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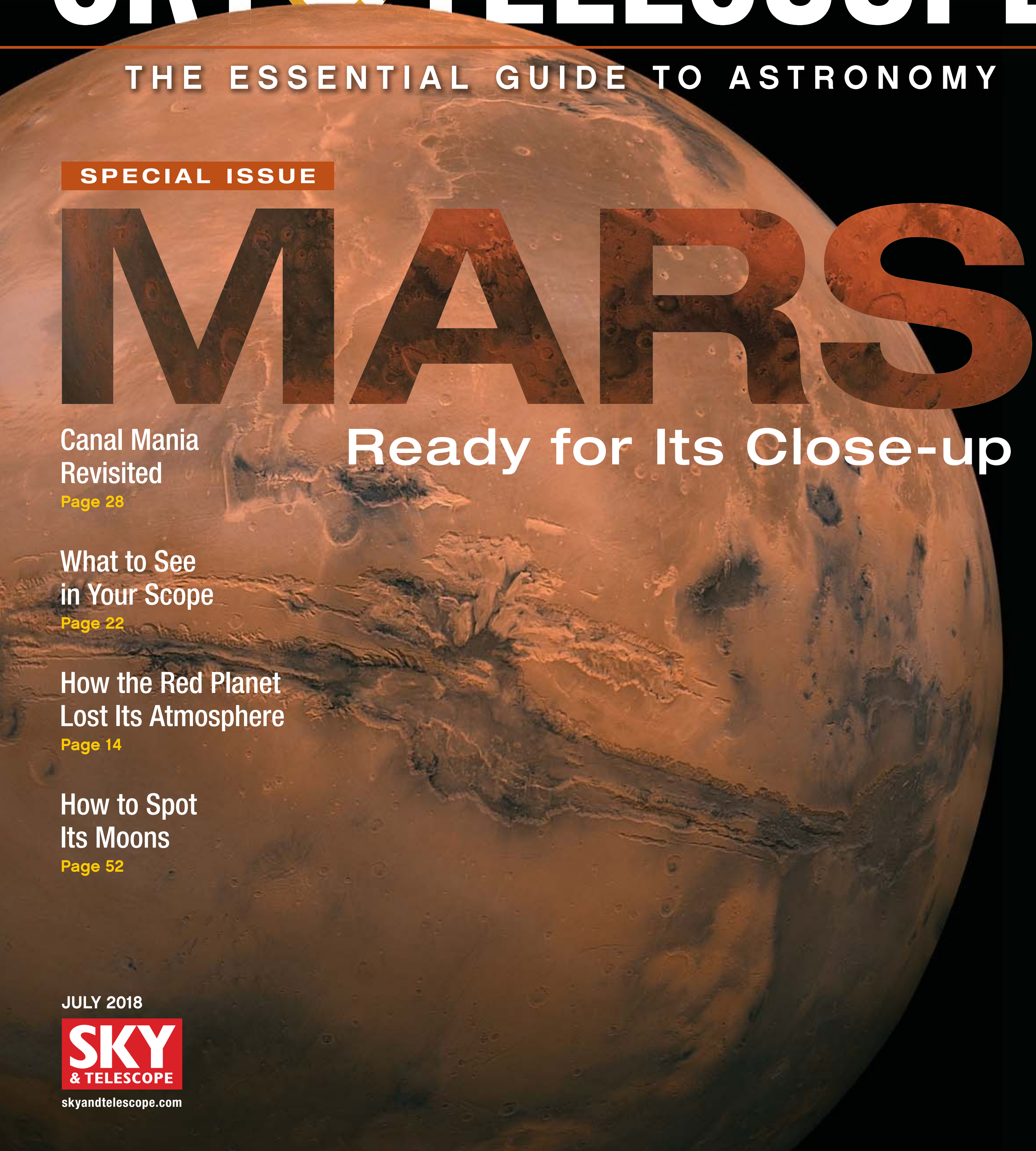
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY



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JULY 2018

SKY & TELESCOPE

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THE ESSENTIAL GUIDE TO ASTRONOMY

July 2018 VOL. 136, NO. 1

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ON THE COVER

This Viking Orbiter mosaic shows off Valles Marineris.

MARS: NASA / JPL-CALTECH; TYPE: ©CORBIS / CORBIS VIA GETTY IMAGES

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Follow Contributing Editor Bob King each week as he takes readers on an adventure through the night sky.
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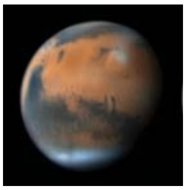
A Meteorologist on Mars

FOR THE BACKYARD ASTRONOMER, the Red Planet offers a certain rare opportunity, one that is particularly pronounced during fine apparitions like this year's, the best since 2003. It's something no other planet can provide, and it's available to anyone blessed with a modest-aperture telescope, good seeing conditions, and, as Bob King puts it in his article on page 22, "the patience of marble."

