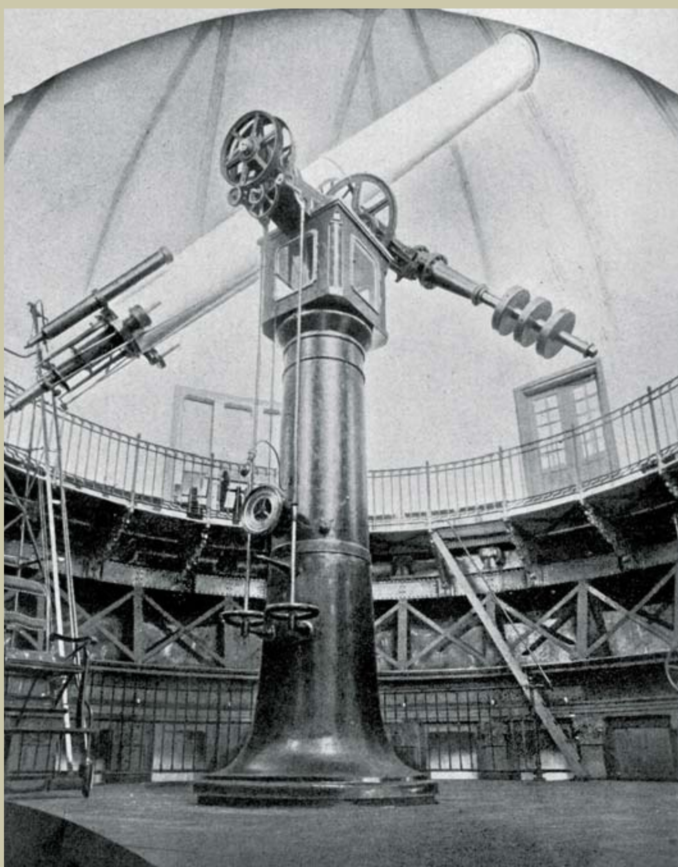
Saegmuller next produced two refractors with 9-inch objectives. Unlike his previous instruments, which had

GEORGETOWN REFRACTOR: TED RAFFERTY; FATHER JOHN HAGEN: COURTESY GEORGETOWN UNIVERSITY LIBRARY



▲ **DENVER DOME** The front end of the Chamberlin Observatory's 20-inch Saegmuller refractor appears here through the slit of the dome. The facility was renovated in 2008 and is still in use today.

◀ **SCOPE CONTROL** Professor Herbert Howe operates the hand wheels that control the Chamberlin 20-inch telescope in this period photograph. The star dials that display the right ascension and declination pointing of the telescope are mounted at eye level.

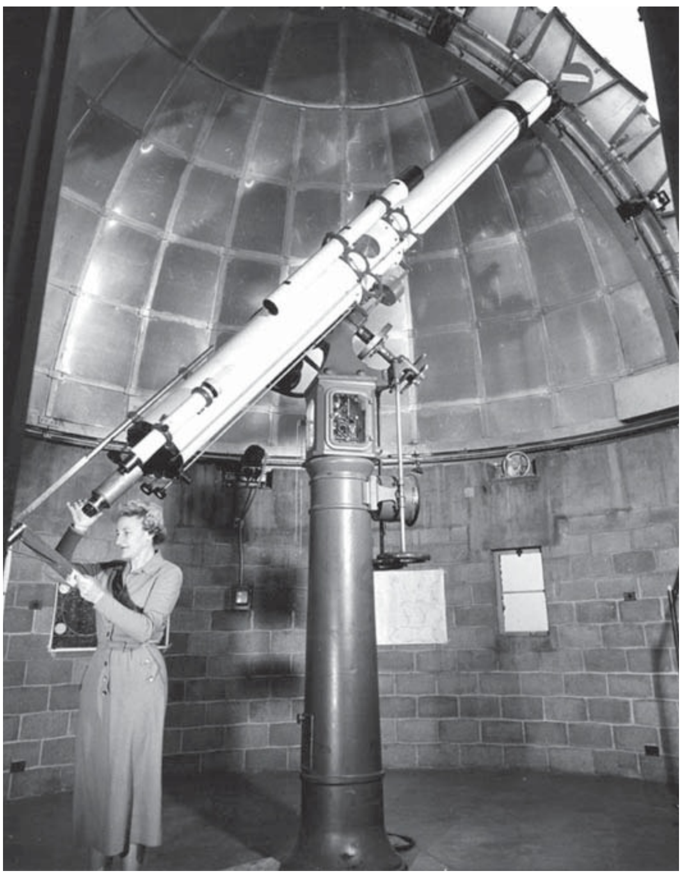


▲ **STAR-CROSSED TELESCOPE** This 1915 photo of the Manila Observatory's 19-inch Saegmuller refractor originally appeared in *Historia del Observatorio de Manila*, by Miguel Saderra Masó. The telescope was destroyed in World War II when the observatory (shown at right) was burned by Japanese soldiers and then later bombed by American forces.

CHAMBERLIN SCOPE: COURTESY UNIVERSITY OF DENVER SPECIAL COLLECTIONS AND ARCHIVES; CHAMBERLIN DOME: DENVER LIBRARY DIGITAL COLLECTIONS; MANILA SCOPE: MIGUEL S. MASÓ / HISTORIA DEL OBSERVATORIO DE MANILA; MANILA DOME: NATIONAL ARCHIVES, WASHINGTON, DC

▲ **ABANDONED PIER** The original pier of the Valkenburg aan de Geul 9-inch refractor is visible near the center of this 2013 photo. The German army abandoned the Jesuit college toward the end of World War II, and the buildings are now deserted.

▼ **ONE LAST SCOPE** Saegmuller's final big refractor was originally housed in an observatory at the top of the Bausch & Lomb building in Rochester, New York. The 10.5-inch instrument appears here at its second home, the Sommers-Bausch Observatory at the University of Colorado in Boulder. (At the eyepiece is Dorothy Trotter, the facility's first manager.) Sadly, the instrument is no longer in use.



mounts designed for specific locations, these featured adjustments to work over a range of latitudes. One was destined for the observatory of wealthy businessman Charles Ezra Hequembourg of Dunkirk, New York. His telescope sat atop a 45-foot-tall pier in a dome near his home. The objective had a focal length of 117 inches, making it f/13, though I wasn't able to discover who supplied the lens. The low focal ratio, however, suggests it might have been the work of Clacey. After Hequembourg's death in 1907, his widow sold the telescope in 1914 to Elmer Harrold of Leetonia, Ohio. In 1923, Harrold donated the telescope to Mount Union College, in Alliance, Ohio, where it was set up in the Clarke Observatory.

The other 9-inch Saegmuller refractor went to the Jesuit Saint Ignatius College in Valkenburg aan de Geul, the Netherlands. Hagen once again played a role, this time by arranging for the instrument to be imported for free and overseeing its installation.

After Saegmuller completed the last of these eight instruments in 1897, he didn't build another large refractor for 15 years. It isn't clear why this is, but it may have been due to a shortage of skilled workers. In his autobiography, Saegmuller states that it was difficult to keep good machinists. Once he'd trained them, they would leave for better-paying government jobs. He may have simply concluded that building telescopes was not profitable.

In 1904, Saegmuller merged his operations with those of Bausch & Lomb of New York. At the time, the German instrument company Carl Zeiss Jena wanted to sell gun sights to the U.S. Navy but was unable to do so since Saegmuller had cornered that market. Ultimately, Zeiss joined with Bausch & Lomb in 1908, and the company's name was changed to the Bausch & Lomb Optical Company, using the "Triple Alliance" logo that listed Bausch & Lomb, Zeiss, and Saegmuller. (Zeiss had to leave the alliance in 1915 when Germany and the Allies went to war.)

In 1912 Saegmuller built his final large refractor. Featuring a 10.5-inch objective made by Carl Zeiss Jena, in Germany, the instrument was installed in an observatory at the top of the Bausch & Lomb building in Rochester, New York. After retiring from Bausch & Lomb in 1924 at the age of 77, Saegmuller moved to Arlington, Virginia, where he died on his 87th birthday on February 12, 1934.

Where Are They Now?

Of Saegmuller's nine large refractor telescopes, two did not survive. A fire on Halloween night in 1924 destroyed the 9-inch instrument built for the Catholic University of America. The 19-inch refractor at the Manila Observatory in the Philippines suffered a similar fate but in a much more dramatic and violent episode.

During World War II, the Japanese occupied Manila, and on February 9, 1945, after it became clear that they would be unable to hold the city against advancing American forces, Japanese soldiers used straw and gasoline to set fire to the observatory, including the dome of the 19-inch refractor. As

OBSERVATORY REMAINS: COURTESY MARCO DELNOIJ; DOROTHY TROTTER AT SCOPE: SOMMERS-BAUSCH OBSERVATORY

Saegmuller's Large Refractors

Original Location	Year	Objective Lens (and Maker)
Catholic University of America, Washington, DC	1890	9-inch f/12 (John Clacey)
Ladd Observatory, Brown University, Rhode Island	1891	12-inch f/15 (Brashear)
U.S. Naval Observatory, Washington, DC	1892	12-inch f/15 (Alvan Clark & Sons)
Georgetown University, Washington, DC	1893	12-inch f/13.5 (John Clacey)
Chamberlin Observatory, Denver, Colorado	1894	20-inch f/15 (Alvan Clark & Sons)
Manila Observatory, Manila, the Philippines	1895	19-inch f/14 (Jakob & Matthias Merz)
Jesuit Saint Ignatius College, Valkenburg aan de Geul, the Netherlands	1896	9-inch f/12 (John Clacey)
Home of Charles E. Hequembourg, Dunkirk, New York	1897	9-inch f/13 (optician unknown)
Bausch & Lomb Observatory, Rochester, New York	1912	10.5-inch f/15.5 (Zeiss)

if that wasn't bad enough, the Americans bombed the facility five days later.

After the Battle of Manila, Victor Blanco, a meteorologist with the U.S. Army (who later became director of the Cerro Tololo Inter-American Observatory in La Serena, Chile), visited the damaged observatory. His encounter with the remains of the 19-inch appears in part at the beginning of this article. The melted objective lens, as Blanco evocatively wrote, ". . . looked like a huge tear drop."

War also played a role in the story of another Saegmuller telescope. During World War II, the German army occupied Valkenburg aan de Geul, home to the Jesuit college's 9-inch refractor. The Germans used the college as a *Reichsschule* — an elite school for educating young men selected to be future leaders of the Third Reich.

After the war, the telescope was assumed to have either been destroyed or taken by the Germans. What the Jesuits didn't know was that in September 1944, with the Allied Forces advancing and the Germans retreating, the town's people dismantled most of the telescope (leaving the pier behind) and hid it in a seminary in the nearby city of Maastricht. The telescope lay there forgotten until it was rediscovered in the 1970s. The instrument was then moved to the Limburg Observatory in Heerlen, in the southeast of the Netherlands. There it was refurbished, minus the original pier, which remains to this day in the deserted dome at Valkenburg aan de Geul.

The other six Saegmuller refractors fared better, and all but one remains operational. Currently out of commission is the 10.5-inch that Saegmuller built for the Bausch & Lomb building in Rochester. In 1941 the telescope was moved to the Sommers-Bausch Observatory at the University of Colorado in Boulder, where it remained in service until 1971. After that, the Zeiss objective was removed for use in a solar telescope, and the rest of the instrument was put on display in the lobby of the university's Fiske Planetarium. In 2013 the telescope went into storage, awaiting the day when the University of Colorado Heritage Museum will display it again.

Charles Hequembourg's refractor is now at Mount Union College in Alliance, Ohio, sporting a new 8.5-inch objective lens. The 12-inch built for the Ladd Observatory remains at its original location, having been refurbished in 2012.

The U.S. Naval Observatory refractor has been significantly modified and, unfortunately, its hand wheels and star dials are long lost. The refractor was relocated to another dome in the 1950s to make room for another telescope and suffered the same fate yet again some years later. From there, the refractor was placed into storage until the late 1970s, when observatory staff refurbished it and returned to its original location.

After the astronomy department at Georgetown University was closed in 1972, students formed the Georgetown Astronomical Society to oversee the use of the facility's 12-inch Saegmuller telescope. This instrument's hand wheels and star dials remain in working order, though the dome has some problems.

The 20-inch refractor at the Chamberlin Observatory in Denver underwent restoration between 2011 and 2014 to correct an accumulation of damage. You can watch a video showing how easily the large telescope moves with the hand wheels at **https://is.gd/Chamberlin**.

Although Saegmuller produced observatory refractors for only a short time, his innovative mounts resulted in telescopes that were much easier to use compared to similar instruments of the era. Despite the ravages of time, 120 years later six of Saegmuller's large refractors remain in use today — a testament to his engineering and manufacturing skills.

TED RAFFERTY is a retired U.S. Naval Observatory astronomer. He participated in the restoration of two 12-inch Saegmuller refractors — one at his home institute, the other at Georgetown University.

An unearthly kind of eruption launches plumes and builds mysterious mountains on worlds throughout the outer solar system.

Cryovolcanism is a geological process that is unfamiliar to many, because it has no analog on Earth. When most of us think of volcanism, we think of a mechanism that brings molten rock from the interior to the surface. We see past or present evidence of this type of volcanism on Earth and several other terrestrial bodies, including Jupiter's active moon Io. Cryovolcanism is similar, as it also brings magma from the interior of a body to the surface. However, in this case the magma is mostly water, and the surface of the body is not rock but ice.

Thanks to observations from several spacecraft, we now suspect that this alien form of volcanism may in fact occur on many worlds in the outer solar system. Out there, far from our star, lie moons and Kuiper Belt objects with large fractions of water and other volatile compounds that are frozen solid at the temperatures of these bodies' icy surfaces. But with the right combination of conditions, water deep inside may erupt in a slushy or even geyser-like event.

Still, even with decades of data and hypothesis, we haven't quite figured out how the process works.

The Voyager Discoveries

We've only known about cryovolcanism for 40-some years, since the Voyager spacecraft took their Grand Tour of the outer solar system. When Voyager 1 flew past Jupiter's moon Io in 1979, it made one of the most exciting discoveries in planetary geology: Io has active volcanoes and volcanic plumes (*S&T:* July 2020, p. 14). But Voyager 1 also flew past Europa, finding there an intriguing and mysterious landscape. Europa looked very bright, which implies a fresh, icy surface — hardly what we expected on a moon several billion years old. Voyager 2, flying by Europa a few months later and about four times closer than Voyager 1, showed that the surface was indeed strange: smooth, bright, and with few impact craters, but also etched with long linear features, making it look like a cracked egg.

There was much speculation among the scientists on the Voyager team about what was causing the cracks. They knew that the tidal forces that cause Io to be volcanically active are also at work on Europa, though to a smaller extent. Such tidal forces would knead the moon's icy interior, heating and melting it. The process might even create a subsurface ocean.

The discovery of crisscrossing bands of cracks with diffuse dark edges also led researchers to suggest gases and soft ice were erupting from the interior, causing the crust to expand away from these fissures much like what we see happening at the Mid-Atlantic Ridge on Earth. The idea that Europa had a

NASA / JPL-CALTECH

Ice Volcano

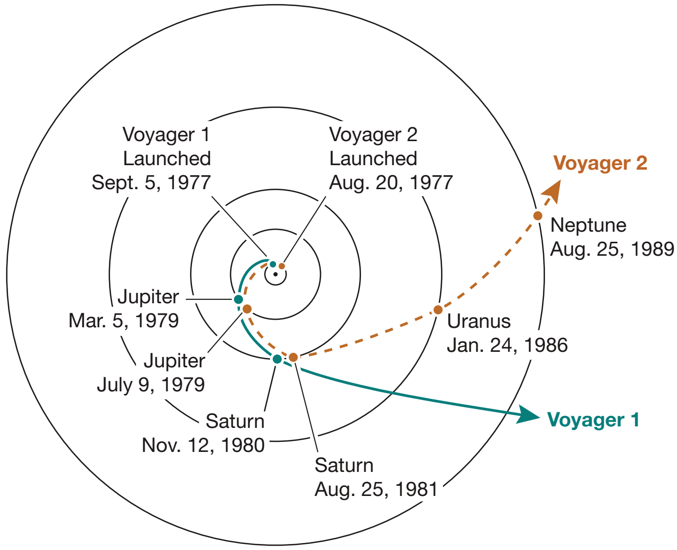
liquid ocean under an icy crust began to gain acceptance.

But scientists couldn't verify another, even more surprising claim by Voyager team member Allan Cook, who thought he saw a geyser-like bright spot in one image that extended beyond Europa's limb. It would be many years before we found convincing evidence of water plumes on Europa, and none at the exact location that Cook proposed.

As Voyager scientists continued to discuss what causes Europa's bright surface and cracks, the twin spacecraft continued their journey to more distant worlds. In 1980 and 1981, they flew by Saturn and its tiny moon Enceladus. Neither Voyager obtained images of Enceladus's south pole, which, as Cassini would find in the mid-2000s, has active jets of water spewing out from the interior. However, the Voyager images showed that parts of the moon were very smooth, crater-free, and appeared to have melted and refrozen.

The oddest thing about Enceladus was the tiny moon's brightness: Even the more cratered regions were sparkling bright. The brilliance implied that the entire surface was covered by very "clean" (dust-free) ice, likely snow. Planetary scientist Kevin Pang and his collaborators even went so far as to suggest that Enceladus had erupting ice volcanoes — which was, frankly, a hard sell. Around the same time Bonnie Buratti suggested that bright particles from Enceladus were launching into space and coating other moons of Saturn, in a process Anne Verbiscer later called a "cosmic graffiti artist caught in the act." Cassini's observations would later prove these ideas correct.

GREGG DINDERMAN / *S&T*



▲ **THE GRAND TOUR** The Voyager spacecraft took advantage of a fortuitous planetary configuration to visit the giant planets, using gravitational assists to speed them on their way. The planetary alignment occurs once every 175 years or so.

As Voyager 2 continued its journey to Uranus and Neptune, scientists spotted signs of cryovolcanism on several moons. Uranus's Ariel, for example, had smooth areas and features that appeared to be the rounded edges of thick, sluggish flows, similar to spilled pudding. But the final surprise came in 1989 as Voyager 2 flew by Neptune's largest moon, Triton, thought to be a Kuiper Belt object captured into Neptune's orbit. Images showed a dark plume rising up to 8 km (5 mi) over the surface and forming long streaks in Triton's rapidly moving troposphere.

The Voyager team finally had confirmation of plumes erupting from an icy moon.

DIVING THROUGH Artist's illustration of the Cassini spacecraft flying through a plume shooting from Saturn's moon Enceladus. Jets from the moon's south pole regularly eject clouds of salty water.

How Does Cryovolcanism Work?

Although we still don't entirely understand how cryovolcanism works, we can agree on what it is, at least in general form.

We have reason to think that the solid icy bodies of the outer solar system have rocky interiors, hidden beneath substantial outer layers of liquid water and ices. Europa, Enceladus, and several other moons have entire oceans under their crusts. Other compounds mix with the ices, such as ammonia and methane, in ratios that depend on where in the solar system's natal disk the worlds formed (*S&T:* May 2020, p. 34). If the liquid water or gases within break through and erupt at the icy surface, it is volcanism. To make things less confusing, we refer to the magma as *cryomagma* and, once it erupts at the surface, as *cryolava*.

How does the water get to the surface and erupt? This is the main question in the physics of cryovolcanism, and it's not an easy one to answer. We all know that ice cubes float in a glass of water. Water has unusual thermal and physical properties: It expands when it freezes, and so it is denser in liquid form than in its solid state. Unlike with terrestrial volcanism, in which the molten phase of rock is less dense than the solid phase, there is no buoyancy force to initiate cryomagma's ascent and eruption — it should sink in the surrounding ice. This means that some specific conditions must be present to make ascent and eruption possible. These differ depending on the exact composition of the cryomagma on each body, which we don't know.

However, generally speaking, some compounds dissolved in the cryomagma can increase its buoyancy. Ammonia, for example, would decrease the density contrast between the liquid water and ice, though not enough to make the water erupt. Additional impurities in the water, such as methane and carbon dioxide, would help, particularly if the liquid is decompressed and bubbles form. The fluid would then become less dense than the surrounding ice and tend to rise.

Another option is to make the ice denser. If the ice shell contains silicate grains or salts, it would be denser than expected. One possibility is that falling meteorites could gradually build up on the icy surface and increase the ice shell's density.

Conversely, instead of changing the density of the cryomagma or of the surface, increasing the *pressure* of the liquid might drive it up and out. If the ocean under the ice shell progressively freezes, thickening the overlying crust, the volume change caused by going from liquid to solid state would cause the ice crust to expand and squeeze the remaining ocean into a smaller and smaller space. The expansion would not only pressurize the ocean but also lead to stresses that might fracture the ice shell, providing pathways to the surface. Tectonic features on several icy moons such as Tethys and Dione may be these scars from global expansion, caused by the freezing of their oceans.

RUPTURED MOONS

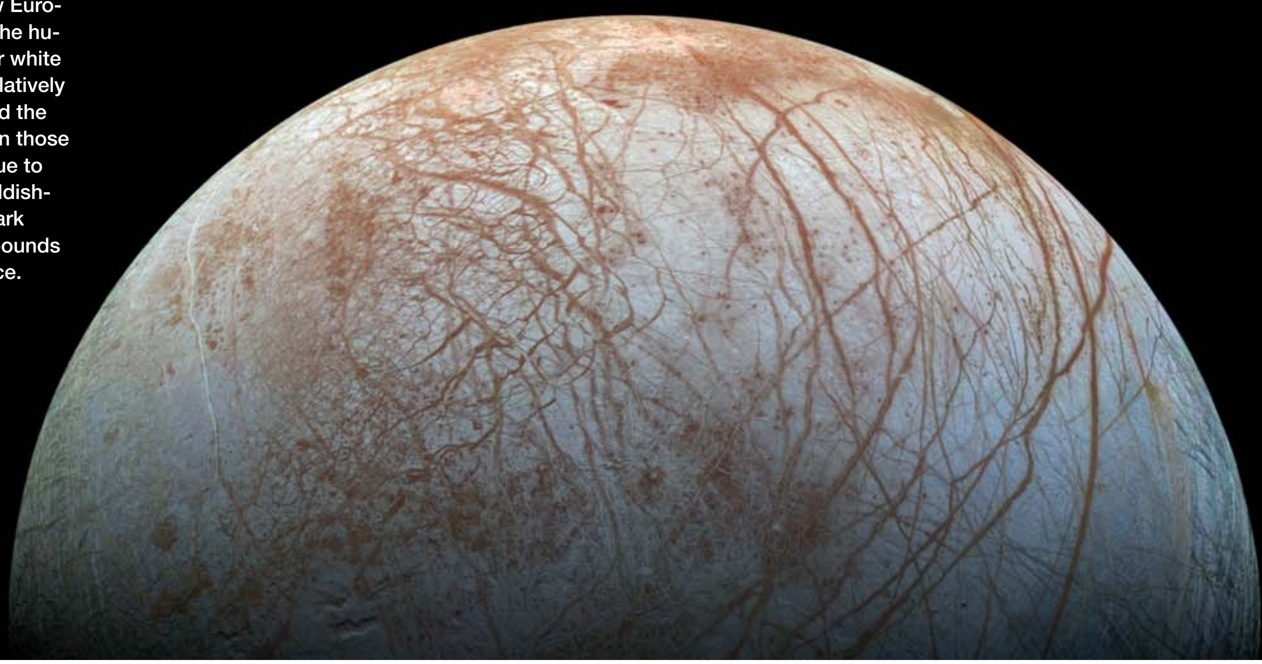
Canyons scar several of Uranus's major moons. The rupturing indicates the moons have expanded 1% to 2% in volume since their formation as they've slowly frozen — except for Miranda, which may have expanded 6%. Miranda's most fantastic canyons stretch 80 km wide and plunge 15 km deep.