That singular fortuity is simply this: If you train your scope on Mars, you can actually *see* seasonal and even localized weather changes occur. I find that astounding. From the comfort of your favorite viewing location, you can observe dynamic environmental phenomena on the surface of another planet! (The only other planet whose surface we can view visually is Mercury, but its tenuous atmosphere offers nothing, well, mercurial for the amateur observer.)

As this year's Martian southern-hemisphere spring progresses, you can monitor winter mists dissipating to reveal the pearly white south polar cap. Train your eye over days or weeks on that cap, which is currently tipped towards us, and you can witness it gradually retreating as its ice sublimates. Gazing at the planet's mid-section, you might catch sight of faint *equatorial cloud bands*, while at its edges, you can look for "limb arcs," a bluish brightening caused by light scattered in dust and dry-ice particles high in the atmosphere.



Mars as it appeared on March 31, 2018

DAMIAN PEACH

Try spotting the snow-white clouds, comprised of water-ice crystals, that form in late spring and early summer above Olympus Mons and the other Tharsis shield volcanoes. Watch, too, for bright "morning clouds" of ground-hugging frost or fog (on Mars's celestial eastern or following edge) as well as their "evening" counterparts (on the western or preceding limb).

Finally, keep an eye peeled for what has been called in these pages "one of the most spectacular planet-altering events in the solar system" — a major Martian dust storm. These yellowish-tinted disturbances are especially noticeable when they blot out parts of dark albedo regions. Just pray the storm doesn't grow to enshroud the entire planet, as one did in 2001 (see photo page 20).

While you're enjoying this standout apparition, you might find yourself contemplating other mysteries of the Red Planet. We address several of them in this special issue: How did Mars lose its once-thick atmosphere (page 14)? What tips can advanced observers offer for sighting the moons Phobos and Deimos (page 52)? And why did a few astronomers in the early 20th century persist in maintaining that Mars bears canals built by intelligent beings (page 28)?

We encourage you to make the most of this close approach. You shall not look upon its like again for another 17 years.

Editor in Chief

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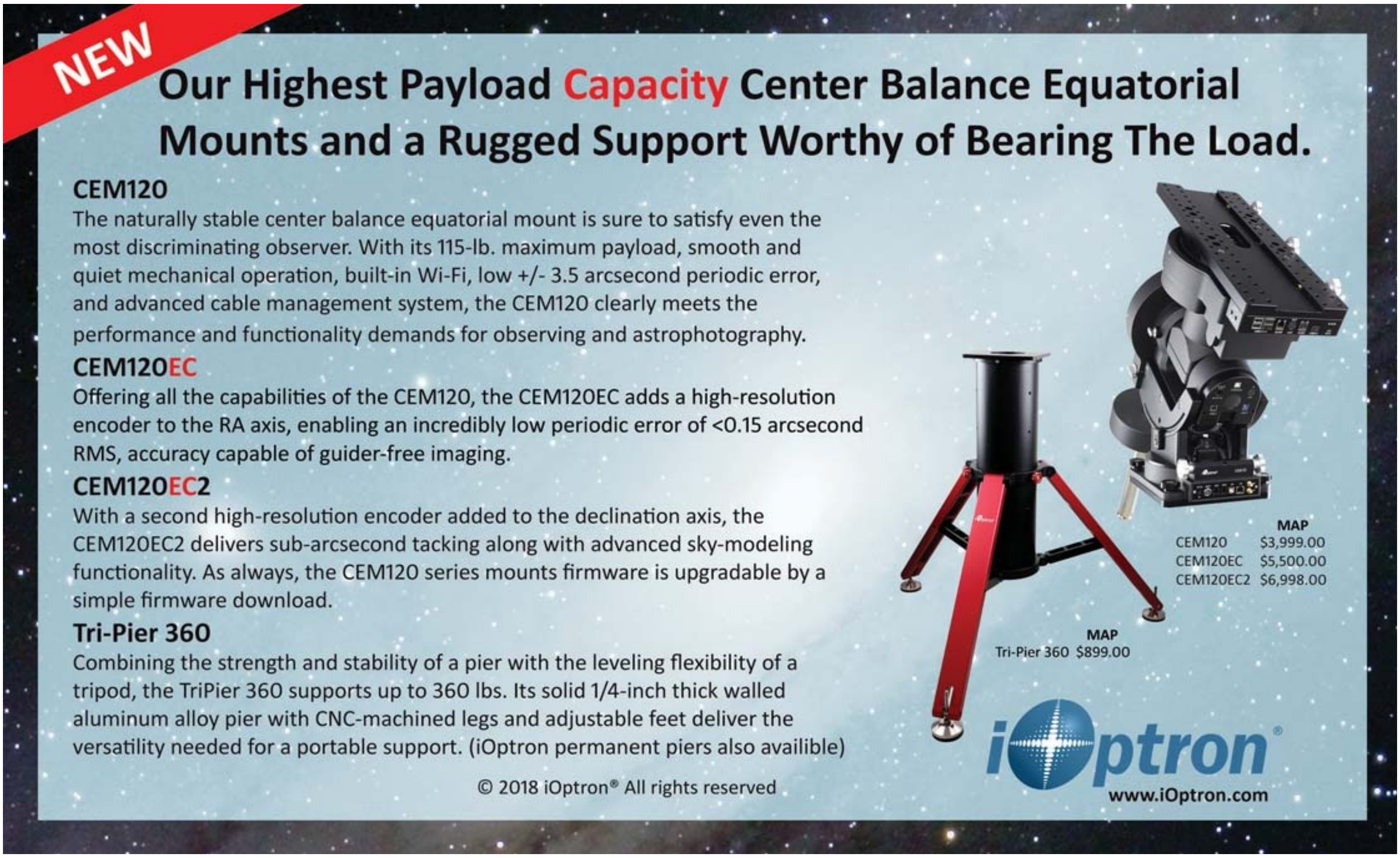
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Down by the Riverside