Icy Plumes

Every mission has a surprise that eclipses all others. In the case of Cassini, it was the discovery of active plumes emanating from the south polar regions of Enceladus. Enceladus is now the poster child for cryovolcanism in the outer solar system, its geyser-like jets seen in images and even detected by flying through them.

I was very lucky to be working on the Cassini mission and to watch this amazing discovery unfold. It was not a single "wow" moment. The plumes revealed themselves slowly, with hints in the magnetometer data in early 2005. Enceladus and its fellow small moons travel through Saturn's magnetic field as they orbit, and they should do so with minimal disturbance to the field. But the instrument saw that Saturn's

NASA / JPL-CALTECH / SETI INSTITUTE



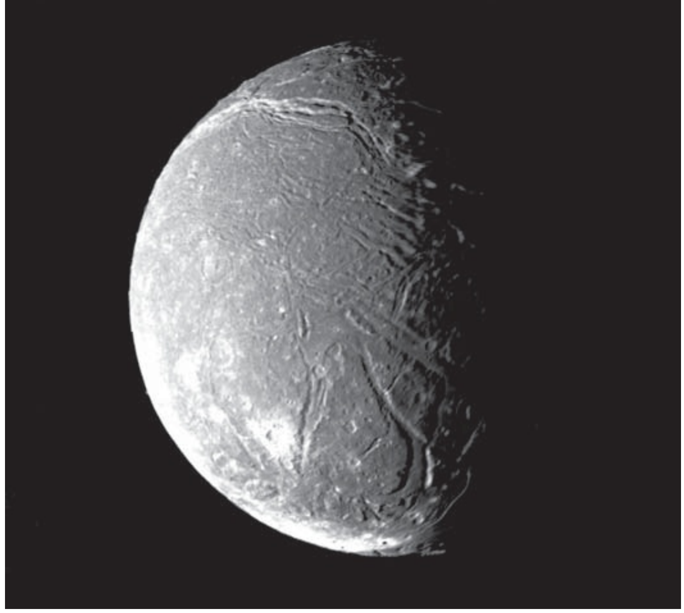
EUROPA This mosaic approximates how Europa would look to the human eye. Bluish or white regions contain relatively pure water ice, and the difference between those colors might be due to ice grain size. Reddish-brown features mark where other compounds contaminate the ice.

magnetic field drapes around the southern polar region of Enceladus, as though "something" there acts like a barrier to the smooth flow. We also saw signs of what seemed to be a thin atmosphere. There was something there, but we needed a closer look.

In July 2005, the incomparable JPL navigation team took us less than 170 km over the surface. A few days after that daring flyby, John Spencer from the Composite Infrared Spectrometer team found that the south polar region of Enceladus was much warmer than expected. We'd finally found clear evidence for active cryovolcanism.

Images from the camera provided the linchpin: spectacular views of geyser-like jets coming out of fractures near the south pole that we had earlier nicknamed *tiger stripes*. We now know that roughly 200 kg of water vapor spews forth each second from the plumes, carrying ice grains and salts such as sodium and chlorine. Individual jets appear to turn on and off, sometimes in only a few months. We suspect that small cracks within the tiger stripes open and close over time, controlled by a combination of tidal forces and ice building up to clog fissures as Enceladus loops around Saturn. Although we don't know how permanent the plumes are, the tiger stripes have likely been active for at least thousands of years.

The salts tell us that the Enceladus plumes are coming directly from a subsurface ocean, where water interacts with rocks. This is exciting because it means that we can directly sample the ocean from space. Enceladus is also spewing out grains that contain organic compounds such as methane and ammonia, and we see chemical signs of hydrothermal activity on the moon's ocean floor. On Earth, deep-ocean hydrothermal vents are teeming with life (*S&T:* Jan. 2020, p. 34). Water, heat, and organics are all essential ingredients for life as we know it. Thus Enceladus is one of the solar system's top targets in our search for life beyond Earth.



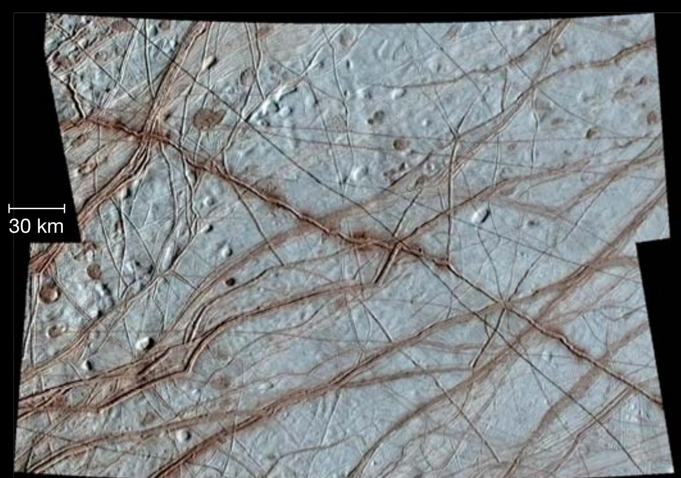
▲ **ARIEL** This mosaic of Uranus's moon Ariel shows a surface criss-crossed by valleys and fault scarps, likely formed as the moon has cooled and expanded. Younger, smoother material has partially filled in the largest valleys near the terminator.

The other icy moon where (we think) we've detected plumes is Jupiter's Europa. Hubble Space Telescope observations have revealed several potential eruptions of water vapor since 2012, at least one of which appeared to stretch some 200 km high. These putative plumes are transient, infrequent, and so far unpredictable. We think that fractures

MITTEN: NASA / JPL / UNIV. OF ARIZONA; RHADAMANTHYS LINEA: NASA / JPL-CALTECH / UNIV. OF ARIZONA; ARIEL: NASA / JPL

▼ **THE MITTEN** This oddly shaped feature on Europa looks like frozen slush. It's about 90 km across and overlies countless lines and cracks, which may arise from the ice crust expanding or even from tectonic recycling.

▼ **RECENT ACTIVITY?** The blotches along the prominent ridge Rhadamanthys Linea on Europa might be from recent or ongoing cryovolcanic eruptions.

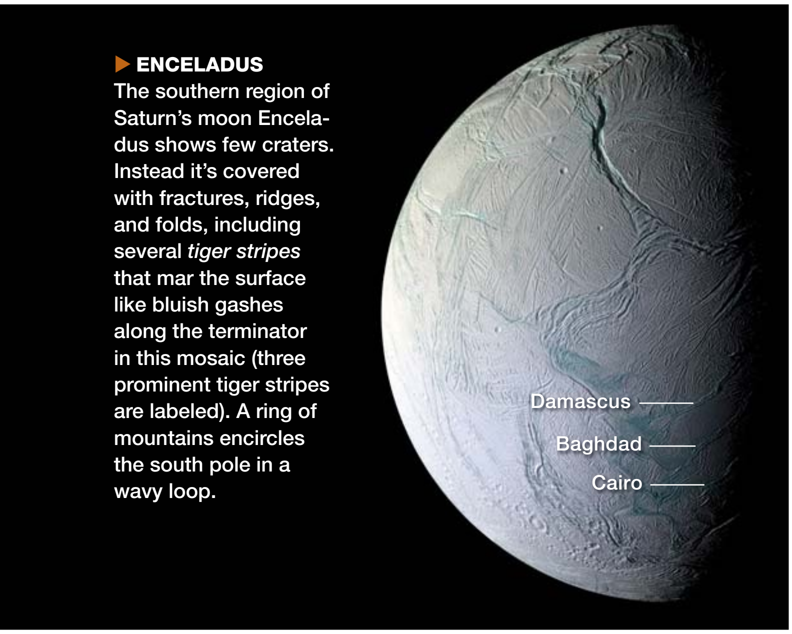


on the moon's surface provide a pathway for liquid to come from the ocean to the surface, although we haven't yet found clear hotspots as we have on Enceladus.

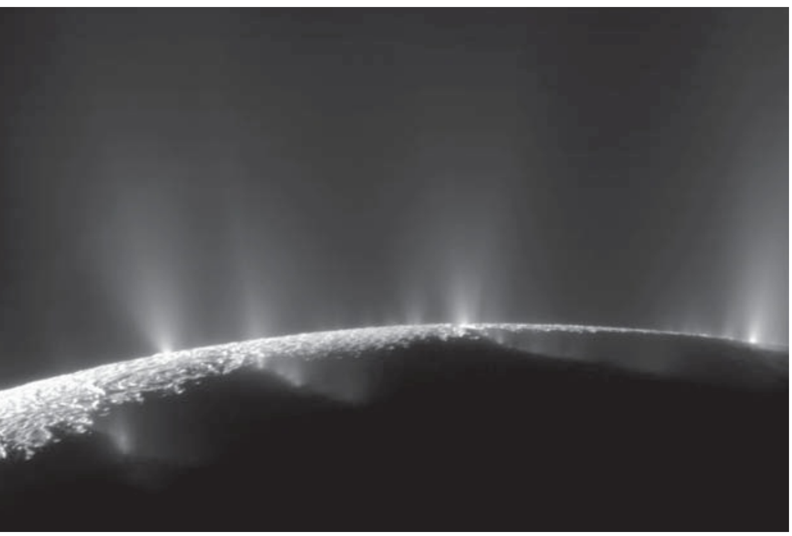
We also see surface signs of eruptions. Some of the giant cracks crisscrossing Europa, such as Rhadamanthys Linea, have uneven blotches of darker, redder material that make them look like beaded necklaces. These blotches may be signs of explosive cryovolcanism. The Europa Clipper mission, expected to launch between 2023 and 2025, will search for plumes and the material they deposit on the surface.

Triton: Still a Mystery

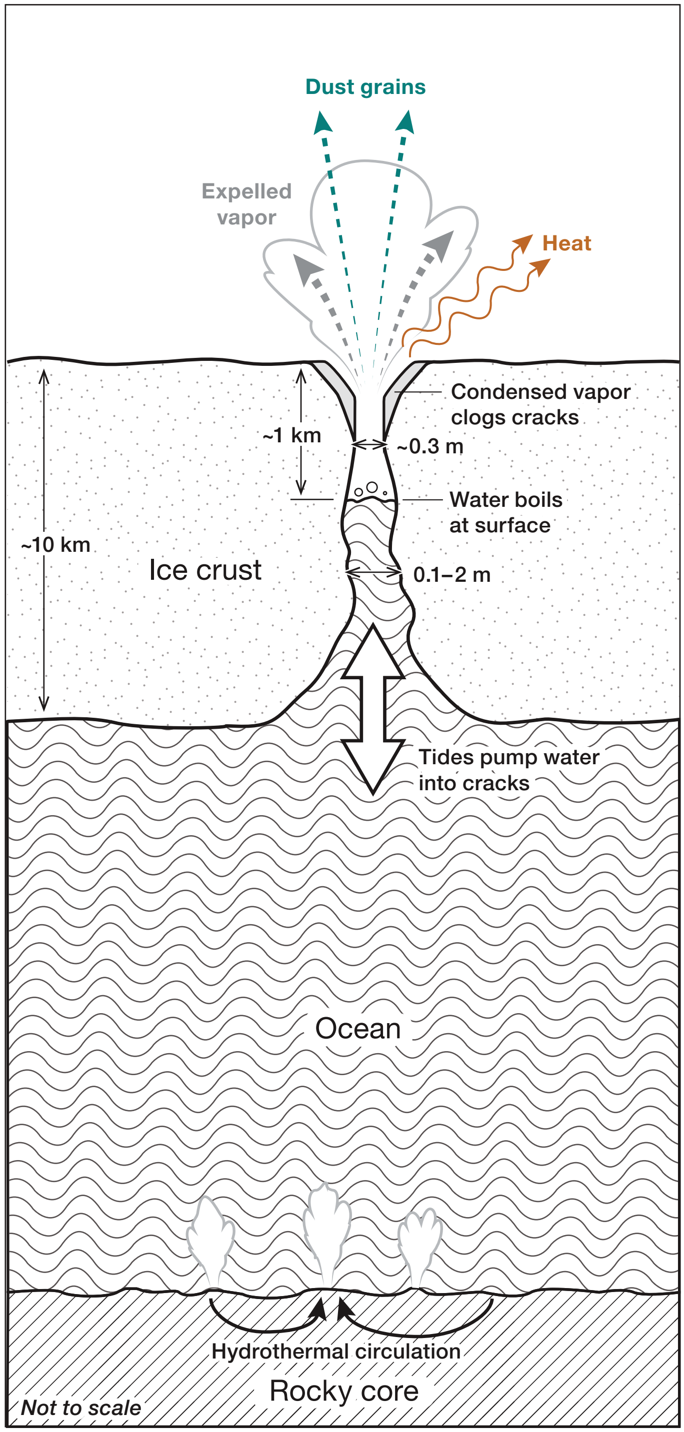
One might think that, since Triton was the first moon where we saw unambiguous plumes, this satellite of Neptune would be our most certain example of cryovolcanism. Voyager 2 detected four plumes rising from Triton's bright southern



▶ **ENCELADUS** The southern region of Saturn's moon Enceladus shows few craters. Instead it's covered with fractures, ridges, and folds, including several *tiger stripes* that mar the surface like bluish gashes along the terminator in this mosaic (three prominent tiger stripes are labeled). A ring of mountains encircles the south pole in a wavy loop.



▲ **PLUMES** Several eruptions of water vapor shoot from Enceladus's tiger stripes in this two-image mosaic. A Cassini survey of this region detected 101 distinct jets.



▶ **TIGER STRIPES** Enceladus's jets spray out of a series of warm cracks near the south pole. Tidal forces open and close the cracks and pump water into them. Over time condensed vapor also freezes and piles up, clogging smaller cracks in the larger fracture features.

NASA / JPL / SPACE SCIENCE INSTITUTE (2); DIAGRAM: GREGG DINDERMAN / *S&T*, SOURCE: J. R. SPENCER ET AL. / *ENCELADUS AND THE ICY MOONS OF SATURN* 2018 polar regions, each associated with dark, fan-shaped deposits on the surface. The spacecraft imaged more than 100 of these fans across the moon.

But we are still debating whether the plumes are a manifestation of cryovolcanism or merely a solar-driven process. The surface of Triton is extremely cold, about 38 Kelvin, and we think a layer of transparent solid molecular nitrogen (N_2) covers the bright southern polar regions. When warmed by sunlight, dark material at the base of the N_2 layer could heat the overlying ice and sublimate some of it, creating a pocket of nitrogen gas trapped just beneath the surface. If enough gas built up, it would become highly pressurized, and the pressure could cause the vapor to erupt through a vent. This "geyser" would also carry some of the underground dark material, which would form the dark streaks seen in the images.

Calculations show that a mere 2 kelvin increase in surface temperature could propel the plumes to the 8-km altitude seen. The fact that Voyager 2 only saw the plumes where the Sun was directly overhead may point to a connection with sunlight, too.

However, it *is* possible that the necessary heat comes from within Triton. Tidal stresses created by Neptune could warm the moon's interior and drive geyser-like activity. If the plumes are driven by internal heat, then they are truly cryovolcanic.

We are unlikely to know which model is right until another spacecraft visits Triton. A mission that arrived before 2040 would be in time to observe southern summer, when sunlight falls most intensely on the bright southern terrain. But the peak heating would lie to the north of where Voyager 2 observed plumes. If activity has followed this *subsolar point*, this would imply that solar heating is indeed responsible. But if the plumes have remained where they were or moved to somewhere far from the impinging sunlight, this would imply that they are driven by internal heat rather than solar activity. Any spacecraft that arrived after 2040 would have to wait for almost a century for the subsolar point to revisit the bright southern terrain.

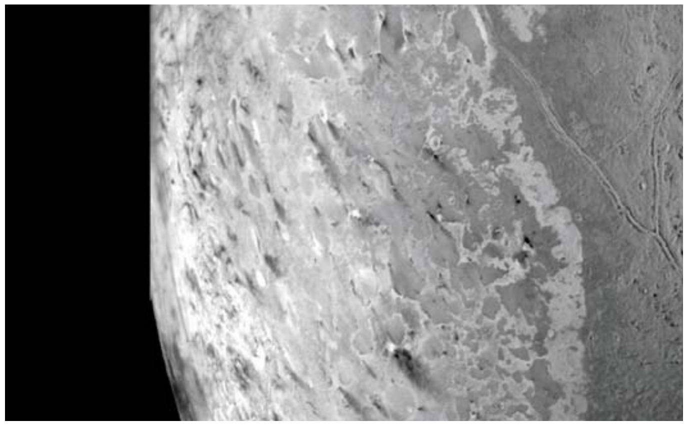
Whatever may be driving the plumes, other terrains do look like they were formed by cryovolcanism. Triton's surface has caldera-like depressions, flows that look like spilled cake batter, chains of pit craters, and the whimsically named *cantaloupe terrain*, which has quasi-circular shallow depressions with slightly raised rims that resemble cantaloupe-melon skin. Thus there is evidence that Triton's internal heat has driven some cryovolcanic activity and, given that Voyager 2 observed few craters, that this activity is geologically recent.

Other Worlds

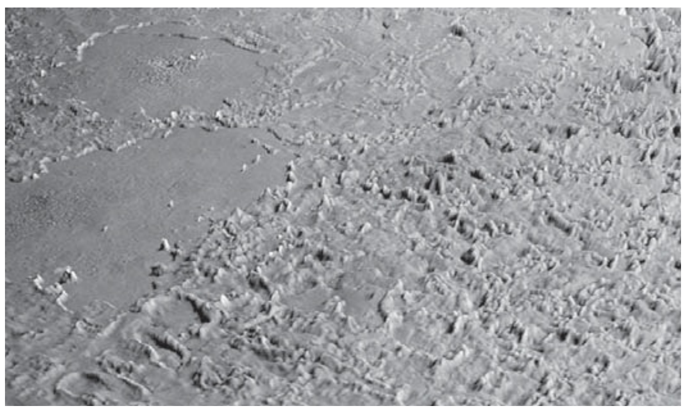
Several other bodies in the solar system show signs that cryovolcanism has happened on their surfaces, but it is hard to prove that features such as smooth plains and rounded flow fronts weren't caused by some other process. We do, however, know of some promising cryovolcano candidates.

Two mountains with large central depressions tower over Pluto's landscape: the "twin" structures Wright Mons and

▲ **TRITON** This mosaic of Voyager 2 images shows the lit southern hemisphere of Neptune's largest moon. Dark streaks are likely debris spread by eruptions of molecular nitrogen gas. A bizarre *cantaloupe terrain* peeks into view near the equator.



▲ **WIND STREAKS** Roughly 50 dark plumes mark Triton's southern region in this image. Southwesterly winds carried the erupted particles and spread them as fan-shaped deposits, which mostly point northeast of their vents.



▲ **CANTALOUPE** This visualization based on Voyager topographic data shows Triton's rugged *cantaloupe terrain* (foreground), with relief exaggerated by a factor of 25 for clarity. The irregular mounds are a few hundred meters tall and look to be rising blobs of ice created as the crust recycles itself.

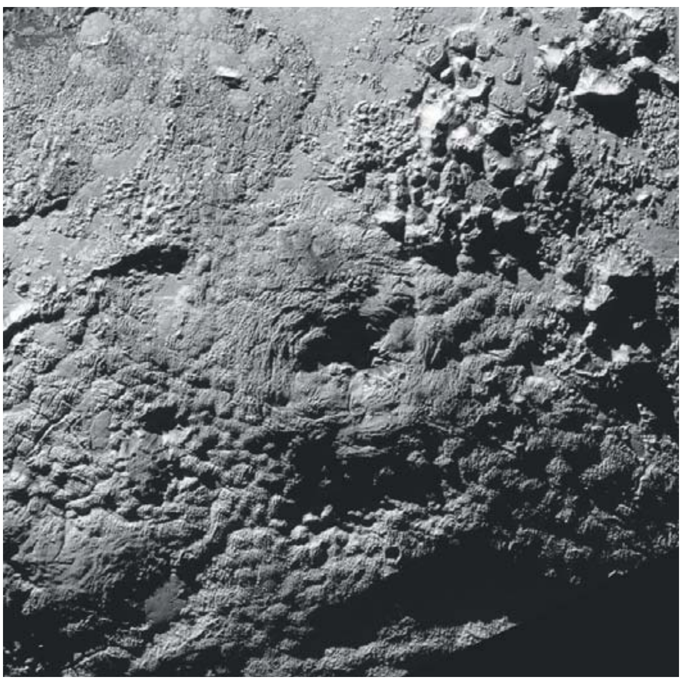
Piccard Mons. Wright Mons is 155 km across and 4 km high, with a pit some 45 km wide on top. Piccard Mons is somewhat larger, but New Horizons was unable to resolve its topography as clearly. Concentric rings surround both mountains' crowning depressions, which could be a sign of collapse after cryomagma erupted. Although the interpretation is still tentative, these two structures are the best candidates for cryovolcanic structures on Pluto.

We know of potential cryovolcanoes on Saturn's moon Titan, too, found thanks to the Cassini spacecraft's radar instrument, which penetrated Titan's smog-like haze to image about half of the surface. The best example is a mountain called Doom Mons, which is more than 1 km high and adjacent to a depression more than 1 km deep called Sotra Patera. Sotra is an irregularly shaped pit rather than a circular depression, making it unlikely that it is an impact crater. Giant features that look like thick flows emerge from Doom Mons and spread over some 200 km. Based on spectra, these candidate cryovolcanic flows and Doom Mons itself both have a different composition than the surrounding regions, which are blanketed by sand dunes. There are even hints that the region could still be active, or at least venting gases from the interior: The Doom Mons area doubled in brightness from 2005 to 2006, possibly due to erupted gas freezing and covering the ground in frost. Unfortunately, Cassini did not detect a thermal glow, so we have no "smoking gun."

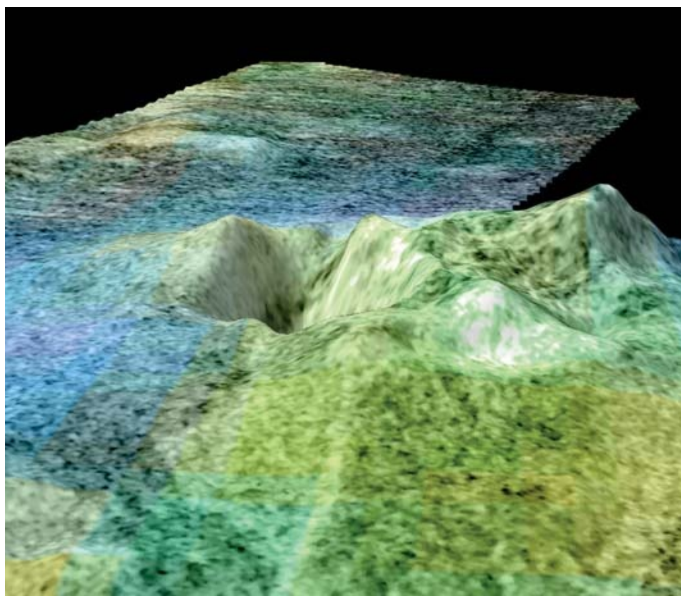
◀ **TETHYS** The vast crater Odysseus (some 450 km wide) mars the bright surface of this icy Saturnian moon. An impact this size could have shattered a solid body. That, combined with the crater's subdued features, suggests the moon was slushy when Odysseus formed.

Several other icy bodies in the solar system show signs that cryovolcanism has occurred there, from Jupiter's Ganymede to Pluto's companion Charon. Even the dwarf planet Ceres in the asteroid belt has a lone mountain, Ahuna Mons, that may have grown to its 4-kilometer height when a giant bubble of muddy, salty water pushed up from below. Although the furthest object ever explored, the Kuiper Belt object Arrokoth, does not show evidence of cryovolcanism, it is possible that larger Kuiper Belt objects such as Eris might. As we keep exploring, we will learn more about this still unfamiliar type of volcanism and how it affects the evolution of surfaces in the far reaches of the solar system.

■ **ROSALY LOPES** is a senior research scientist at NASA's Jet Propulsion Laboratory, Caltech. She was a member of the Galileo and Cassini missions and studies volcanoes on Earth, Io, Titan, and anywhere else she can find them.



▲ **WRIGHT MONS** Just south of Sputnik Planitia on Pluto sits this mountain. The giant depression on its summit appears to reach as deep as the mountain is high — which is on par with Mauna Kea in Hawai'i.



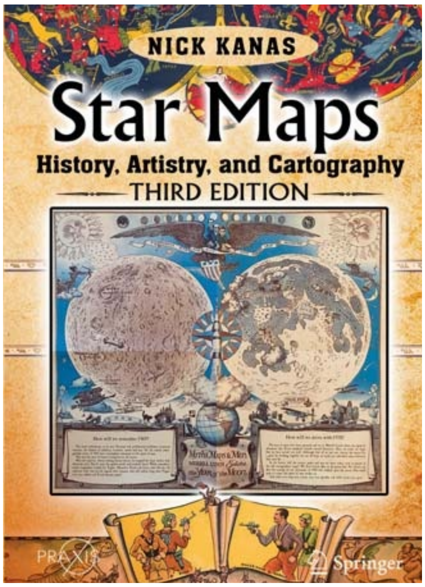
▲ **DOOM MONS** Scientists combined radar and infrared spectrometry data from the Cassini spacecraft to construct this view of the landscape around Titan's Doom Mons and the pit at its side, Sotra Patera. Colors mark different compositions: Blue is the surrounding sand dunes, while the green and yellow regions are covered by material that appears to be cryovolcanic in origin.

TETHYS: NASA / JPL / SPACE SCIENCE INSTITUTE; WRIGHT MONS: NASA / JHU APL / SWRI; DOOM MONS ON TITAN: NASA / JPL-CALTECH / USGS / UNIVERSITY OF ARIZONA

Heavenly Impressions

STAR MAPS: *History, Artistry, and Cartography, Third Edition*

Nick Kanas
Springer Praxis Books, 2019
563 pages, ISBN 978-3-030-13612-3
US $54.99, hardcover.



THE MORE THINGS CHANGE, the more they stay the same. That's what one concludes after delving into Nick Kanas's in-depth investigation into our changing views of the firmament through recorded history. We've come a long way both in cosmology and cosmography since the Sumerians first began scratching constellation names onto clay tablets about 5,000 years ago. But certain basic elements of how we perceive the celestial vault remain remarkably unchanged.

Kanas begins by exploring the cosmological systems of ancient China, Mesopotamia, Egypt, and India. He then dives headlong into the Greek period, during which some of our most enduring conceptions of the cosmos developed. Pythagoras, Kanas notes, is thought to be the first person to have viewed Earth as a sphere. He also saw harmony in the universe. It arose from tones inaudible to the human ear that the Sun and planets emit as they travel along their orbits, Pythagoras thought, and it was inherent in the ratios of their distances from one another, which he deemed similar to the ratios of notes on a musical scale.

Plato also held with a harmonious universe, which he considered charged with intelligence. Later philosophers, including Aristotle and Ptolemy, built on the Platonic system to fashion their own models. These Greek cosmologies persisted well into the early Renaissance. Imagine honing ideas that last more than a thousand years! Ptolemy's c. AD 150 *Almagest* in particular rests on what today we would consider a solid scientific foundation — "a compendium of cosmology," Kanas writes, "that was not only descriptive but . . . empirically derived and mathematically precise."

Heliocentrism altered everything, of course, and Kanas doesn't stint on covering the groundbreaking efforts of Copernicus and his successors, most notably Brahe, Galileo, and Kepler.

But this volume concerns celestial cartography, and it was Johannes Gutenberg who set the stage for the golden age of illustrated star maps in the 17th and 18th centuries. Kanas focuses on what he calls the "Big Four": Johann Bayer (*Uranometria*), Johannes Hevelius (*Firmamentum Sobiescianum*), John Flamsteed (*Atlas Coelestis*), and Johann Bode (*Uranographia*). (Apparently to have had any chance to make the big time, you had to be named John.) *Star Maps* reproduces many richly colored and intricately designed illustrations from the works of the Big Four and their many imitators.

Some cartographers tried to force their own constellations upon us. One sought to give Centaurus and the rest Christian names and depictions. Another placed new creatures into the stars, including a toad, spider, worm, and slug. (The word *zodiac*, like *zoo*, comes from the Greek word for animal, Kanas notes.) Yet another fabricated a constellation he named Gladii Electorales Saxonici. It pictured the crossed swords of the Electors of Saxony as a tribute to the German Emperor Leopold I. Bode himself sought to loft a printing office into the sky: Officina Typographica was meant to honor the 350th anniversary of movable type's invention.

None of these revisions caught on, and in 1922 the IAU put its foot down and settled on 88 official constellations. Of these, no fewer than 48 have survived from Greek or even earlier times, including Taurus, Leo, and Scorpius.

Altogether, you get a real bang for your buck with Kanas's tome. Now in its third edition, the book is well written, thoroughly researched, and beautifully illustrated with 226 images (141 in color) from actual antiquarian books and atlases. It includes extensive bibliographies, an appendix on collecting antique maps and prints, and a glossary where you can brush up on obscure terms for your next game of Bananagrams such as *clepsydra* and *hippopede*. I could have skipped the two new chapters, on pictorial-style maps and celestial images in art; to me these were less captivating, and the book wouldn't have suffered without them.

On the whole, though, *Star Maps* should greatly appeal to amateur astronomers, map collectors, and historians of astronomy and art.

■ Editor in Chief **PETER TYSON** would like to hang a few of the antique star maps this book showcases on his wall.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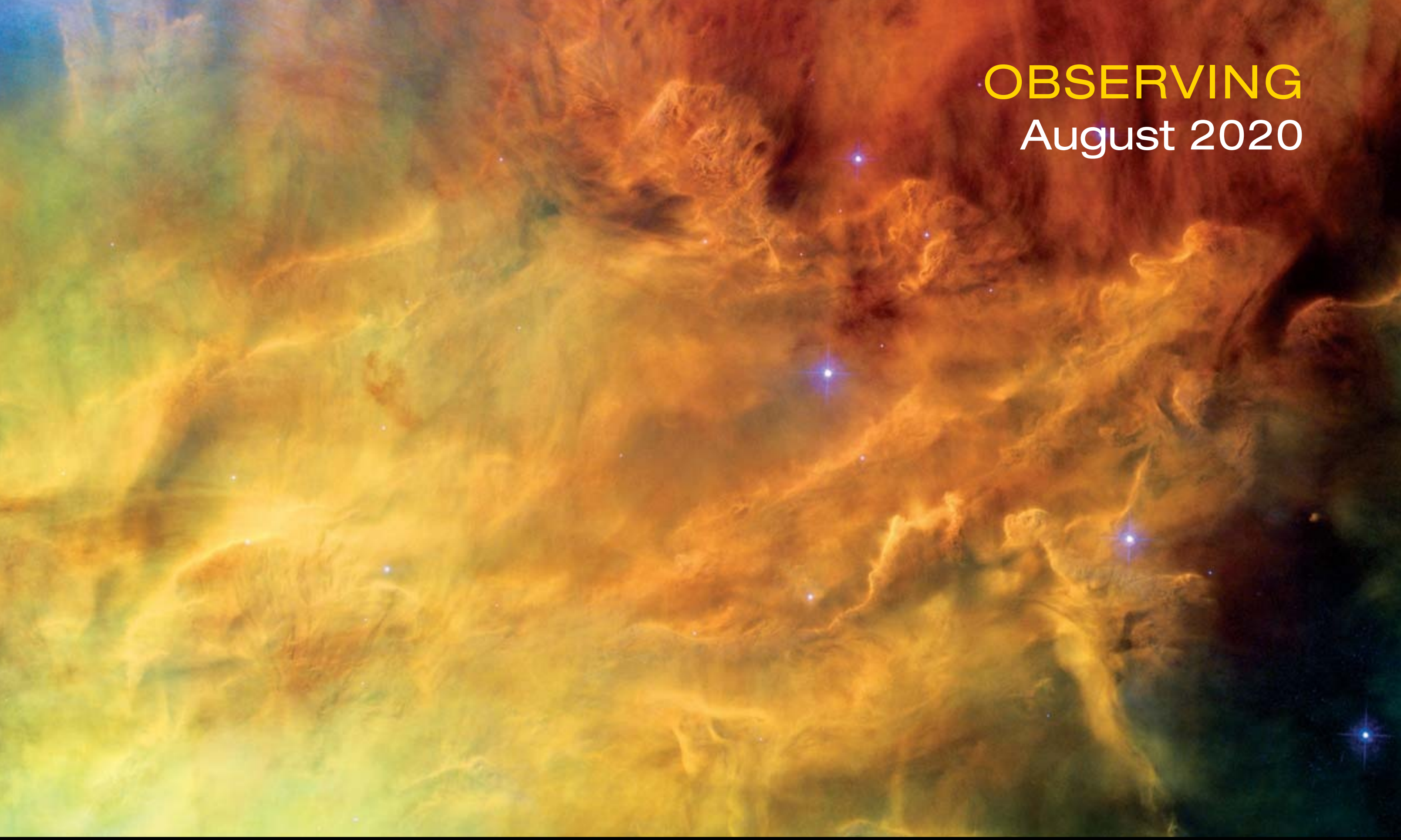


OBSERVING
August 2020

1 DAWN: Kick the month off by finding Venus and Zeta (ζ) Tauri shining less than 2° apart. While you're at it, look lower left of this pair to espy Mercury rising in the east-northeast, shepherded by Pollux to its upper left. The planet and the star remain within 7° of each other the next two mornings.

1 DUSK: The waxing gibbous Moon, Jupiter, and Saturn form a triangle above the southeastern horizon. The following evening, the Moon teases itself away from the gas giants and the three celestial bodies rearrange into a graceful arc.

9 MORNING: Only about 1° separates the waning gibbous Moon from Mars. Catch this sight before the rising Sun washes it away.

11–12 ALL NIGHT: This year's Perseid meteor shower peak coincides with a last-quarter Moon that rises around midnight. But meteors will start appearing earlier in the evening, so head out after sunset. The Perseids are a notoriously long shower, and you should see meteors any time after mid-July and well into the second half of August (see page 48).

13 MORNING: The waning lunar crescent rises in tandem with Aldebaran, the Eye of the Bull, with less than 4° separating the two.

15 DAWN: Look to Gemini, the Twins, to see the slender Moon and Venus lying a little more than 3° apart. Castor and Pollux mirror the Moon and the planet to their lower left.

22 DUSK: Find the waxing crescent Moon slightly more than 5° from Spica, Virgo's brightest star. Watch as the pair sinks toward the horizon in the ever-deepening twilight.

25 DUSK: The first-quarter Moon gleams in Scorpius some 5° to 6° from the smoldering supergiant Antares, the heart of the Scorpion.

27 DUSK: As the Moon pays its second visit to Jupiter and Saturn this month, the three form a line above the southern horizon.

28 DUSK: The waxing gibbous Moon nestles up to Jupiter and hangs some 2° below the gas giant, with Saturn to the pair's left.

29 DUSK: The fattening Moon has leapfrogged over Saturn, and the three orbs now form a graceful arc.
— DIANA HANNIKAINEN

▲ This Hubble image of the Lagoon Nebula (M8) highlights delicate wisps of nebulosity that are colored according to filter used: Light from glowing hydrogen is red, while that from ionized nitrogen is green. On really dark nights you might catch the Lagoon without optical aid near the Teapot asterism in Sagittarius — take your binoculars out for a closer look at this fuzzy patch. (See page 20 for more on this intriguing object.) NASA / ESA

AUGUST 2020 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

FULL MOON
August 3
15:59 UT

LAST QUARTER
August 11
16:45 UT

NEW MOON
August 19
02:42 UT

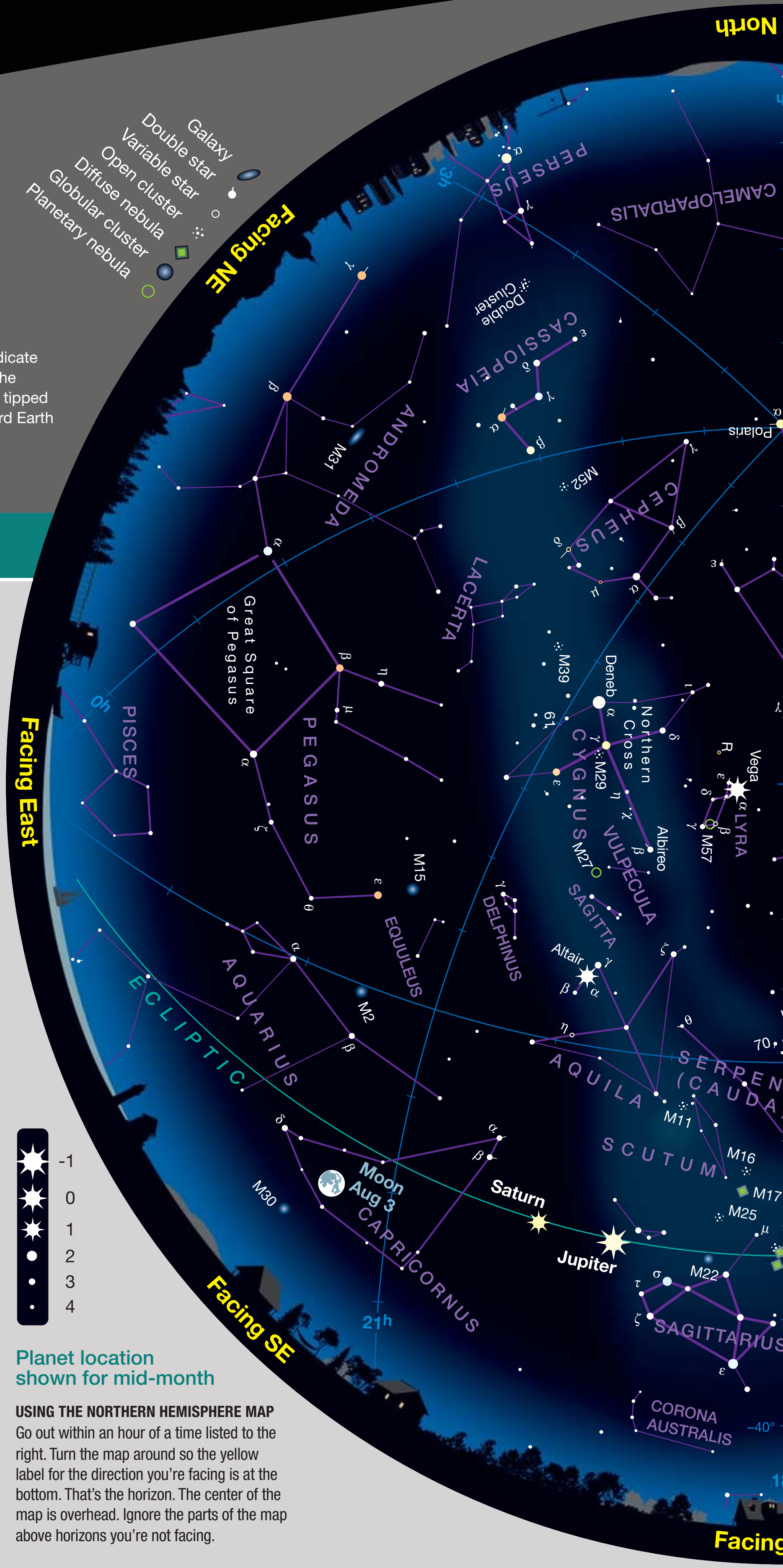
FIRST QUARTER
August 25
17:58 UT

DISTANCES

Apogee	August 9, 14h UT
404,659 km	Diameter 29′ 32″
Perigee	August 21, 11h UT
363,513 km	Diameter 32′ 52″

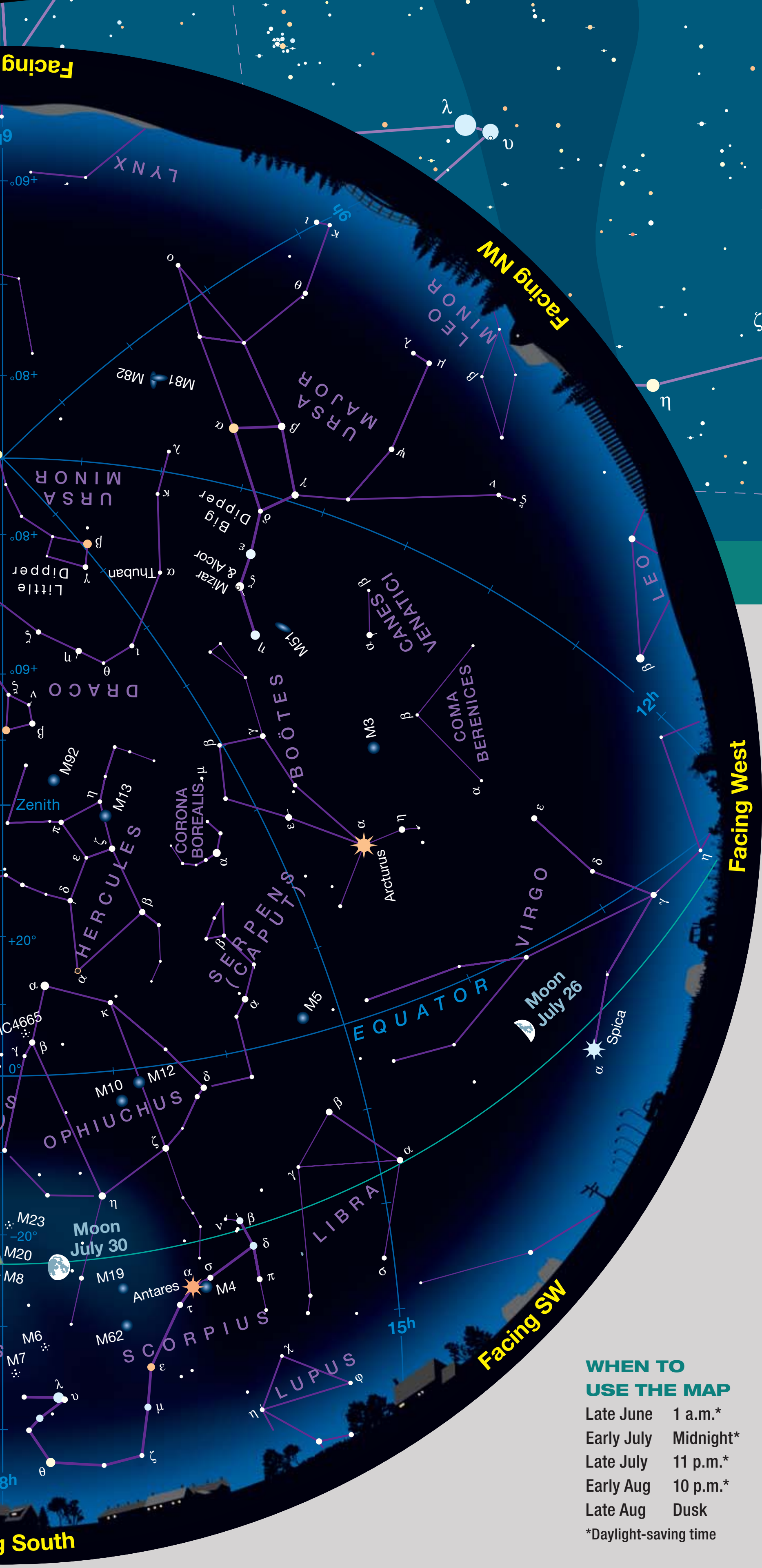
FAVORABLE LIBRATIONS

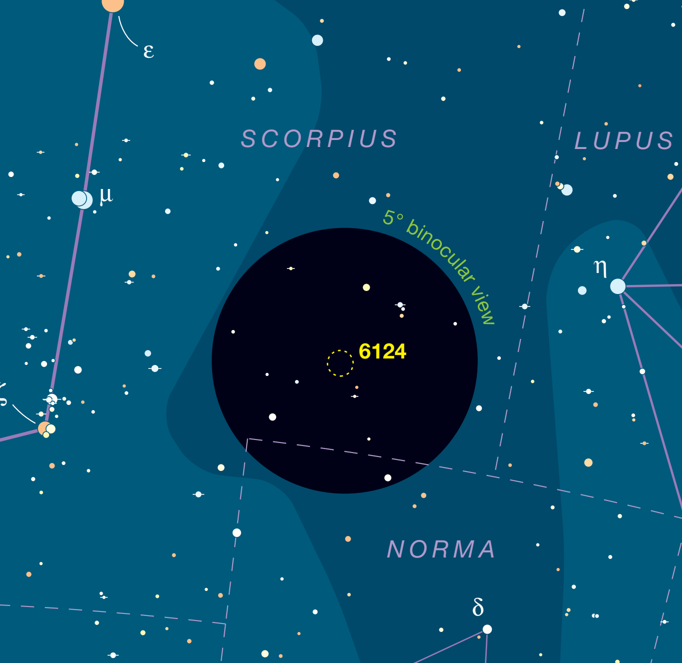
• Mare Marginis	August 1
• Mare Orientale	August 16
• Mare Australe	August 24
• Mare Smythii	August 27



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

Gathering Dust

As an observer I'm both fascinated and haunted by cosmic dust. Under very dark skies the twisting, shadowy webs that wind through the Milky Way are almost hypnotic to trace. But at the same time, I'm frustrated by knowledge that every dark cosmic cloud is only visible because it obscures the light of the stars, nebulae, and galaxies that lie beyond it. Other than a few cheats — like gravitationally lensed quasars, for example — everything we see up there we see at the expense of something else.

This is much on my mind when I observe the open cluster **NGC 6124** in the southwestern corner of the constellation Scorpius, the Scorpion. That region of the galactic band is clotted with prominent dark nebulae and more elusive tendrils of cosmic dust. Polarization studies suggest the presence of at least three different light-absorbing clouds or sheets of interstellar dust between our solar system and NGC 6124, as well as dust in the cluster itself. The latter may be responsible for the dark band that visibly separates the northwest corner of the cluster from the main body.