It was a pleasure to read about the early days of the Riverside Telescope Maker's Conference (*S&T:* Feb. 2018, p. 64). I attended the first one in 1969, as a student in the Citrus College optics program. A year later I joined Chabot Observatory's Telescope Makers' Workshop under the mentorship of Paul Zurakowski (Frank Wright started the workshop in the 1930s). Paul was instrumental in influencing many of the students who are pictured in the article.

For more than 30 years Paul and I were on the team of RTMC judges and together inspected at least a thousand telescopes. For our efforts we both received the Clifford W. Holmes Award; Paul got the very first one in 1978. Students from the workshop went on to earn many merit awards and serve as judges over the years.

We hope RTMC will continue for another 50 years; young people need its pathway into science careers under the STEM programs. Perhaps one will be encouraged to become an optical engineer or astronomer.

Robert Schalck • North Bend, Oregon

Although I did not attend the earliest RTMC gatherings at Riverside Community College, I went to two at the Idyllwild site, probably in 1973 and 1974. From personal experience, the story of John Dobson sleeping in his telescope tube is true.

I had driven a short distance from the main area to a turnout said to give a view of the Hale Telescope's dome on nearby Palomar Mountain. Pulling into the site, I noticed a school bus and a large tube on the ground next to it. Dobson was just emerging from the front of the tube and said he was just getting up for the day. I believe that this experience confirms the story.

The tube was huge, and I later realized that it was for his 24-inch Newtonian reflector. He had to remove the diagonal to enter, and he showed me how he remounted it for viewing. The diagonal was on a wooden cross, fitted to be pressed to the inside of the tube and then pulled into place while looking through the eyepiece holder. I had some nice deep-sky views with the instrument that evening.

Michael O'Neal • Blue Jay, California

▲ John Dobson's 24- and 22-inch reflectors tower over participants at the 1978 Riverside Telescope Maker's Conference near Big Bear, California. It was the ATM community's first major encounter with Dobson and his big scopes, which were brought to the conference by the San Francisco Sidewalk Astronomers.

S&T / DENNIS DI CICCO

Longer Odds

Regarding Earth's changing magnetic field (*S&T:* Mar. 2018, p. 16), if the existence of Earth's robust magnetic field is vital to making our planet habitable, yet it took a freak event to stir the mix (the collision that produced the Moon), then a new sub-variable would need to be added to the Drake equation, namely, the odds that such an event would happen *and* the planet also survives.

Intelligent life seems to be growing ever more improbable!

Tom Sales
Somerset, New Jersey

So Far and Yet So Near

In the Spectrum column "Lonely Wanderer" (*S&T:* Feb. 2018, p. 4), Peter Tyson refers to the newly discovered interstellar visitor 'Oumuamua as a "near-Earth object." This seems reasonable, as this asteroidal object's perihelion was 0.255 astronomical unit (on September 9, 2017), and the official definition of NEOs is "asteroids and comets with perihelion distance q less than 1.3 au" (**cneos.jpl.nasa.gov/about/neo_groups.html**).

However, NASA also adds the following proviso: "Near-Earth Comets (NECs) are further restricted to include only short-period comets (i.e., orbital period P less than 200 years)." It seems to me that the same proviso was not applied to near-Earth asteroids simply because an asteroid coming from beyond the asteroid belt, not to mention beyond the solar system, was never imagined.

Presumably, whatever reasoning led to the restriction in the case of comets would apply as well to asteroids. Therefore 'Oumuamua is not, strictly speaking, a near-Earth object.