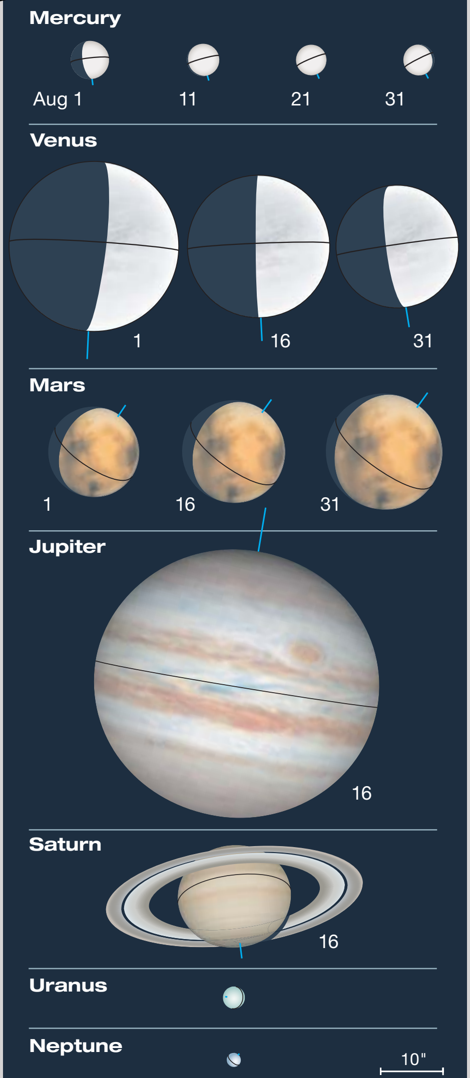
All of this gives us a lot to chew on as observers. NGC 6124 is a perfectly pleasant object, but with a visual magnitude of 5.8 spread out over an area roughly 40′ in diameter, it's hardly a showstopper. It *should* be, though. At a distance of only 1,700 light-years and sporting a physical diameter of 20 light-years, NGC 6124 should be as bright and prominent as some of the showier Messier clusters. There's just too much darn dust. So go see what you can and let your mind fill in what you can't — which, come to think of it, is a pretty fitting manifesto for any deep-sky observer.

■ Between his dusty house, dusty fossils, and cosmic dust, **MATT WEDEL** has just about had it with dust.

WHEN TO USE THE MAP

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

*Daylight-saving time



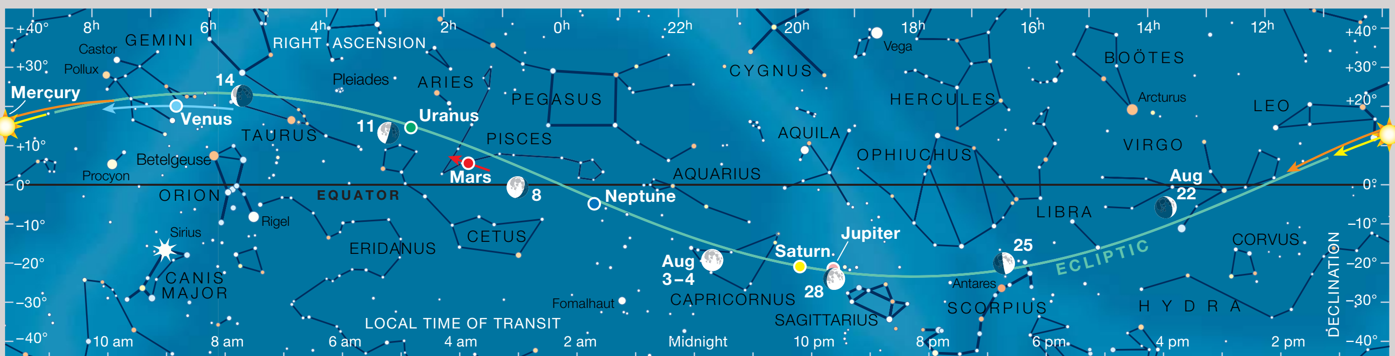
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury:** visible at dawn to the 8th • **Venus:** is the brilliant Morning Star all month • **Mars:** rises in late evening • **Jupiter:** visible at dusk and sets around 3:30 a.m. local daylight-saving time • **Saturn:** visible at dusk roughly 8° east of Jupiter

August Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$8^h\ 45.5^m$	+18° 01′	—	–26.8	31′ 31″	—	1.015
	31	$10^h\ 37.8^m$	+8° 39′	—	–26.8	31′ 41″	—	1.009
Mercury	1	$7^h\ 36.3^m$	+21° 29′	17° Mo	–0.9	6.1″	70%	1.096
	11	$8^h\ 56.9^m$	+18° 47′	7° Mo	–1.6	5.2″	96%	1.293
	21	$10^h\ 16.8^m$	+12° 31′	4° Ev	–1.6	4.9″	99%	1.365
	31	$11^h\ 24.7^m$	+4° 54′	12° Ev	–0.7	5.0″	93%	1.345
Venus	1	$5^h\ 34.1^m$	+19° 16′	45° Mo	–4.5	27.2″	43%	0.613
	11	$6^h\ 12.0^m$	+19° 58′	46° Mo	–4.5	24.1″	49%	0.692
	21	$6^h\ 53.7^m$	+20° 06′	46° Mo	–4.4	21.7″	54%	0.770
	31	$7^h\ 37.7^m$	+19° 31′	45° Mo	–4.3	19.7″	59%	0.847
Mars	1	$1^h\ 12.0^m$	+3° 29′	111° Mo	–1.1	14.6″	86%	0.642
	16	$1^h\ 33.8^m$	+5° 22′	120° Mo	–1.4	16.5″	89%	0.566
	31	$1^h\ 46.9^m$	+6° 29′	130° Mo	–1.8	18.7″	92%	0.500
Jupiter	1	$19^h\ 26.2^m$	–22° 20′	161° Ev	–2.7	47.2″	100%	4.180
	31	$19^h\ 15.6^m$	–22° 43′	130° Ev	–2.6	44.4″	99%	4.436
Saturn	1	$19^h\ 58.7^m$	–20° 54′	169° Ev	+0.1	18.4″	100%	9.012
	31	$19^h\ 51.1^m$	–21° 17′	138° Ev	+0.3	18.0″	100%	9.233
Uranus	16	$2^h\ 32.6^m$	+14° 30′	103° Mo	+5.7	3.6″	100%	19.539
Neptune	16	$23^h\ 24.9^m$	–5° 00′	153° Mo	+7.8	2.4″	100%	29.021

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



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

Night of the Perseids

Meteors are just one of the attractions when this famous summer shower peaks.

AKIRA FUJII

▲ **PERSEUS PLUS** With the aid of our Northern Hemisphere Sky Chart on pages 42–43, see if you can pick out Perseus, Cassiopeia, and Andromeda, as well as the Double Cluster and M31. The radiant of the Perseid meteor shower lies near the Double Cluster.

What do the following have in common: filmmaker Steven Spielberg's childhood inspiration beneath the night sky of southern New Jersey; the single most dangerous object known to humankind; and the burning tears of an executed saint?

If you guessed that all three are connected with August's famed Perseid meteor shower, you're right! Spielberg's first summer under a really starry sky inspired him to later include meteors in many of his movies (most notably, two meteors in *Jaws*). As for the "most dangerous object," consider that Comet Swift-Tuttle (the parent of the Perseids) has a larger nucleus than Halley's Comet, and that it's on an orbit that could eventually put it on a collision course with Earth. That makes Swift-Tuttle potentially the greatest threat to our survival. Lastly, the Perseids long ago became known as the fiery "tears of Saint Laurence" because the shower's peak originally coincided with the day of his martyrdom, August 10, 258 AD.

But my topic this month isn't the shower itself, rather, the starry sky you can experience while watching Perseus rise throughout the night.

Early evening. As detailed on page 48, this year's display peaks on the night of August 11-12. The radiant is in northern Perseus, just over the border from Cassiopeia and not far from the Double Cluster. As our Northern Hemisphere map on pages 42–43 illustrates, this area is still very low in the north-northeast in the early evening, which is why at mid-northern latitudes few Perseids can be seen as the night begins. In contrast, the wonders of the summer Milky Way lie near (or on) the meridian. The nebulae M16, M17, M20, and M8, open star cluster M11, and planetary nebula M57 are all well placed for binocular and telescopic viewing. But my advice is don't tire yourself out by observing too much early on.

Late evening and the midnight hour. Looking northeast you'll see the zigzag pattern of Cassiopeia and the stars of Perseus slowly climbing higher. To the right of Perseus are the two curved lines of Andromeda, the maiden that Perseus heroically rescued. And attached to Andromeda is the Great Square of Pegasus, standing on its southeast corner like a giant diamond. Under good conditions, you should catch quite a few swift Perseids shooting away from the northeast as midnight (daylight-saving time) arrives. The slightly bad news for Perseid watchers this year is that the nearly last-quarter Moon rises not long after midnight as the night of the 11th transitions into the morning of the 12th. Fairly bright moonlight will decrease the visibility of meteors just as the shower's radiant gains altitude and the pace of the display should be picking up.

1 a.m. to dawn. These are the hours when Perseid meteors should be most numerous. By 1 a.m., the bright light of Capella has risen, while off to its right is the lovely Pleiades star cluster, not far from the Moon. In the next few hours, Aldebaran and the Hyades also appear. However, you'll have to wait until a little after 3 a.m. for Orion to fully clear the east horizon. For many of us, Perseid night often provides our first view of Orion since mid-spring. It's also the first chance we'll have to check the brightness of Betelgeuse.

Morning twilight begins to interfere with Perseid observing soon after 4:30 a.m. I'm almost always too tired by then to stay up any longer and watch the heliacal rising of Sirius.

■ **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 skyandtelescope.org.

A Parade of Bright Planets

Jupiter, Saturn, Mars, and Venus put on a fine summer show.

A few hours after sunset this month, Jupiter and Saturn are at their highest in the south at nearly the same time Mars rises. On the other hand, brilliant Venus rises several hours before dawn, which by late August is when Jupiter and Saturn set.

These planets all look great in telescopes this month. Jupiter and Saturn were both at opposition around mid-July, and Venus is at greatest elongation in mid-August. Mars is still two months away from its impressive opposition but is already big enough for some truly extraordinary views of its surface.

DUSK AND EVENING

Jupiter and **Saturn** shine in the south-southeast after dusk. They start the month almost 8° apart and continue slowly pulling away from each other as they both *retrograde* (move westward) in eastern Sagittarius. During August, Jupiter dims a bit from magnitude –2.7 to –2.6, and Saturn's brightness decreases from magnitude +0.1 to +0.3. Jupiter's apparent diameter shrinks from 47″ to 44″, and Saturn diminishes ever so slightly, from 18.4″ to 18.0″. Its rings remain well-displayed at 42″ across and tilted more than 22° from horizontal. Calm summer nights are usually good for obtaining crisp, steady images in a scope, but because Jupiter and Saturn are quite far south from mid-northern latitudes they're viewed through air that is often turbulent.

The dwarf planet **Ceres**, the largest body in the asteroid belt, is at opposition on the 28th. It shines at magnitude 7.7 from southern Aquarius (see page 50 for a finder chart).

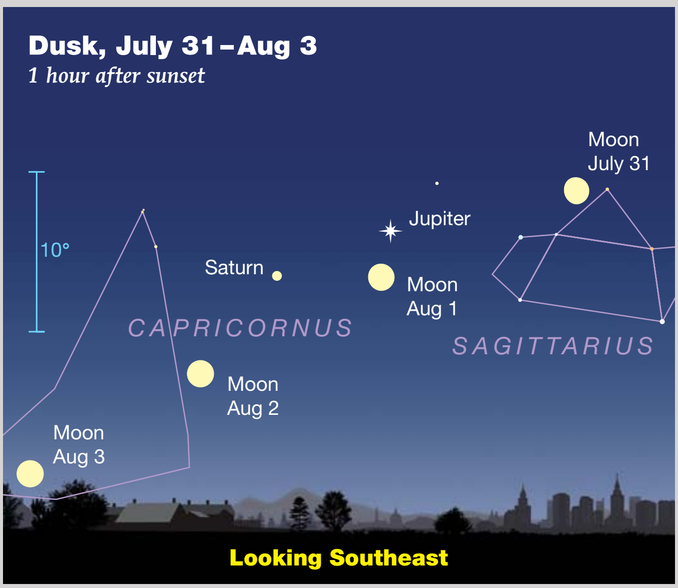
LATE EVENING TO DAWN

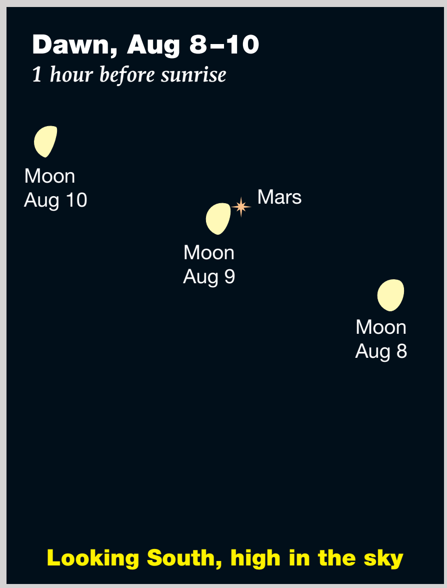
Mars rises 3 hours after sunset at the beginning of August and 2 hours after sunset by the end of the month. The Red Planet flames up from magnitude –1.1 all the way to –1.8 during that time as it continues to move with *direct* (eastward) motion through Aquarius. Mars reaches *perihelion* (nearest to the Sun in space) on the 3rd — a little more than two months before what will be one of the planet's closest oppositions. During August, Mars's apparent diameter grows from 14.6″ to 18.7″. The steadiest views in a telescope usually come when the planet is near the meridian, which happens half an hour before sunrise on the 1st and 2½ hours before sunrise on the 31st.

PRE-DAWN TO DAWN

Venus rises at virtually the same time all month for observers at mid-northern latitudes, who will see the planet clear the horizon at around 2:45 a.m., local daylight-saving time. Because the Sun

▶ 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.

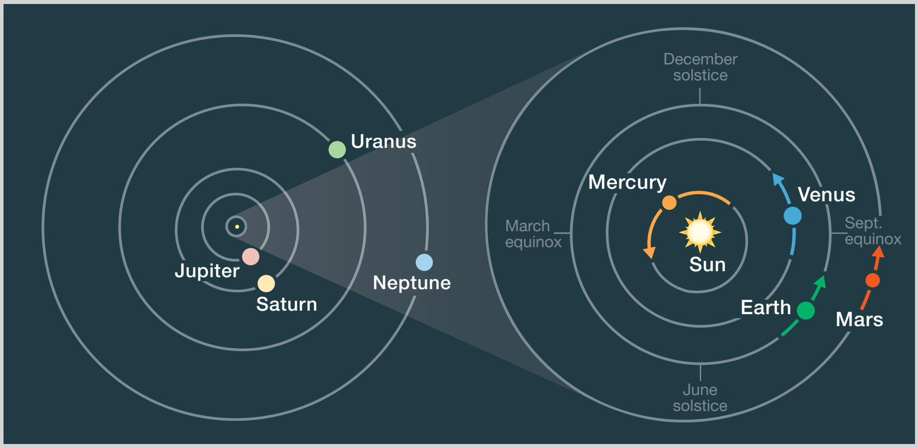




rises later and later throughout the month, the interval between Venus-rise and sunrise actually increases by more than 20 minutes. The brilliant planet reaches greatest elongation on August 12th when it's positioned 46° west of the Sun. But for observers around latitude 40° north, Venus doesn't reach its highest sunrise altitude (roughly 40°) until the end of the month. The Morning Star's brightness decreases a bit in August, from –4.5 to –4.3 as its apparent width shrinks from 27″ to 20″ and its illuminated percent grows from 43% to 59%. Venus moves eastward and passes through Taurus and northern Orion before arriving in southern Gemini, where it ends the month slightly less than 9° from Pollux.

Uranus spends August in southern Aries and transits around sunrise. **Neptune** is in eastern Aquarius and transits the meridian at roughly the same time Venus rises. The planet reaches opposition next month.

Mercury is very low in the dawn sky at the start of August and reaches superior conjunction on the 17th.



ORBITS OF THE PLANETS

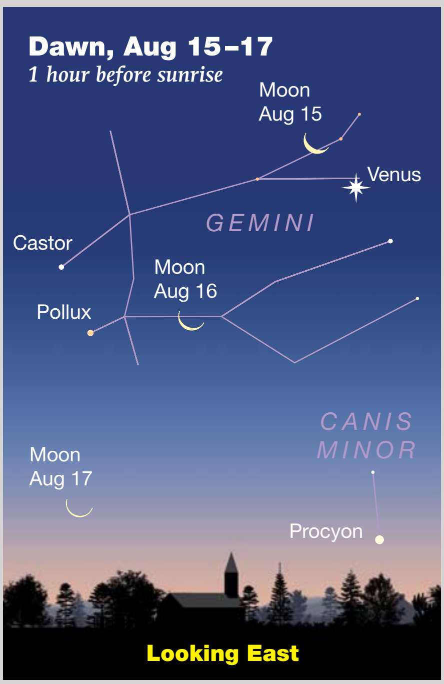
The curved arrows show each planet's movement during August. The outer planets don't change position enough in a month to notice at this scale.

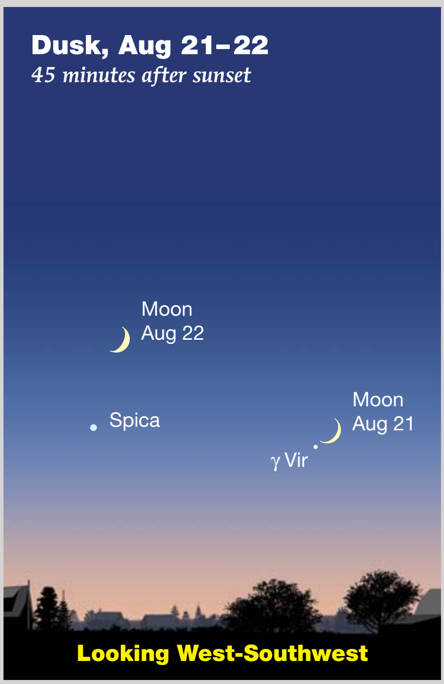
MOON PASSAGES

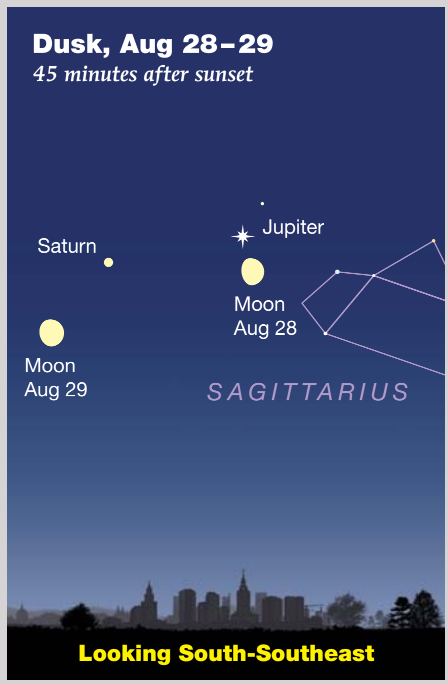
On the evening of August 1st, the nearly full **Moon** shines less than 3° below Jupiter. The following night, it sits well left of Saturn. The most dramatic lunar conjunction of the month occurs on the morning of the 9th, when the waning gibbous Moon passes a little more than 1° south of brilliant, red Mars. At dawn on the 15th, the slender, waning lunar crescent is roughly 3½° above blazing Venus as the pair rise. The next morning, the very thin Moon is 6½° right of Pollux.

Returning to the evening sky as August starts to wind down, the young waxing crescent Moon is slightly more than 1° from the famous double star Gamma (γ) Virginis (also known as Porrima) on the 21st. The next evening, the Moon is well above Spica. On the 28th the waning gibbous Moon hangs just below Jupiter for the second time in August. And, again, on the following night it's lower left of Saturn.

■ FRED SCHAAF began writing the first of his many books, *Wonders of the Sky: Observing Rainbows, Comets, Eclipses, the Stars and Other Phenomena*, 40 summers ago.







ORESTE SHVADCHAK

Peerless Perseids

Warm August nights are ideal for relaxing under the stars and watching one of the best meteor showers of the year.

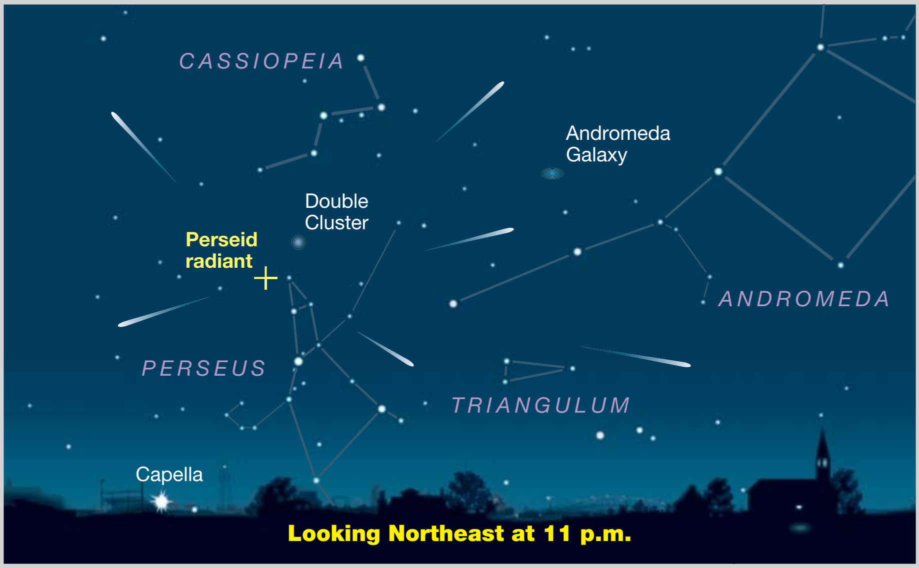
This photograph of Perseid meteors over Lucerne, Switzerland, was captured during the peak of the 2018 shower with an Olympus E-M1 Mark II camera in Live Composite mode. The image shows a 30-minute accumulation of meteors.

Embedded in the ice of Comet Swift-Tuttle for eons, a rice-grain-sized fragment of rock suddenly finds itself aloft, tumbling and spinning in a geyser of gas and dust. Set free by the warmth of the Sun, the fragment drifts farther and farther down the comet's tail along with billions of newly liberated companions to form a glinting stream of ice and silicate splinters.

Centuries pass. The tiny fragment travels from one end of the solar system to the other, alternately heated by the Sun and plunged into a deep freeze beyond the orbit of Pluto. Cosmic rays and solar storms etch its surface as the planets pass in a slow parade.

One day, the Earth looms larger than usual and continues to grow until a collision becomes unavoidable. Traveling at around 100,000 kilometers per hour (62,000 miles per hour) directly toward the blue-and-white sphere, the comet particle experiences the first inklings of the planet's atmosphere 90 kilometers above its spidery web of city lights. It begins to warm, and in a flash achieves incandescence as it tunnels its way through the air. Oxygen and other molecules energized by its passage ionize and glow, creating a sudden streak of light. Far below, a child looks up, points a finger skyward and excitedly shouts, "A meteor!"

Each August, Earth plows through a gritty stream of debris left behind by Comet 109P/Swift-Tuttle, creating the illusion of particles shooting from a single spot in the sky called the *radiant*. You can see a similar effect through your windshield while driving



on a snowy night. Snowflakes appear to come from a point in the distance and fan out as you approach them. In reality the comet particles are parallel to one another and only appear to converge at the radiant.

This effect makes it easy to tell a Perseid from a random or sporadic meteor. No matter where a meteor flares, if you can follow its path back to Perseus, it's a genuine Perseid. However, Perseids can trace a path from the radiant across the entire sky, which means one direction is as good as another when it comes to deciding which way to orient yourself. That said, I like to point my reclining chair southeast, with the radiant off to my left. That way I can catch both the short-trailed meteors near the radiant location as well as their long-trailed cousins streaking off to the sides.

Countless cometary fragments fuel the annual Perseid meteor shower, which reaches its peak on the night of August 11–12. Under a dark, moonless sky you can expect to see 50 to 75 meteors per hour. On that night the first meteors will show around 9:30 p.m. when Perseus is still hunkered down in the northeastern sky. This relatively early hour means that kids can watch, too. But the later you stay up the more meteors you'll see. Not only does the radiant climb higher but the Earth rotates into the direction of the meteor stream. This rotational speed increases the relative velocity at which meteoroids strike the atmosphere, which in turn increases the brightness and visibility of the resulting streak. Meteor expert Peter Jenniskens predicts an extra bump of Perseid activity might occur around 10 UT (3 a.m. PDT) on August 12th — ideal for West Coast sky-watchers (the sky is already too bright for those on the East Coast).

The Moon, just shy of last quarter, will rise around midnight local time and knock back meteor numbers by at least a third. However, this is less damaging than last year's full Moon. Those wishing to avoid moonlight or risking bad weather on the peak night can take advantage of the fact that the Perseid stream is quite wide. As a result, the shower starts as early as July 17th and lingers into the third week of August.

Perseids are swift meteors, barreling into the atmosphere at around 60 kilometers per second. They're also rich in fireballs. Bill Cooke of NASA's Meteoroid Environment Office has tracked numerous meteor showers with all-sky cameras and calls the Perseid display the annual "fireball champion." Cooke believes that's because the parent comet has a larger-than-normal nucleus (about 26 kilometers across) and is capable of producing the larger fragments that create brilliant flares.

First mention of the Perseids dates back to at least 36 AD according to a Chinese record, but it wasn't officially recognized as a recurring meteor shower until the late 1830s. That's when three European observers independently noted that an unusual number of meteors routinely appeared at the same time each August. It's fascinating to consider how threads of human history intertwine with cosmic events to create a narrative spanning eons. Be part of the story this August — go out and meet a meteor.

Double Duty at Jupiter

August is high season for Jupiter watching, including following the antics of its four brightest moons. When a Jovian satellite passes in front of the planet's disk, it casts a small, midnight-black shadow on Jupiter's cloud "surface." Called *shadow transits*, these events are a delight to watch and add a three-dimensional feel to the scene. In steady seeing conditions, shadow transits can be observed in telescopes with apertures of around 4 inches and larger.

Most shadow transits are single-shadow events but on the night of August 14–15 and August 21–22 you can watch a double-shadow transit courtesy of Ganymede and Io. On August 14th, Ganymede's shadow bites into Jupiter's disk at 10:31 p.m. Eastern Daylight Time followed by Io's at 12:08 a.m. on August 15th. The double-shadow transit lasts until 1:54 a.m. when Ganymede's shadow departs Jupiter's disk. Observers across most of North America should get a fine view of this event.

The second double-shadow transit is best seen from the western half of the continent. On August 21st, Io's shadow lands on Jupiter's disk at 11:04 p.m. Pacific Daylight Time and shares the planet's disk with Ganymede's shadow from 11:32 p.m. that night to 1:20 a.m. on August 22nd.

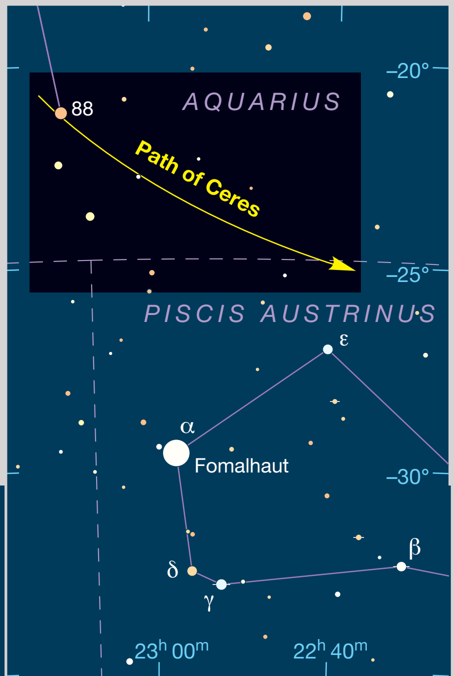
A Dwarf Planet at Opposition

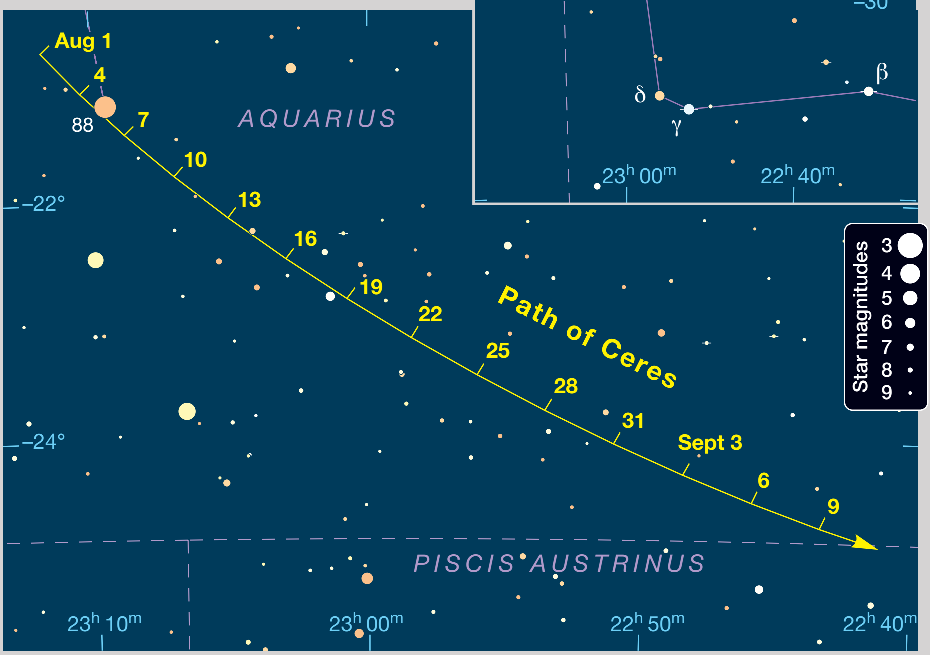
CERES IS A BIG DEAL. It has a diameter of 940 kilometers, which is about a quarter the size of the Moon. When you think of how many millions of asteroids there are, it's remarkable that Ceres alone accounts for 25% of the asteroid belt's total mass. Its stupendous bulk is a big part of its "dwarf planet" status. To qualify as a dwarf planet, an object must orbit the Sun directly, be massive enough for self-gravity to shape it into a sphere yet not so massive that it dominates its region of space, thus clearing it of other small bodies. Ceres checks all these boxes.

Ceres reaches opposition on August 28th in southern Aquarius, just north of the Piscis Austrinus border. That night it shines at magnitude 7.7, putting it within easy reach of binoculars from the outer suburbs and countryside. It remains brighter than 8th magnitude all month while inching westward in retrograde motion.

On opposition night, Ceres rises at roughly 9 p.m. local daylight-saving time and transits the meridian around 1:30 a.m. Given its southern declination (–24°), you'll get the best views of the dwarf planet an hour or so either side of its transit time.

Use the chart below to locate Ceres. Note that from August 4–7, its path carries it near 3.7-magnitude 88 Aquarii. Ceres is positioned less than ½° from the star from August 2–8 and sits just 4′ south of it on the morning of the 5th. This should make the dwarf planet easy to locate.





Action at Jupiter

AT THE START OF AUGUST, Jupiter rises around 7 p.m. local daylight-saving time and transits the meridian shortly before midnight, when it's well placed for telescopic viewing. On August 1st the planet gleams at magnitude –2.7 and presents a disk 47″ in diameter.

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

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

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

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

August 1: 2:32; 12:28; 22:23 **2**: 8:19; 18:15 **3**: 4:10; 14:06 **4**: 0:01; 9:57; 19:53 **5**: 5:48; 15:44 **6**: 1:04; 11:35; 21:31 **7**: 7:26; 17:22 **8**: 3:18; 13:13; 23:09 **9**: 9:05; 19:00 **10**: 4:56; 14:52 **11**: 0:47; 10:43; 20:39 **12**: 6:34; 16:30 **13**: 2:25; 12:21; 22:17 **14**: 8:12; 18:08 **15**: 4:04; 13:59; 23:55 **16**: 9:51; 19:46 **17**: 5:42; 15:38

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

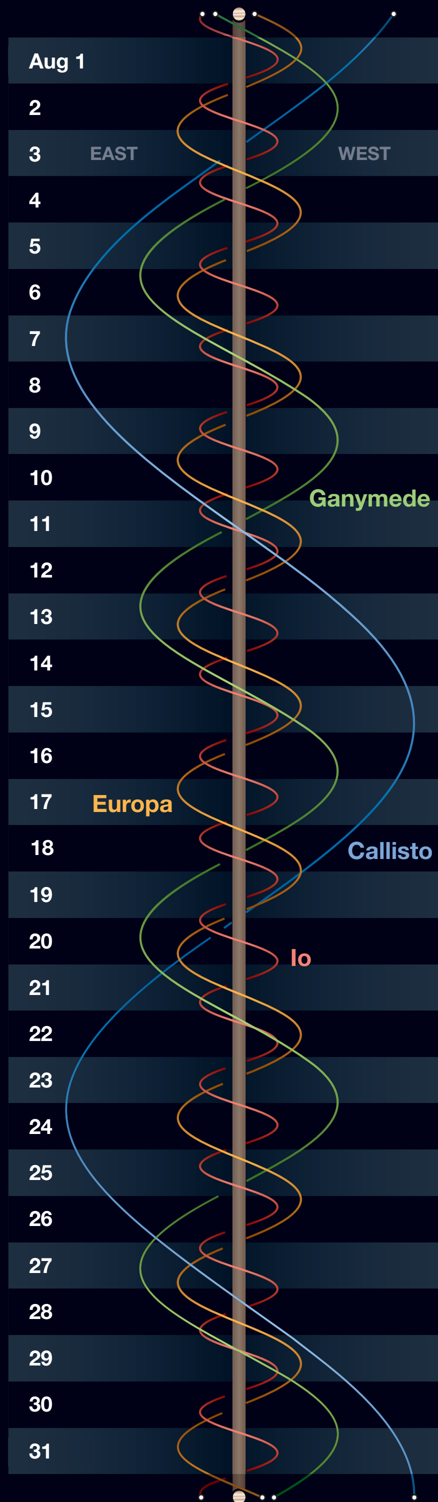
These times assume that the spot will be centered at System II longitude 338° on August 1st. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 338° and 1²/₃ minutes later for each degree more than 338°.

Phenomena of Jupiter's Moons, August 2020

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

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.

August Librations

This month presents an excellent opportunity to view several limb-hugging maria.

▲ Four limb-hugging maria are well placed for observers during the last week of August. This simulation shows the Moon as it will appear on the evening of the 28th.

NASA'S SCIENTIFIC VISUALIZATION STUDIO

If you think of the Moon as a head, it does an endless series of rolling tilts with cycles of nodding up and down "yes" and shaking back and forth "no". These *librations* tip the polar regions alternately towards and away from the Earth (libration in latitude) and similarly for the east and west limbs (libration in longitude). Librations can be as extreme as 8°, and anything over 5° gives a noticeably better perspective on features near the limb than the typical view. The last week of August shows most of the eastern limb tilted Earthward by 5° to 6°, providing worthwhile opportunities to compare four different lunar maria and basins of different ages and character.

From north to south, the maria in question are Humboldtianum, Marginis, Smythii, and Australe. Like other lunar maria, most of these dark lavas fill large impact basins — most, but not all of them, as we shall see.

Along the Moon's northeastern limb is **Mare Humboldtianum** and basin, which, based on the number of superposed impact craters, is the third-youngest large impact basin on the Moon. The best opportunity to view the basin in August is on the evening of the 31st due to the nearly 6° libration in latitude that favorably tips the entire northeastern limb our way. The Moon's phase is nearly full on the 31st, making the dark Mare Humboldtianum the easiest feature to spot. Look closely and you should detect the bright mountainous peaks of the 320-km-diameter inner basin ring that contains the mare. About two-thirds of the way from the inner ring to the dark-floored **Endymion** crater is the basin's 620-km-wide main rim. This feature rises just above the surrounding terrain but drops about 500 meters to the smoother terrain between the basin rim and inner ring.

Nearly 40° south of Humboldtianum lies **Mare Marginis**, an irregular dark patch with no evidence for an underlying basin. It was assumed in the 1970s that the Marginis lavas filled an ancient impact basin whose rim subsequent impacts had long since destroyed. But laser topography from orbiting spacecraft failed to detect the expected depression, and high-resolution gravity data from NASA's GRAIL (Gravity Recovery and Interior Laboratory) spacecraft found that Marginis has only a weak and diffuse positive gravity anomaly, meaning that there is no significant excess mass hidden below the surface such as found beneath other circular mare. As a result, Marginis is no longer considered a basin. Yet Marginis retains two interesting distinctions — it is antipodal to the Orientale Basin, and it contains a faintly visible swirl just northeast of the crater **Goddard**.

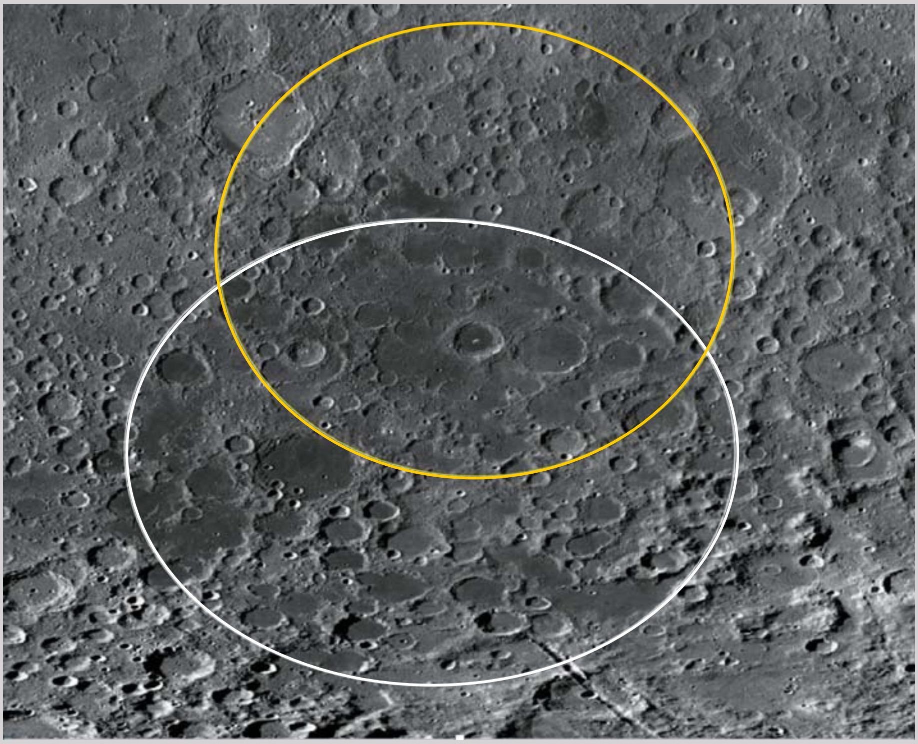
South of the distinctive, dark-floored crater **Neper** is **Mare Smythii** and its underlying basin. Mare Smythii is two-tone, with lavas in the northern half being distinctly darker and younger than those in the southern portion. Interestingly, the lavas in all the eastern maria are typically about 3.6 to 3.7 billion years old, except for ages of 3.1 billion years for Smythii's dark lavas and a small patch in the northern portion of Mare Australe. What caused small amounts of lavas to reach the surface 500 million years after that of nearly all filling the other eastern limb maria?

The structure of the Smythii Basin is hard to discern because it lacks a conspicuous rim. The relatively sharp edges of the western side of the mare are due to a 1.5-km-high inner ring that apparently contained the spread of lava. The inner lava field corresponds to the basin's positive gravity anomaly. Smythii's roughly 880-km-diameter main basin rim is best seen in Lunar Reconnaissance Orbiter topography maps, where a mountainous arc of peaks surrounds the basin's eastern and southern edges. When the Sun is setting over Smythii, I've occasionally observed a narrow shadow extending from the inner ring onto the basin floor. Both Smythii and Marginis are well placed for observers on the evenings of August 27 and 28.

The southernmost named lunar mare is **Mare Australe**, which is and isn't what we have thought for nearly 200 years. Named by Beer and Mädler in their classic 1830s map *Mappa Selenographica* and book *Der Mond*, Australe has long been recognized as being unique due to its collection of scattered mare ponds and lack of surrounding mountains or hills.

Mare Australe is defined by a roughly circular collection of frozen lakes — lava-filled craters with similar smooth lavas between the craters. Current estimates put Australe's diameter at about 900 km, which encompasses nearly all of the mare-filled craters. However, the GRAIL data have turned up new evidence, forcing us to rethink the feature's true extent and nature. The gravity anomaly that GRAIL detected is restricted to the northern portion of the lava-filled crater area. This led Gregory Neumann (NASA Goddard Space Flight Center) and colleagues to propose in 2015 that the roughly circular positive gravity anomaly is the center of a roughly 800-km-wide basin they call Australe North.

▲ Mare Humboldtianum and the anciently flooded crater Endymion are visible the last week of August, with slightly better viewing on the 31st.



▲ Although Mare Australe is considered to include each of the mare-flooded craters seen along the southeastern limb (circled in white), gravity measurements put the basin's center roughly 400 km north, within the yellow circle.

MARE HUMBOLDTIANUM: DAMIAN PEACH; MARE AUSTRALE: NASA / GSFC / ARIZONA STATE UNIVERSITY

The proposed basin is not congruent with the named maria. At this time, no satisfactory explanation exists for why Australe North, with its presumed basin fractures leading to deep magma source regions, looks the same as the contiguous lava-filled crater areas to the south, with no likely connection to deep magma. You can puzzle about this anomaly as you gaze upon Australe in the early evenings of late August.

Despite being our nearest astronomical neighbor, the Moon still retains many secrets that add to its allure.

■ Contributing Editor **CHUCK WOOD** often looks beneath the lunar surface to piece together the Moon's history.

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.

Bird of the Mighty Wing

The celestial eagle harbors a wide variety of deep-sky objects.

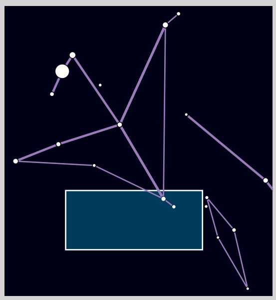
The dome of heaven is thy house
Bird of the mighty wing,
The silver stars are as thy boughs
Around thee circling.
Thy perch is on the eaves of heaven
Thy white throne all the skies
Thou art like lightning driven
Flashing over paradise!

— George Edwin Curran,
The Eagle, 1920

Aquila, the star-born eagle, now soars on mighty pinions in our evening sky, bringing with him a flock of celestial wonders to survey.

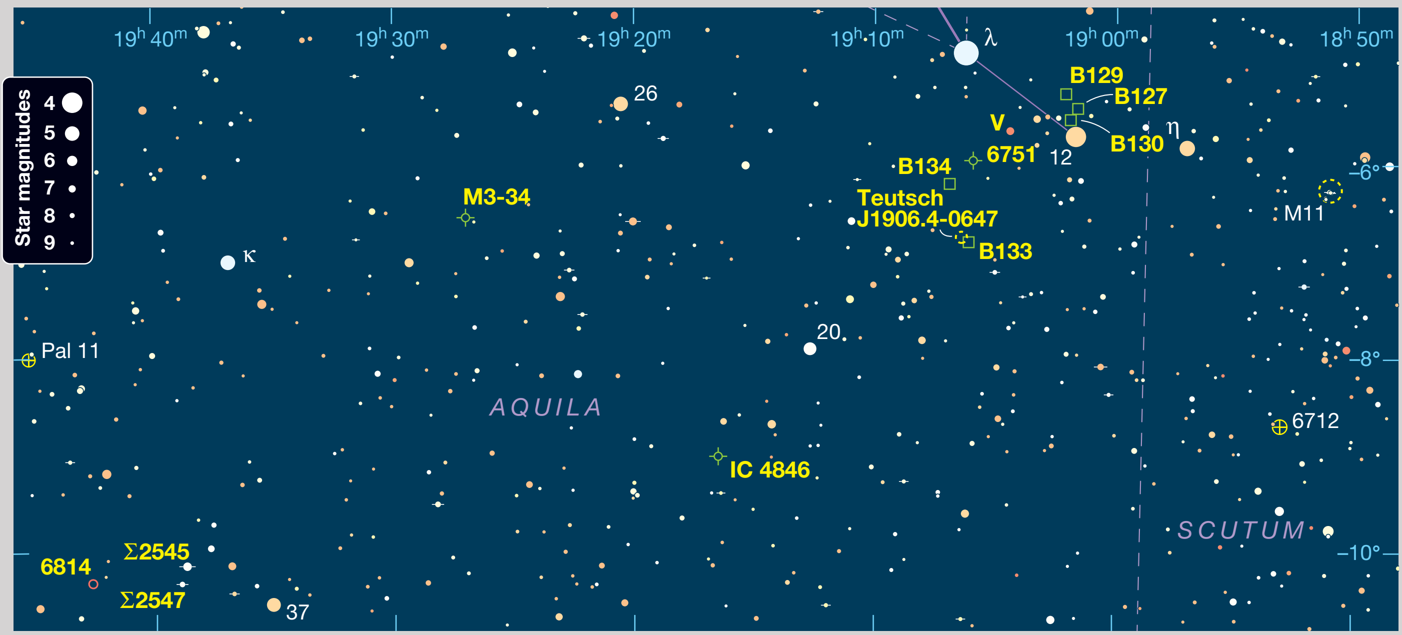
One of my favorite objects to visit in the realm of the Eagle is the carbon star **V Aquilae**, one of the reddest stars visible in a backyard telescope. A carbon star is a red giant whose atmosphere is rich in carbon-bearing molecules that absorb blue light, making the star look redder than an ordinary giant. According to the 19th-century astronomer Eduard Schönfeld, the brilliant mathematician and astronomer Friedrich Wilhelm Bessel was the first person to note this star's crimson glow. Bessel observed V Aquilae in 1823 while working on a catalog that would eventually include more than 75,000 stars.

Pointing 12×36 image-stabilized binoculars at the naked-eye stars Lambda (λ) and 12 Aquilae, I'm smitten by the lovely red-orange tint of V Aquilae. About one-quarter of the way from 12 Aql to Lambda, a little arc of three stars leads my eyes east-southeast to the ruddy star. Some observers aren't particularly sensitive to the color of reddish stars and might need a larger instrument to appreciate them. I find the hue strikingly vivid in my 130-mm (5.1-inch) refractor.



Most carbon stars are variable, but V Aquilae remains within the reach of binoculars throughout its cycle. The star changes from about magnitude 6.7 to 7.2 and back in a semiregular period of 1.1 years.

North of 12 Aquilae, an arc of three dark nebulae appears as an indistinct congregation of shadows from my moderately light-polluted yard. Several years ago I took advantage of darker skies at the Stellafane Convention in Vermont for a better view through my 105-mm refractor at 47×. **Barnard 130** rests 11′ north-northeast of 12 Aquilae and is the largest, but least star-free, of these dusky patches. **Barnard 127** hovers near B130's northwestern edge, and it's escorted on the



southwest by a 3′ triangle of 8th- and 10th-magnitude stars. To the northeast, **Barnard 129** is inky, but it's not as well framed with stars as its companions and appears only semidetached from B127. The whole sooty arc spans a mere 22′.

The distances to most dark nebulae aren't well determined. A 2006 study by Gopinathan Maheswar and Harish Chandra Bhatt in the *Monthly Notices of the Royal Astronomical Society* places B127 at 590 ± 110 light-years and B129 at 650 ± 130 light-years. We could reasonably assume that B130 is at a comparable distance.

Sliding 29′ southeast from V Aquilae takes us to the planetary nebula **NGC 6751**. The nebula and star share a field of view through my 130-mm refractor at 63×, with NGC 6751 presenting a tiny disk. It becomes a sizable spot at 102×. At 234× the disk has a dimmer center that harbors an elusive central star, while the annulus seems a little brighter in the southeast. Two very faint stars bracket the nebula. The slightly brighter one is 23″ east and a bit north, the other is 38″ west and a bit north. The planetary's central star looks about as bright as the closer star.

NGC 6751 is a cute little robin's-egg-blue disk in my 15-inch scope at 49×, offering a lovely color contrast with V Aquilae. At 248× the nebula's annulus is a fat ring roughly 25″ across.

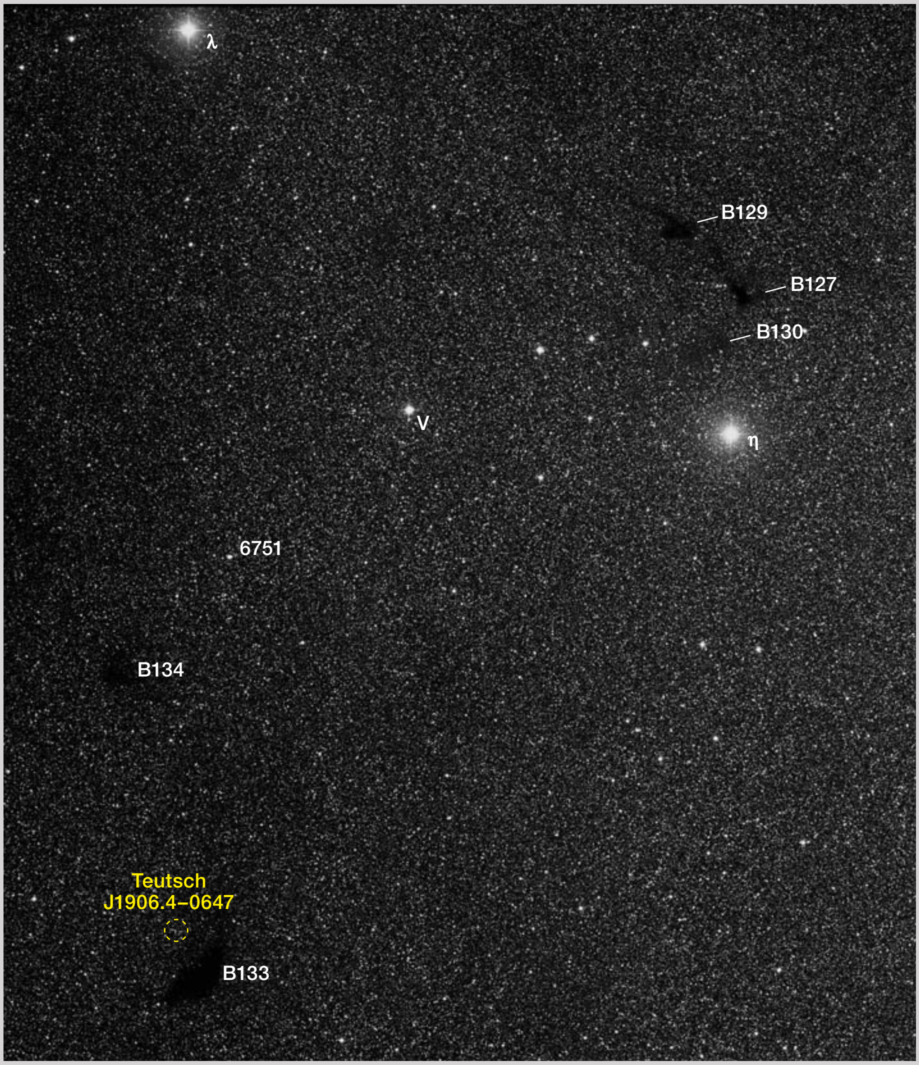
Under some conditions NGC 6751 displays a bright center that can be mistaken for a star. If so, try higher magnifications to pluck out the true central star, which is much fainter.

NGC 6751 is sometimes called the Dandelion Puff Ball, and it looks very much like the head of a dandelion gone to seed in the remarkable Hubble image shown on page 56.

The dark nebula **Barnard 134** sits 21′ southeast of NGC 6751. It covers about 4½′ through my 130-mm refractor at 63×, and the two disparate nebulae share the field of view. Maheswar and Bhatt put B134 at the same distance as B129.

▶ The dark nebulae near the carbon star V Aquilae show particularly well in this red-plate mosaic assembled from the first *National Geographic — Palomar Observatory Sky Survey*.

Dropping 40′ south-southwest from B134, we come to **Barnard 133**. In my 130-mm refractor at 48×, it's a fairly obvious 8½′ × 3½′ oblong of darkness tipped northwest. Just beyond the nebula's edge, south of center, a 5′-tall-asterism of nine faint stars reminds me of the blocky numeral 8 on a digital clock. Off the opposite side of the nebula is **Teutsch J1906.4–0647**, discovered by Philipp Teutsch, a participant in the former Yahoo group known as the Deep Sky Hunters. Once deemed a possible open cluster, the group is now known to be an asterism. It's a challenging collection of stars to observe, and my 10-inch reflector at 299× shows its brightest members as a daisy chain of several faint to extremely faint stars draped along the shallow curve of an east-west garland about 2′ long.



▲ The face-on spiral galaxy NGC 6814 requires relatively large apertures in order to reveal its arms in the eyepiece.

Next, we'll set sail for the tiny planetary nebula **IC 4846**. To locate it, head 1° southeast from the blue-white, 5th-magnitude star 20 Aquilae to a 7th-magnitude, east-west pair of deep-yellow stars ½° apart. IC 4846 dangles 21′ south of the eastern member of the

NGC 6814: ERIC AFRICA / ADAM BLOCK / NOAO / AURA / NSF:
POSS MOSAIC: POSS-I / STSCI / CALTECH / PALOMAR OBSERVATORY

pair and floats in a 7′ pail of seven 11th-magnitude stars that opens northeast. At 48× through my 130-mm refractor, this drop in the bucket doesn't quite look like a star, and a magnification of 117× confirms a teensy blue-gray disk.

Minkowski 3-34 is a somewhat larger planetary nebula 2° southeast of yellow, 5th-magnitude 26 Aquilae. A 10′ triangle of 9th-magnitude stars just southeast of 26 Aql points toward the nebula. M3-34 makes a 17′-long straight line with three stars. From south-southwest to north-northeast, they are magnitude 10.7, 12.5 (the planetary), 11.9, and 10.5. A 9th-magnitude star rests 6.2′ west southwest of the nebula.

M3-34 is moderately faint and not as sharp as the stars in my 130-mm scope at 48×. It becomes a small disk at 102×, while at 164× it looks quite nice and is fainter around the periphery. The nebula dons a blue-green hue in my 10-inch scope at low power, and it gains a substantial contrast boost through an O III filter when using my 15-inch scope.

▲Visible in modest telescopes as a small blue disk, NGC 6751 resembles a dandelion gone to seed in this Hubble Space Telescope image.

NASA / HUBBLE HERITAGE TEAM / STSCI / AURA

Now we'll move on to the triple stars **Struve 2545** and **Struve 2547**, which dwell 57′ east-northeast of deep-yellow, 5th-magnitude 37 Aquilae. Struve 2545 (Σ 2545) is the brighter trio. My 130-mm refractor at 63× shows the white, 6.8-magnitude primary star barely separated from its 8.5-magnitude secondary to the northwest. The third star is considerably farther away, south-southeast of the primary, and much fainter. The close companion is more comfortably split from its primary at 102×.

Only 11′ to the south-southeast, Σ 2547 shares the field of view with Σ 2545, but it doesn't require as much power to reveal its components. At just 37× the 8.7-magnitude primary displays a 9.5-magnitude attendant north-northwest, and a much fainter one more than twice as far away in the opposite direction.

The spiral galaxy **NGC 6814** also shares the same low-power field of view, 55′ east of Σ 2547. It's a fairly small, very faint, round, misty spot. At 102× it spans about 1½′ and has uniform surface brightness. There's a very faint star close to the galaxy's northwestern edge and another more distant from its south-southeastern side. My 10-inch scope at 213× adds a small, brighter core. How large a telescope do you need to see the spiral arms of this nearly face-on galaxy?

■ Contributing Editor SUE FRENCH wrote this column for the July 2009 issue of *Sky & Telescope*.

Several Stars, Many Nebulae, and One Fine Galaxy in Aquila

Object	Type	Mag(v)	Size/Sep	RA	Dec.
V Aquilae	Carbon star	6.7 – 7.2	—	$19^h\ 04.4^m$	–05° 41′
Barnard 130	Dark nebula	—	7′ × 7′	$19^h\ 01.9^m$	–05° 34′
Barnard 127	Dark nebula	—	4′ × 4′	$19^h\ 01.6^m$	–05° 27′
Barnard 129	Dark nebula	—	5′ × 5′	$19^h\ 02.1^m$	–05° 18′
NGC 6751	Planetary nebula	11.9	26″	$19^h\ 05.9^m$	–06° 00′
Barnard 134	Dark nebula	—	6′ × 6′	$19^h\ 06.9^m$	–06° 15′
Barnard 133	Dark nebula	—	10′ × 3′	$19^h\ 06.2^m$	–06° 54′
Teutsch J1906.4-0647	Asterism	—	2′	$19^h\ 06.4^m$	–06° 47′
IC 4846	Planetary nebula	11.9	11″	$19^h\ 16.5^m$	–09° 03′
Minkowski 3-34	Planetary nebula	12.5	11″	$19^h\ 27.0^m$	–06° 35′
Struve 2545	Triple star	6.8, 8.5, 11.6	4″, 25″	$19^h\ 38.7^m$	–10° 09′
Struve 2547	Triple star	8.1, 9.5, 11.1	21″, 50″	$19^h\ 38.9^m$	–10° 20′
NGC 6814	Spiral galaxy	11.2	3.0′ × 2.8′	$19^h\ 42.7^m$	–10° 19′

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

 by Damian Peach

Revealing THE PLANETS

Contributing to the study of our neighboring worlds is easier than you might think.

▲ **AMAZING DETAILS** Resolving details on the planets within our solar system has never been easier. Author Damian Peach shares some tips on how to capture and process your images to reveal tiny features that are only fleetingly glimpsed at the eyepiece. He recorded the montage above using a Celestron C14 Schmidt-Cassegrain telescope and FLIR Systems (formerly Point Grey Research) Grasshopper 3 high-speed video camera.

Photographing the Moon and planets has long been a mainstay of both amateur and professional astronomy. Using high-speed digital video cameras and innovative processing techniques, amateurs today regularly produce pictures of our neighboring worlds that resolve tiny details only fleetingly glimpsed in the eyepiece.

Taking high-resolution photos of delicate clouds in the atmosphere of Mars, interacting storms in the belts of Jupiter, or the polar hexagon on Saturn is well within the grasp of anyone with patience and a relatively modest telescope. Here's what you need to get started.

Choosing Your Tools

The resolution of your planetary images will be dependent on the telescope you use. Most any instrument can produce excellent planetary images. But to record the smallest swirls in Jupiter's cloudtops or changes in the receding polar cap on Mars, you'll need an instrument of at least 8 inches aperture.

Each of the most popular optical designs have their strengths and weaknesses, but the Schmidt-Cassegrain telescope (SCT) is perhaps the best compromise between adequate aperture and a manageable size. The SCT design combines reflective optics with a corrector plate to produce sharp, color-free images while simultaneously housing large-aperture optics in a short optical tube. The drawback is that such compound instruments usually need to be recollimated, especially if you transport the scope to your observing location each night.

Regardless of which kind of telescope you choose, there are a few accessories you'll need to take detailed planetary images. The first is an electric focuser. You don't want to touch the telescope when focusing, as vibrations from your hand are greatly magnified, and you'll simply be fighting with a jiggling image. Not only that, but you'll frequently need to refocus as the temperature changes and seeing conditions fluctuate throughout the night.

ALL PHOTOS PROVIDED BY AUTHOR UNLESS OTHERWISE NOTED

Planetary photography requires a focal ratio of about f/20 to f/30, depending upon the target (with only Mars tolerating the upper end of this scale). Commercial telescopes tend to come in focal ratios of f/5 to f/10, so you'll need some way to boost your instrument's effective focal length to achieve the image scale necessary to resolve small features on your target planet. So, your next accessory purchase should be either a Barlow lens, eyepiece projection adapter, or another amplification optic like a Tele Vue Powermate.

Another useful tool in a planetary imager's arsenal is an Atmospheric Dispersion Corrector (ADC). This small device consists of two weak prisms in a compact, adjustable housing placed in front of your camera. Changing the tilt between the prisms allow you to correct for *atmospheric dispersion* — the smearing of light into its component colors by the refractive properties of Earth's atmosphere. The closer a planet is to the horizon, the worse the effect becomes. This prismatic separation appears as blue and red fringing on the top and bottom of the target, though the entire view is affected and robbed of small-scale details. These devices can completely tune out this dispersion and present a sharper image than would otherwise be possible. ADCs are widely available, some costing as little as $150. They are well worth investment, especially for observers at more northerly locations, particularly as planets often appear positioned south of the ecliptic.

Cameras, Computers, and Control

Your next consideration is your camera. Planetary photography is based on a technique known as "lucky imaging," in which you record a series of exposures or a video of your target at a rapid frame rate, then import those frames into a computer program that sorts and stacks only the sharpest ones. Today's planetary cameras feature low-noise CMOS sensors with lightning-fast readouts of more than 100 frames per second transferred to your computer via a USB 3.0 or GigE connection. All typically include software that allows you to control important settings such as exposure, frame rate, and gain.

Nearly all planetary imagers are built around Sony CMOS sensors and are offered as either monochrome or in one-shot-color format. Color cameras are excellent for beginners or casual imagers, while monochrome models require the addition of a color filter wheel and filters if you want to produce color images. Monochrome cameras are particularly useful for recording images in wavelengths beyond the visible spectrum (such as ultraviolet and infrared) as well as several specific wavelengths that can penetrate deeper within Jupiter's atmosphere.

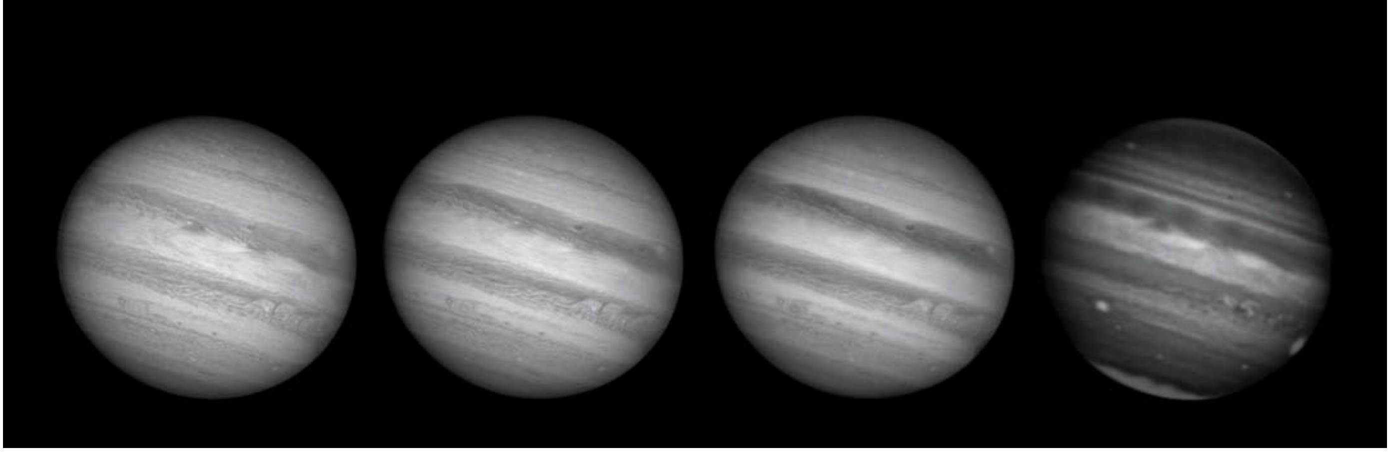
Planetary cameras record video files in either AVI or SER format, though some have the option of recording individual FITS images. You can import these files into the stacking programs discussed later.

▶ **EASY SETUP** The author's typical planetary imaging rig appears here on a typical night in his backyard. Although not a requirement, he prefers a high-resolution monitor attached to his laptop to provide a more detailed image, which greatly helps when focusing.

CAMERAS: SEAN WALKER / *S&T*

▲ **HIGH-SPEED VIDEO** Several manufacturers offer planetary imaging cameras, including Celestron (**celestron.com**), FLIR Systems (**flir.com**), The Imaging Source (**theimagingsource.com**), Meade (**meade.com**) QHYCCD (**qhyccd.com**), and ZWO (**astronomy-imaging-camera.com**). You can even use a DSLR camera with HD video capabilities, though it would weigh much more than the video cameras shown above and require a very sturdy focuser.

Such high-speed cameras produce a massive stream of data, churning out dozens of megabytes of data per second, requiring a computer that incorporates a large hard drive with a fast write speed. Many of the solid-state drives (SSD) found in laptop computers these days can record 300-500 MB per sec-

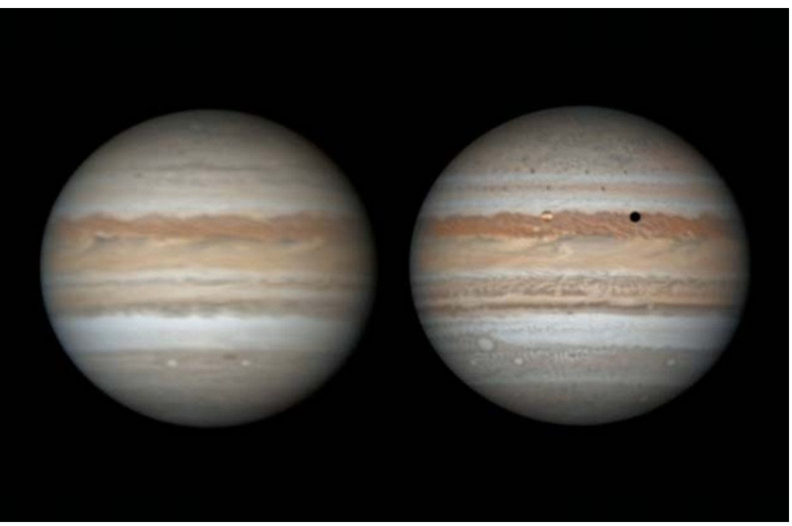


▲ **ISOLATING WAVELENGTHS** A monochrome camera equipped with color filters provides better isolation of individual wavelengths and is particularly desirable for imaging beyond the visible spectrum. The examples of Jupiter above show differences among the red, green, and blue data, as well as the near-infrared wavelength (far right) centered at 889 nanometers where methane strongly absorbs light, revealing features deeper within Jupiter's atmosphere.

ond, easily accommodating such fast cameras. Older hard disk drives (HDD), with the exception of 7200 RPM models, have slower write speeds and may struggle with and drop frames during a recording. Be sure to investigate the specifications of your computer to see if it supports USB 3.0 or GigE and fast write speeds. And as you'll quickly accumulate several dozen gigabytes of videos each night, be sure your computer has at least a terabyte of storage space available. Also consider a large external drive to back up your video files.

Although your camera may come with its own control software, most planetary imagers prefer to operate their cameras, filter wheels, and focusers using the third-party program *FireCapture* (**firecapture.de**). This free PC software includes many useful features specific to planetary imaging, including the ability to pre-program exposure changes for each color filter, region-of-interest cropping, and program presets you can create for each planet.

▼ **VARIABLE SEEING** Even if you've carefully collimated your telescope and made sure it's acclimated to the ambient temperature, turbulence in the atmosphere will still limit the detail in your images. The images of Jupiter below show the results produced on consecutive nights in which conditions were average to poor (left) versus a night with very good to excellent seeing conditions (right).



At the Telescope

Now that you've assembled your equipment, you need to consider several crucial before recording your first video sequence.

First and foremost is making sure your telescope is in perfect collimation. Even a slight misalignment can noticeably degrade the image being recorded. You should check this before starting your first image series of the night, preferably after aiming the scope in the general direction of the planet you are photographing. An excellent tutorial on collimating Newtonian reflectors appears in our April 2019 issue (page 68) and one for collimating SCTs can be found in our February 2018 issue, page 28.

Another consideration is ensuring your telescope has reached *thermal equilibrium*. If your scope is warmer than the outside air, it will radiate heat, producing a blurry image that is virtually impossible to focus. Give your scope about an hour or more to cool down, especially if you store it indoors. Larger apertures will typically need even more time to cool. You can speed up the process, though, with fans or other active cooling devices.

All these preparations will help you get the most out of your equipment, but your biggest limitation will be the atmospheric seeing conditions. "Seeing" is the amount of blurring imparted on your target by the turbulent mixing of air masses of different temperature in the atmosphere. While we can't control seeing, there are many forecasting tools online today that can help you determine if conditions are good enough to bother setting up or not. One site is **meteoblue.com,** which offers seeing forecasts for your location under its Outdoor & Sports section.

Focus, Focus, Focus

Once you're at the scope, the most important consideration is focusing. I use a monochrome camera with RGB filters and focus visually with the computer screen by concentrating on the planet's disk. I slowly adjust focus back-and-forth until I'm confident that I've found the sharpest image. I then record a video, switch filters, and refocus for the next filter.

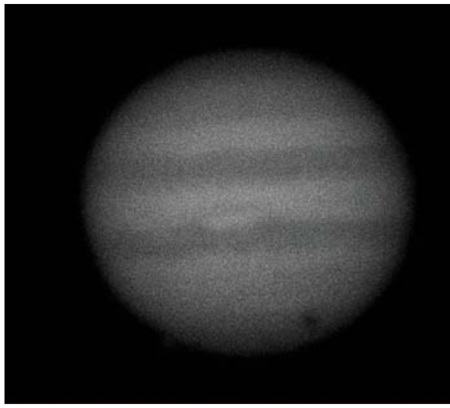
Focusing in good seeing is usually easy, but under poor seeing it can be extremely difficult, so don't be discouraged. To gauge focus, use areas of high contrast on your target, such as the Cassini Division in Saturn's rings, albedo features on the Martian surface, and small storms in Jupiter's belts. Venus, Mercury, and even Mars can be difficult to focus when they're far from Earth and feature small disks, but the sunward limb is often a good spot to use to judge whether you're in focus or not. Simply take your time and practice. The more you do it, the better you'll get at it.

When you start recording video, you'll typically be operating your camera at about 30 to 80 frames per second or more, depending on the brightness of your target, capturing a minimum of 1,000 frames for a single image stack. Your camera's frame rate is a balance between the exposure length and gain settings, which are partially dictated by the brightness of the planet. Regardless, try to keep the camera's gain setting well below its maximum. Setting the gain to about 70% is a good starting point, then adjust your exposure until the planet is bright but not over-exposed on the screen. If you use *FireCapture*, be sure the histogram of the image does not go above about 80%. Also, ensure that the gamma setting is at its default value.

Video Reduction

This stage is perhaps the most fun part of the whole process, as you finally get to see what surprises your video sequences have in store. Currently there are two popular choices for stacking your planetary videos: *RegiStax 6* (**astronomie.be/registax**) and *Autostakkert! 3* (**autostakkert.com**). While both do an admiral job, *RegiStax 6* includes powerful Wavelet sharpening, which works extremely well, and I often stack my videos in *Autostakkert! 3* and then sharpen the resulting image in *RegiStax 6*.

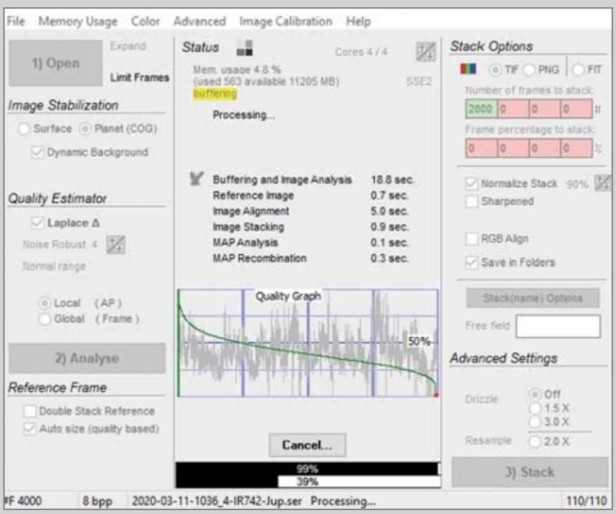
Both programs will stack your videos in basically the same way. (A tutorial on using *Autostakkert!* appeared in the September 2016 issue of *Sky & Telescope*, page 68.) Each program

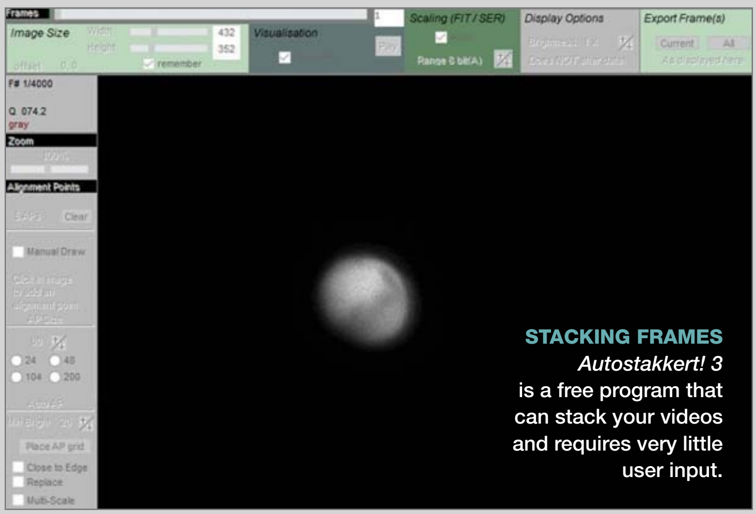


▲▶ **SPECIALIZED CONTROL** While most planetary cameras come with control software, a better option is the freeware *FireCapture* (**firecapture.de**), which controls cameras, focusers, and filter wheels while offering many additional features helpful for planetary photography.

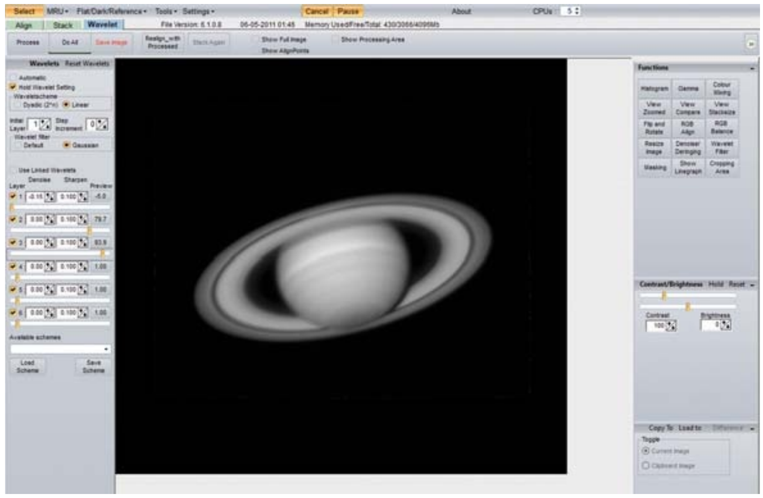
sorts and aligns all the frames in an image sequence using a choice of alignment modes — single-point and multipoint alignment. Single-point alignment works well on small planetary targets such as Mercury, Venus, and Mars (when they're just a few arcseconds across) as well as Uranus and Neptune. Multipoint alignment permits you to select multiple points to monitor, and the program will stack the best areas around each point, producing a superior result on larger planets like Jupiter, Saturn, Mars, and Venus, and also on lunar close-ups.

Once the software has aligned your video frames, you'll need to determine how many individual frames to stack — the greater the number, the better the signal-to-noise ratio





STACKING FRAMES *Autostakkert! 3* is a free program that can stack your videos and requires very little user input.



▲ **WAVELET SHARPENING** The best tool for sharpening your stacked videos is the multi-layer Wavelets in the free program *RegiStax 6* (**astronomie.be/registax**). This powerful tool permits both sharpening and noise control, producing crisp images with minimal processing artifacts.

of the resulting image, making it less grainy and improving its ability to withstand sharpening. The number of usable frames you stack varies depending on the seeing conditions. Under good seeing you can stack a great many frames (maybe 75% or more), but in poor conditions this goes down to maybe about 30%. Stacking more frames taken under poor seeing simply produces a blurrier result, because more sub-par frames are included in the final stack. That said, don't be fooled into thinking just selecting the 100 best frames will work. It may well deliver a sharper result, but it will be extremely noisy when sharpened.

After you've completed reducing your video into stacked images, it's time to sharpen the result. At this step, the best tool to use is the Wavelets in *Registax 6*. This multi-layer sharpening tool quickly reveals subtle details in your images. Its six sliders offer varying ranges of enhancement. Slider 1 affects very fine detail while slider 6 brings out coarser details. I often use sliders 2 and 3 exclusively on my lunar and planetary images, but you should experiment to find a combination that works best for your photos.

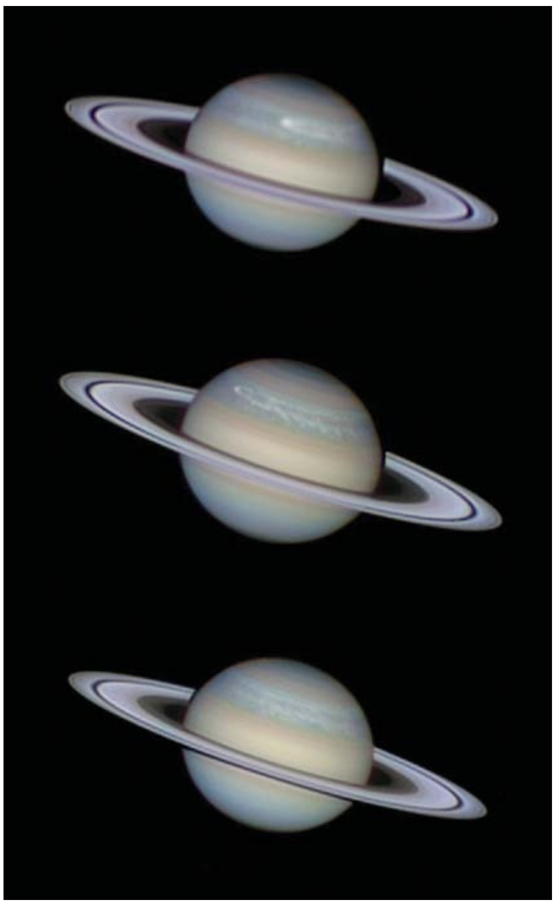
Although you might consider your image done at this point, another free program, WINJUPOS, offers a powerful tool that can compensate for the effects of planetary rotation. The program's de-rotation feature permits you to combine several images captured over a long timespan. For example, Jupiter rotates so fast that you must limit your video length to about a minute or less before the planet's fast rotation blurs details in a single stacked video. Combining several stacked and de-rotated images produces even better pictures, allowing you to eke out even more detail in the final planetary portrait. A guide to the technique can be found in our May 2013 issue, page 70.

Contributing Real Science

Monitoring the planets is of considerable interest to professional researchers, and dedicated enthusiasts have made many discoveries. Image quality today is so good that researchers have published detailed papers on the atmospheric dynamics of Jupiter based purely on the analysis of data that amateurs have provided.

You can contribute by joining one of the established organizations dedicated to monitoring solar system bodies. Both the British Astronomical Association at **britastro.org** and the Association of Lunar and Planetary Observers (ALPO) at **alpo-astronomy.org** welcome new members who want to contribute images and observations. Asian organizations include the International Society of Mars Observers (ISMO) at **https://is.gd/des4ml** and ALPO Japan (**alpo-j.sakura.ne.jp/indexE.htm**). These groups provide nearly uninterrupted monitoring of solar system bodies — an invaluable resource for planetary scientists.

It's amazing to consider how far planetary imaging has improved in the last 25 years. Amateurs now routinely resolve planetary features that approach the theoretical resolving limit of their instruments. Give it a try yourself.



▶ **MONITORING CAMPAIGN** Photographing the planets each clear night and sharing them with several organizations dedicated to their study helps contribute to our understanding of our neighboring worlds. This series of images shows the development of a storm in Saturn's North Temperate region that appeared at the end of 2010 and eventually spread to encircle the entire planet. These shots captured on March 21, March 28, and April 17, 2011, document its changing appearance, and were used by professional astronomers studying the phenomena.

■ **DAMIAN PEACH** is a dedicated planetary observer based in Hampshire County, UK. Visit his website at **damianpeach.com**.

▲ LARGE-FORMAT CMOS

Finger Lakes Instrumentation (a division of IDEX Health & Science) adds a new large-format CMOS to its line of professional-grade astronomical cameras. The Kepler KL6060 Cooled sCMOS camera (starting at $45,000) is designed around a huge, 37.7-megapixel monochrome sCMOS detector with 10-micron-square pixels in a 6,144 × 6,144 array measuring 86.8 mm from corner to corner. Thermoelectric cooling allows stable temperatures of down to 45°C below ambient. Combined with low 4.6e- read noise, this results in smooth, noise-free images. The unit is capable of recording 11 full-resolution, 12-bit frames per second through its USB 3.0 interface, or 19 frames per second when using an optional QSFP fiber interface. Faster rates are possible when using a small region-of-interest. The camera is available with a standard front-illuminated detector with a peak quantum efficiency of 72% or a thinned, back-illuminated option with 95% QE. Contact the manufacturer for additional details.

Finger Lakes Instrumentation
P.O. Box 19A, Lima, NY 14485
585-624-3760; flicamera.com

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

▲ SYNSCAN ENHANCEMENTS

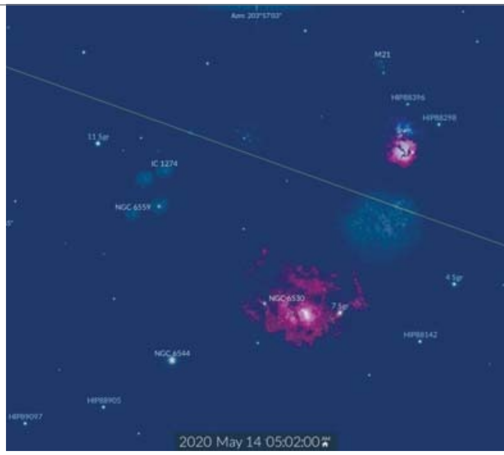
Sky-Watcher adds two helpful upgrades to its SynScan Go To system for Sky-Watcher Go To mounts. The SynScan GPS Module ($175) eliminates the requirement of inputting your location and time data when starting up your Sky-Watcher mount. The GPS plugs into the bottom of your Sky-Watcher SynScan hand controller and pulls all time and location data directly from GPS satellites. Additionally, the SynScan WiFi Adapter ($65) allows you to control any Sky-Watcher Go To mount wirelessly with your PC or iOS and Android devices. Using the unit in conjunction with the *SynScan Pro* app, you can now align, point, and control many of the mount's normal functions via your wireless device. The WiFi dongle will also import your location and time data from your device as long as it has a GPS feature. This WiFi dongle replaces the SynScan hand controller for complete wireless control.

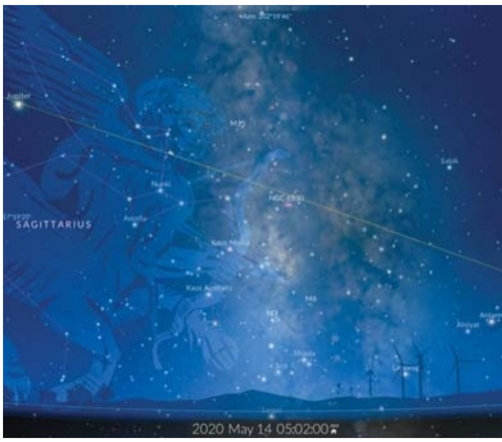
Sky-Watcher USA
475 Alaska Ave., Torrance, CA 90503
310-803-5953; skywatcherusa.com

▶ PLANETARIUM APP

Redshift Sky announces a major upgrade to its powerful planetarium app *Redshift Sky Pro* ($8.99) for Apple and Android smartphones and tablets. This portable planetarium puts the sky in your pocket. It accurately plots the positions of more than 100,000 stars; 10,000 spectacular deep-sky objects such as galaxies, nebulae, and star clusters; and thousands of other celestial objects, including Earth-orbiting satellites as seen from your current location. The app lets you explore our solar system and visit other known star systems to experience the sky from a completely different perspective. *Redshift Sky Pro* also includes a robust calendar showing you notable events to watch for each night. An upgrade to the *Redshift Sky Ultimate* yearly subscription ($14.99) expands the app's database to more than 2.5 million stars and 70,000 celestial targets and permits you to control your WiFi-enabled telescope.

Redshift Sky
Available on Google Play or
the Apple App Store
redshiftsky.com





Celestron's StarSense Explorer 102

Introducing a revolutionary new approach to finding your way around the sky.

CELESTRON HAS LONG PIONEERED ways to quickly and accurately help us find our way around the sky. The company was the first to introduce Go To pointing on commercial telescopes, and over the years it improved the necessary alignment routines required to ensure its telescopes were accurately pointing towards celestial targets.

One issue with most alignment routines is that the user still needs a cursory knowledge of the sky to initialize the telescope before it can find comets, galaxies, and star clusters. Which star is Arcturus that the Go To computer is asking me to point to? Is that Jupiter or Sirius in the southwestern sky? While the answer to these questions may be trivial for an experienced amateur, the same can't be said for a novice with a new telescope. Identifying these objects can be the make-or-break moment determining whether amateur astronomy is a hobby for them or not.

But now there's a new way to get started exploring the night sky, thanks to Celestron's new line of StarSense Explorer telescopes.

The StarSense Explorer is different than any Go To or push-to telescope I've ever tried. For one thing, each of the four scopes in the series includes no electronics whatsoever. None! Instead, Celestron takes advantage of the powerful computer that you most likely have in your pocket right now — your smartphone. With a combination of a downloadable app and the camera in your phone, the StarSense Explorer telescope can rapidly locate celestial objects with a touch on the smartphone's screen.

◀ Celestron's StarSense Explorer DX 102AZ offers a new way to undertake computer-assisted observing that makes alignment easy for anyone, especially beginners with no knowledge of the night sky.

▲ The StarSense dock attaches to the right side of the alt-az head. It uses a spring-clamp to firmly hold most smartphones manufactured after 2016. A knob on the bottom permits you to move your phone into position in front of the 45° angled mirror, which lets your device see the same area of sky as the 102-mm refractor.

Out of the Box

I received the StarSense Explorer 102AZ telescope early this year and quickly assembled it to get out under the stars. Although the alt-azimuth mount is similar to those on many telescopes marketed for beginners, it has a few notable differences. The most obvious is the removable StarSense dock that attaches to the mount's altitude axis. This accessory includes a mirror mounted at a 45° angle, as well as an adjustable X-Y platform where you install your smartphone. (It's very similar to the cradle on the company's NexYZ adapter made to attach a smartphone to a telescope eyepiece.) This dock permits your phone to see the sky where the telescope is pointing while keeping your device at a convenient viewing angle. The dock can accept smartphones of almost any size.

Assembling the tripod and telescope was straightforward. The mount uses

ALL PHOTOS BY THE AUTHOR

StarSense Explorer DX 102AZ Smartphone App-Enabled Telescope

U.S. Price: $359.96
celestron.com

What We Like

Easy alignment

Interchangeable OTAs

Usable with or without smartphone

What We Don't Like

Tripod is too lightweight

Amici prism diagonal degrades the view

▲ After centering your camera over the mirror in the StarSense dock, you then look through the eyepiece in the telescope and drag the screen so that the object in the eyepiece view is centered under the red crosshair.

knobs on flexible extensions to fine-tune the telescope pointing. Celestron has replaced the tiny thumbscrews typically used to attach these knobs with recessed hex screws. And it stores the required hex wrench in the mount head in case you need to tighten the screws — a nice touch. The only assembly required for the telescope tube is to add the diagonal and red-dot finder.

The 102-mm telescope connects to the mount via a short, Vixen-style dovetail saddle. This feature makes it, as well as the larger StarSense Explorer 130-mm f/5 Newtonian reflector, more versatile than the smaller LT models, which have the StarSense docking port permanently attached to 80- and 114-mm tube assemblies. Having the ability to easily detach the telescope tube from the mount makes transportation and storage easier, and it allows users to swap out the telescope tube with another they may own, provided it attaches with a Vixen-style dovetail.

After everything is assembled, you need to download and install Celestron's *StarSense Explorer* app on your Apple or Android smartphone. Celestron states that your phone should be of recent vintage, including Android devices running Android 7.1.2 or higher, or an iPhone 6 or later. A list of phones that can operate the app is available at **starsenseexplorer.simcur.com**. To activate the app, you'll need to input the unlock code that came with your telescope. The app then walks you through its simple telescope-alignment procedure with a few embedded videos.

The StarSense dock allows the phone to see a wide swath of sky in the direction the telescope is pointing. The app works by taking short photos of the sky, then matching patterns of stars to known patterns in its internal database. It's like fingerprint matching or facial recognition, but in astronomy the process is known as plate solving.

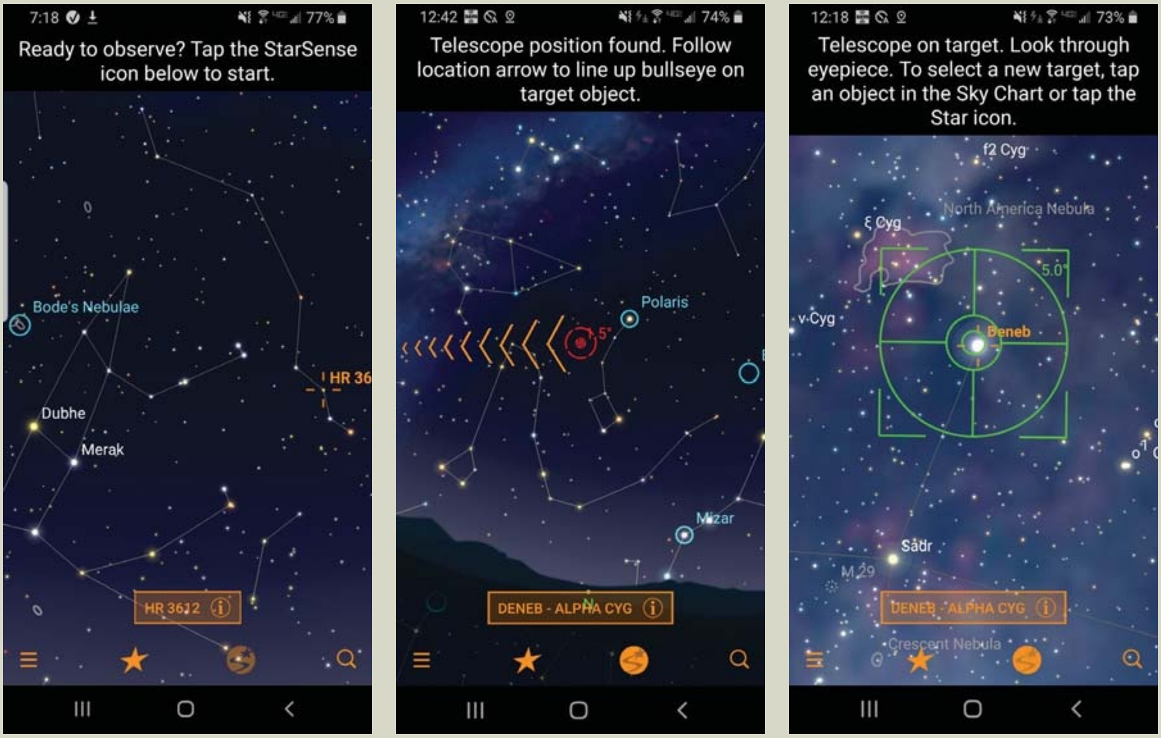
Under the Stars

Here's how a typical session begins. After twilight ends, you click on the StarSense icon in the app at lower right. It asks you if your phone is still aligned with the telescope, and after adjusting the pointing of your phone (if necessary) it directs you to point the scope toward a clear area of the sky. Using my Samsung Galaxy 9, within about 15 seconds the app would display a message at the top of the screen announcing, "Telescope position found. Follow location arrow to line up bullseye on target object." As you push the scope towards the chosen object, the arrow shrinks as you approach your goal, and the screen zooms in just as it enters the bullseye. When you've reached your target, the app takes a photo, verifies its position, and states, "Telescope on target. Look through eyepiece. To select a new target, tap on an object in the Sky Chart or tap the Star icon." You're then free to wander about the sky.

Perhaps the best part of the system is that once it is aligned, you can bump the tripod or even pick it up, move it across the yard, and place it back down.

▼▶ The StarSense Explorer DX 102AZ's tube assembly connects to the alt-az head using a short, Vixen-style dovetail bar. Both axes of the mount use slip-clutches with geared slow motion controls that allow you to push the scope around the sky, then make fine adjustments with the slow-motion controls. A small hex wrench to tighten the screws on the flexible slow-motion control extensions is conveniently hidden in the front of the mount (seen below).

▲ Included with the scope are 25- and 10-mm 1¼-inch eyepieces with plastic barrels providing 26× and 66×, respectively.



◀ Aligning Celestron's *StarSense Explorer* app to the telescope is easy. *Far left:* Click the StarSense icon, and the app asks you to point at a clear area in the sky. *Middle:* Within moments, the app recognizes the field and points in the direction to move the scope to center a bright object. *Near right:* Once centered, the app is aligned and you're ready to start chasing down targets.

Using your phone's camera and accelerometer, the system will still recognize where it's pointed.

The StarSense Explorer app's database includes all the objects from the Messier list, the Caldwell Catalog, as well as many brighter NGC and IC objects, and of course the Moon, planets, and any star plotted in its sky map. Touching the Star icon at lower right brings up a list of the night's best objects, as well as a listing of "tonight's challenge objects," which included both Comet C/2019 Y4 ATLAS and C/2017 T2 PanSTARRS when they were visible in my sky. It was noteworthy that ATLAS disappeared from the challenge listing after an update, when it became clear the comet had broken apart and faded.

The app contains many pages of helpful information on every clickable object on the sky map, including a general description, some observing tips, a table of useful data, and pleasantly narrated audio tours describing the object's appearance in various instruments.

Using the app throughout the late winter into early spring, I would often spot dozens of targets through the telescope either by following its best objects list, or by choosing an area and hopping from target to target as they appeared on the app screen. One excellent night with no Moon, I explored the Virgo Galaxy Cluster and spotted galaxy after galaxy.

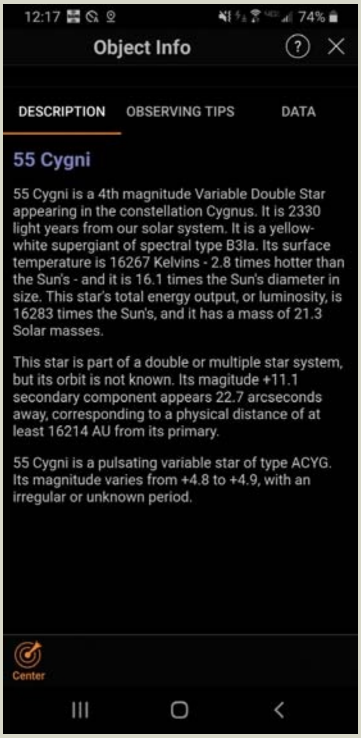
Operating the app for an hour or two would drain my Galaxy 9's battery when the temperature was in the low 20s° F, but keeping a quick-charger USB power pack handy allowed observations to continue for as long as I wanted on these winter nights. This improved in warmer conditions to the point that an additional power supply wasn't necessary. Because the mount and telescope have no electronics of their own, you can keep observing even after your phone's battery dies — simply turn on the red-dot finder and start star-hopping.

One caveat to this system is that the app struggles to align the telescope when a bright Moon is in the sky, though it warns you of this when you initiate the app when the Moon is up. I suspect that severe light pollution may cause the same problem, though I wasn't able to test this theory.

◀ The StarSense Explorer DX 102AZ's 1¼-inch erect-image 90° star diagonal produces a right-reading view through the refractor.

Build Quality and Accessories

The StarSense Explorer DX 102AZ is a 102-mm f/6.5 achromat with decent optics. The scope comes with 25- and 10-mm eyepieces (yielding magnifications of 26× and 66×, respectively). While adequate, users would be well-served by upgrading to better eyepiece



◀ The app includes a wealth of information on every clickable target, including a detailed description (far left) and a data table that includes information specific to your location, such as rising, transit, and setting times (near left).

designs. Swapping these out for several of my own quality Plössls noticeably improved the view.

The scope also includes a 90° erect-image diagonal that uses an Amici prism. While this diagonal renders an image that matches the orientation of the app's display, it also noticeably degrades the view by introducing a vertical diffraction spike on bright targets, especially when using the 10-mm eyepiece. This was most annoying when observing Venus in a dark sky. Replacing this prism diagonal with a 2-inch mirror diagonal eliminated the problem, allowing me to clearly see diffraction rings around bright stars. Stars appeared fairly symmetrical on both sides of focus, with the noticeable purple fringe expected for a relatively fast achromat. This chromatic aberration was only obvious on the brightest stars and on Venus, Jupiter, and the Moon. It was easily overlooked on everything else. I often forgot I was observing through an achromat as I enjoyed the view of several double stars, particularly 24 Comae Berenices and Castor.

One other shortcoming of the StarSense Explorer is the long damping time after touching the scope. It usually took 5 to 6 seconds before vibrations settled down enough to judge whether I had tweaked the focus properly or whenever I touched the slow-motion controls. Damping improved slightly by keeping the tripod legs extended only about half way and observing while seated, but overall I felt the telescope was under-mounted. Swapping the OTA with a smaller though heavier refractor I own only increased the vibration problem.

At times I had an issue that was more to do with my smartphone. Sometimes the app had a hard time verifying the initial calibration target, which during this past winter and spring evenings tended to be Venus. The problem turned out to be fingerprint smudges on the camera's lens window due to its proximity to the fingerprint reader normally used to wake up the phone. Ensuring the window was clean before placing the phone in the StarSense dock fixed the issue. That's something to be aware of with different phone models.

▶ The StarSense Explorer leads the author toward Venus in this photo. The app tends to use the brightest object visible in the sky (except the Moon) as its calibration target.

Using the StarSense Explorer was a lot of fun. I live only a short distance from the border of the biggest city in New Hampshire, so my skies aren't particularly dark — I can just make out the band of the Milky Way on the best nights. I often limit my backyard observing with small refractors to the Moon, casual glimpses of planets, double stars, and the rare bright planetary nebulae. But when using the StarSense Explorer DX 102AZ, I was pleasantly surprised by just how many galaxies, star clusters, and planetary nebulae are actually visible with a small scope aided by this trouble-free app. This encouraged me to observe far more than I usually do.

Celestron has long been a pioneer in revolutionizing observing. Its SkySense Explorer series is a real game-changer for the hobby, much like Go To scopes were not too long ago.

■ Associate Editor **SEAN WALKER** often observes from his backyard in Litchfield, New Hampshire.

Backyard Observatory Innovations

Build a permanent home for your telescope with one of these creative solutions.

THERE COMES A TIME in nearly every amateur astronomer's life when we wish we didn't have to carry our telescopes out into the yard or the driveway, or worse, pack them in the car and drive them somewhere to set up. Wouldn't it be nice to have our own observatory right there in our backyard where we could leave our scopes set up and just open up the roof and start observing?

Thousands of amateurs have built just that. The standard design, if there is such a thing, is the "roll-off-roof" observatory, which has a more or less normal peaked roof that rests on the walls of a typically rectangular building — except the roof rolls away on rails. Those are fine and work great, but they take up quite a lot of space and are relatively expensive and difficult to build. Those of us with smaller yards or smaller budgets would like something a little simpler. Fortunately, the ATM world is full of innovators. Here are four interesting designs that fit the bill, and quite possibly your own backyard.

Cloth Dome

California amateur Dan Belemecich's fabric dome is perhaps the simplest of the lot. It's simple because it has to be light enough for Dan to remove the top and sides when he observes, and to put them back up with cold, tired hands when he's done for the night. So, he used PVC pipe to form the curved framework of the dome and covered it with linen fabric. He cut the fabric in long arcs about a foot wide, wrapping each strip in concentric circles as he worked his way up to the top. He glued the cloth to the PVC tubing, then waterproofed it with more than five coats of latex house paint.

The lower wall sections are made of three curved panels framed with 2-by-2-inch wooden slats. Plywood strips cut to the proper diameter join the slats at top and bottom. Each wall section is covered in canvas. Dan didn't waterproof the canvas; it keeps the telescope plenty dry as is and allows any moisture that's trapped inside to evaporate out through the porous panels.

The dome weighs only 16 pounds, and the side panels weigh 20 pounds each, so they're easy to handle.

▼ *Left:* Dan Belemecich's fabric dome is lightweight and easy to open and close. It allows a 14-inch Dobsonian to fit in a 6-foot-diameter space yet leaves plenty of room for observing by the simple expedient of removing the dome and walls when ready to use. *Right:* The dome tips over on a metal hinge onto a waiting PVC framework, while the sides are carried out of the way. Pegs at the base of the wall sections fit into holes in the floor, and the whole works latches together with screen door hooks. Note the hole in the floor and the solid pad the telescope rests on. This isolates the instrument and eliminates vibration caused by moving around from transferring to the telescope.

DAN BELEMECICH (2)

The Icebox

A little more on the boxy side, we find the late North Carolina amateur Bill Madden's "Icebox Observatory." It certainly does look like an icebox you'd find in front of a grocery store, and it serves much the same function: It protects what's inside from the elements and lets you get at it easily when you need to. The two roof panels hinge upward to become light barriers and windbreaks, and the front wall panels swing outward to allow access.

Easy to build and comfortable to use, this design is a quick and effective observatory project.

◀ Bill Madden's Icebox Observatory is simple and functional. The structure is made of 2 × 4s and plywood, and the top is covered with rolled roofing with a generous overhang to keep the rain out.

▶ The roof splits in two and hinges upward and outward to become light- and wind barriers, and the front panels swing outward to allow easy access. Narrow shelving on the walls holds charts, eyepieces, and other equipment.

A-Frame

Saskatchewan, Canada deep-sky observer Mark Bratton had a little more room in his yard, so he decided to go with a roll-off-roof observatory, but his observatory is an A-frame, which is all roof! So he split the building in half and rolls each half away to open up a generous portion of sky for observing.

The design is based on one by Greg Mort that was featured in the March 1990 issue of *S&T*, p. 329, but Mark made a few improvements. Each half of the observatory uses 2-by-4s in a simple frame construction, overlaid with ¾-inch plywood panels for the roof and ½-inch panels for the walls. Roofing underlay topped by asphalt shingles completed the 60° pitched roof, while the walls are finished with white vinyl siding. The building halves rest on in-line castors, three under each wall, that roll on 6-by-6-inch posts laid sideways and are covered with ⅛-inch aluminum plate. Ratchet straps pull the building closed to form a tight seal, and hooks and eyebolts hold it to the floor when closed. A small door provides access when the observatory is shut.

One feature all these observatories have in common is a solid resting place for the telescope itself. You don't want to set your telescope on the same wooden floor you're walking on, because any movement on the floor is transferred to the telescope and magnified in the eyepiece. Dan, Bill, and Mark all cut out sections of the floor and set their scopes on solid concrete foundations. Mike made a solid concrete floor and concrete pedestal for his mount.

▼ *Left:* Mark Bratton's A-frame observatory is a variation on the common roll-off-roof design, with a twist: His observatory is all roof! *Right:* The A-frame halves roll sideways on in-line castors riding on aluminum-covered 6-by-6-inch rails set on a firm foundation. The scope rests on a separate pedestal that's isolated from vibration of the wood floor (which is decidedly warmer underfoot than an entirely concrete floor would be).

ICEBOX: BILL MADDEN (2); A-FRAME: MARK BRATTON (2)

Hinged Roof

Across the Atlantic, Nottinghamshire, UK amateur Mike Paling has come up with a different solution to the roof question: Rather than roll it off sideways or tilt it upward, he uses a compound hinge to fold it over and down to the sides of the building. Mike used computer-aided design software to work out the geometry of the hinges and roof movement, then built a 1:10 scale model to test the idea before building the full-size observatory.

The footprint is only 2 × 2 meters, and the roof peak is 2 meters high. A single door in front opens outward to provide access. Mike reports that the roof is easy to manipulate and cinches down tight.

▼ *Left:* Mike Paling's hinged-roof observatory fits a good-sized building in a relatively small (2-meter-square) space. *Right:* By splitting the roof in half and hinging each piece up and over the sides, the design ensures that the observatory takes up little more space when it's open than when it's closed. A door in front allows easy access.

The Walled Deck

Maryland ATM Ted Rafferty has done something a little different: Ted's observatory is just a sheltered deck with an adjacent shed, so he cut three individual holes in his deck for the legs of his tripod to fit through, where they rest on solid concrete pads below. Wooden covers fit over the holes when he's not observing.

▶ Ted Rafferty's observatory is a sheltered area of deck with a storage shed nearby. Note the holes in the deck for his tripod legs to reach solid ground, and the wooden covers that go over the holes when not in use.

HINGED ROOF: MIKE PALING (2); WALLED DECK: TED RAFFERTY

These are just a few of many backyard observatory designs, but they illustrate how varied observatories can be and still do their job. You can customize yours to fit your space, your equipment, your budget, and your temperament, and wind up with a very functional place to call your astronomical home.

For further information about these designs, contact Dan Belemecich at **danfind2@yahoo.com**, Mark Bratton at **mr.deepsky@hotmail.ca**, Mike Paling at **mikepalingxyz@gmail.com,** and Ted Rafferty at **raffw650@verizon.net**.

Mark also has a discussion on Cloudy Nights online forums with detailed notes on the construction of his A-frame at **https://is.gd/observatories**.

■ Contributing Editor **JERRY OLTION** still hauls his scopes in and out every clear night, but he's eyeing these designs carefully. Send him your ATM project ideas at **j.oltion@gmail.com**.

CLOUDY COLLISION

Douglas Struble

Sharpless 2-235 is an H II region arising from the collision of two enormous gas clouds. Sh 2-235 is the compact feature at lower right, while the large, diffuse area is Sh 2-232.

DETAILS: *Explore Scientific 152-mm refractor with a ZWO ASI1600MM Pro camera. Total exposure: 23 hours through Astrodon narrowband filters.*

▷ **SWAN SURPRISE**

Gerald Rhemann

One of the loveliest and brightest comets in recent years, Comet SWAN (C/2020 F8) is shown here as it appeared on the morning of May 1, passing northward through Cetus.

DETAILS: *ASA 12-inch f/3.6 Newtonian astrograph with FLI ML 16200 imaging camera. Total exposure: 18 minutes through LRGB filters.*

▽ **THE NEBULOUS SWAN**

Alistair Symon

Cygnus, the Swan, is rich with deep-sky treasures, including this expansive swath of nebulosity occupying the space between and surrounding Deneb and Gamma Cygni.

DETAILS: *85-mm Sigma lens and Takahashi FSQ-106EDX4 106-mm refractor, both used with a SBIG STXL-11002M camera. Total exposure: 65 hours through narrowband filters.*

MANHATTAN MOON

Chirag Upreti

A peach-colored Moon hovers above the Big Apple, New York City. The May full Moon was one of 2020's closest, occurring just 32 hours after perigee.

DETAILS: *Sony 17-200mm zoom lens with 2× teleconverter (set to 226mm at f/11), with a Sony α7R III camera. Total exposure: ½ second at ISO 100.*

▷ LYRA'S "OTHER" MESSIER

Ron Brecher

Often overlooked by observers content with finding Lyra's famous Ring Nebula (M57), globular cluster M56 is an attractive object in its own right — especially in mid-sized telescopes.

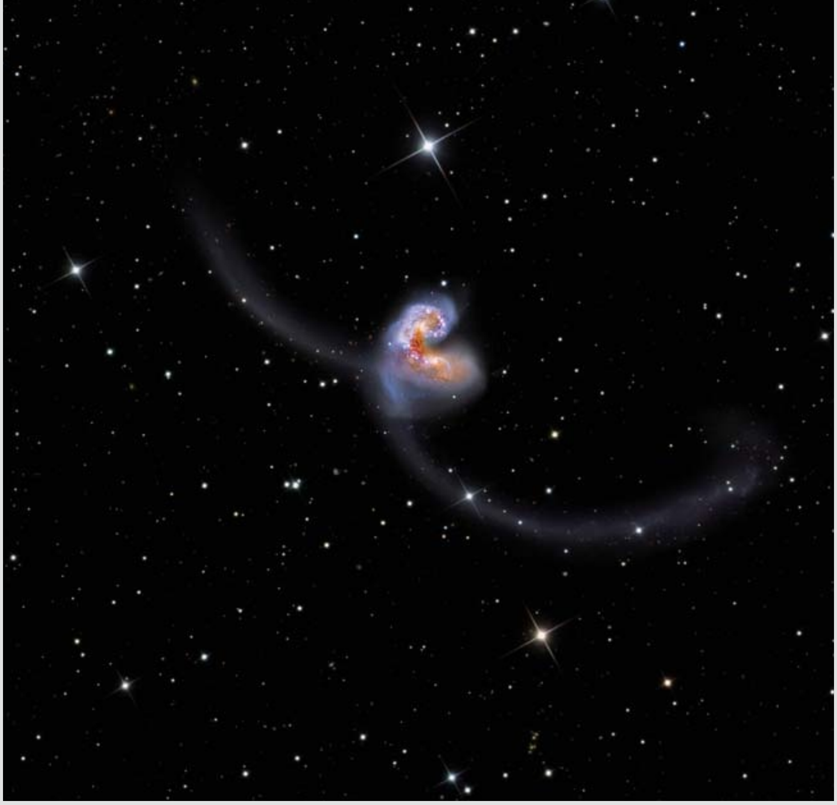
DETAILS: *Sky-Watcher Esprit 150mm ED Triplet APO and Takahashi FSQ-106 ED refractors equipped with QHY 16200-A and QHY367C cameras, respectively. Total exposure: 11¾ hours.*

PIRATE'S TREASURE

Kfir Simon

Stellar nursery NGC 2467 is informally known as the Skull and Crossbones Nebula. It's an appropriate nickname considering the nautical nature of its home, Puppis, the Stern.

DETAILS: *16-inch f/3.75 Dream Astrograph with Apogee Alta U16M CCD camera. Total exposure: 5½ hours through Hα and LRGB filters.*



◁ UNRAVELING GALAXIES

Nicholas Rolland

Although seemingly tearing each other apart, colliding galaxies NGC 4038 (top) and NGC 4039 are merging into a single object. This represents the likely fate of the Milky Way and Andromeda galaxies too.

DETAILS: *PlaneWave Instruments CDK17 with SBIG STXL-11002 CCD camera. Total exposure: 27.1 hours through LRGB and hydrogen-alpha filters.*

▽ BEACON BELOW THE STARS

Barry Burgess

The Cape Auguet Lighthouse in Nova Scotia, Canada, shines below the rising Milky Way.

DETAILS: *Canon EOS 6D DSLR camera with Sigma 14mm lens. Total exposure: 30 seconds at f/2.8, ISO 1250.*

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

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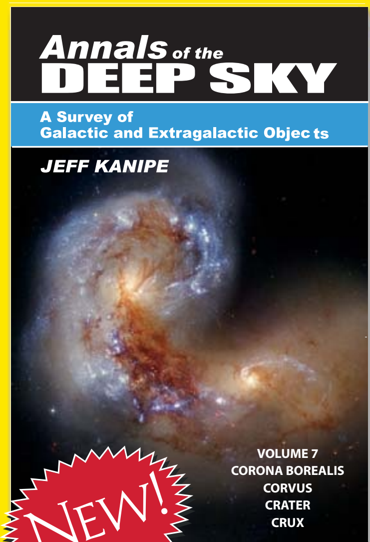

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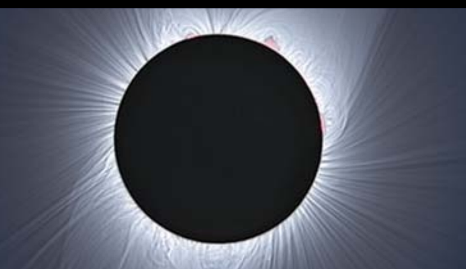

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Lunar Influence

Memories of an eclipse witnessed at age 10 inspire a return to science decades later.

LEAH TISCIONE / *S&T*

A CHILD'S COLORED PENCIL SET cannot possibly capture the sublime contours of light and shade displayed during a total lunar eclipse. Maroon, vermillion, carmine, crimson — recreating each hue would challenge the finest artists among us.

I was no match for them, of course. It was the wee hours of July 6, 1982, the night of the longest lunar eclipse in a century. I knew this because my parents had bought me a subscription to *Sky & Telescope*. Ten years old, with tortoiseshell eyeglasses perched under a pageboy haircut, I was a misfit everywhere but in my backyard. There, I was an astronomer. It was the most spectacular night of my life.

At half past midnight, an unthinkable hour for a child to be awake, I stepped outside. My mother stayed in the kitchen, preparing vital snacks. I opened my "Hello Kitty" notebook, peered through my tiny telescope as Earth's shadow started to creep across the Moon, and began to sketch.

It was a heady time to be entranced by the heavens. Five years earlier, the twin Voyager spacecraft had begun their expedition through the solar system. Then came *Cosmos*, the brilliant TV series. I lost myself in the marvels of the universe and thought Carl Sagan a kindred spirit. The maiden voyage of the Space Shuttle *Columbia* in April 1981 sealed the deal. I was a voyager, too, and astronomy was my playground.

Until college broke me. The huge classes were intimidating, the lectures went over my head, the problem sets felt interminable. In short, the magic of childhood had disappeared. One day I marched out of a science lecture for good, switched my major to Russian, and resolved never to look back.

Perhaps my early love of science would have stayed a memory, faint tendrils of a nebula emanating from around a forgotten star. But life doesn't always work that way.

Six years ago, I learned I was expecting a son. I imagined telling him that he could do anything he wanted in life if he put his mind to it. And then I remembered the eclipse. The notebook was long gone, but in my memory it was all there again — the colored pencils, the sketches of Earth's shadow, even "Ode to a Lunar Eclipse," the poem I wrote that night in rhyming couplets. How could I tell my son what he was capable of doing when I'd given up so easily on myself?

Unless, of course, I tried again.

At five months pregnant I hauled my growing tummy into a biology classroom for the first time in a quarter-century. This year I will complete premedical coursework in the Washington State community college system. To say this new adventure has been a challenge would be a massive understatement; in addition to explorer, I am worker, wife, and mother. But that enchanting eclipse and the dreams of exploration that lay before me as a child had more staying power than I would have imagined. I am a midlife 10-year-old again, steeped in the wonder of the universe.

Recently, I asked my mother what had inspired her to stay awake that long-ago evening so that I could watch the eclipse. It was the da Vinci school of parenting, she explained. "Leonardo da Vinci was left to figure things out for himself," she said. "So remember: When a child knows what she wants to do, just get out of her way." It was the best parenting advice I could have hoped for. Mom would sleep another night. And, in a heartbeat, no matter what he puts his mind to, I know I will always do the same thing for my son.

■ **NICOLE NAZZARO** is a writer based in Edmonds, Washington.