But why did NASA include the restriction on comets in the first place? Did the dictates of planetary defense trump astronomy (or common sense), and long-period comets were deemed too rare or too large to defend against, given present technological and economic constraints?

Joel Marks
Milford, Connecticut

Mission Omissions

Your "Space Missions in 2018" summary (*S&T:* Jan. 2018, p. 16) omits some space weather and other missions. I noticed that these missions were also absent from the list the previous year, and since there have been no corrections, I thought it time to send this information.

The most notable omissions are NASA's Van Allen Probes, two satellites studying Earth's radiation belts, as well as the Magnetospheric Multiscale (MMS) mission, four spacecraft moving through Earth's magnetosphere in highly elliptical orbits.

According to the list at **science.nasa.gov/missions-page**, TWINS and Geotail, other space weather missions, are also still operational. Other missions on this list that are still operational are MESSENGER, AIM, and GRACE, as well as other Earth observation satellites. I have used GRACE data for space weather studies on how much auroral currents heat and expand the thermosphere. I also use data from TIMED, another NASA mission that is presently operational.

There are also ESA's three Swarm satellites (**earth.esa.int/web/guest/missions/esa-operational-eo-missions/swarm**) that I'm currently using for space weather research, mainly for measuring auroral currents and atmospheric density.

Daniel Weimer
Blacksburg, Virginia

Camille Carlisle replies: *Thank you for pointing out these omissions. I went back through my notes and found MMS and Geotail on my original list, but somehow they never made it into the spreadsheet used to create the illustration. I'll make sure we include them when creating next year's list.*

Adler Memories

It was a treat to read Michelle Larson's article on the Adler Planetarium entitled "#LookUp with Us" (*S&T:* Mar. 2018, p. 64).

In October 1947 I was beginning studies at the University of Chicago, and one of my first trips downtown was a visit to the Adler. The topic of the lecture I attended was "Entropy," and the lecturer was a fellow in astronomy at Chicago named Gerard Kuiper. It was unforgettable.

Fred Matthies
Portland, Oregon

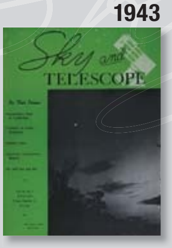
FOR THE RECORD

• Due to a production error, the AARP ad in the April 2018 issue was glued onto an editorial page (p. 68). We regret the errant placement as well as any tearing of the page when the ad was removed.

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

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

1943



1968

1993

◖ July 1943

Blue Moon "This month's question is from Mrs. H. W. Shimer, of Hingham, Mass.

"Q. Can you tell me anything about a 'blue moon'?

"A. There are at least two possible origins of this expression. The more elaborate is given in the *Maine Farmers' Almanac* for 1937. 'The moon usually comes full twelve times in a year, three times in each season. . . . [But] occasionally the moon comes full thirteen times in a year. This was considered a very unfortunate circumstance. . . . Also this extra moon had a way of coming in each of the seasons so that it could not be given a name appropriate to the time of year like the other moons. It was usually called the Blue Moon."

Columnist Laurence J. Lafleur failed to give a specific example, thereby paving the way for the now-famous error, three years later, where another S&T *contributor thought the term referred to the second full Moon in a month (see* **https://is.gd/bluemoon***).*

◖ July 1968

Novae Compared "A rare spectacle occurred in the spring sky this year: two naked-eye novae were simultaneously visible less than 20 degrees apart. They had been discovered by the same English amateur, G. [George E. D.] Alcock — Nova Delphini on July 8, 1967, Nova Vulpeculae on April 15, 1968.

"At McDonald Observatory in Texas, Brian Warner used the 82-inch Otto Struve reflector to photograph the spectra of both novae on the same night, April 20, 1968, when the stars were of about magnitude 5. The Vulpecula object had passed maximum just three days before [while the other was] nine months after its outburst. . . .

"The [spectra] look very different, the Delphinus one . . . having generally narrower emission lines than the Vulpecula star, which has a very complex spectrum."

◖ July 1993

Oddest Comet "I swung the [18-inch Palomar Schmidt] to our next search area, then sneered as a bright glow almost swamped the view in the telescope's finder. 'Dollars to doughnuts,' I cried out, 'Jupiter's in this field!' Nevertheless, we took three exposures of the region before the clouds thickened. . . .

"[Studying the images later,] suddenly Carolyn straightened up in her chair. 'I don't know what this is,' she said. 'It looks like . . . like a squashed comet.'

"Indeed, hovering amid the stars was the strangest object we had ever seen. It looked like a comet, all right, but instead of having a nice round coma, this one was rectangular! Was it a light streak? No, because it appeared on both films."

David Levy, with Gene and Carolyn Shoemaker, had just found Comet Shoemaker-Levy 9. They didn't yet know that just a year later the enigmatic object would crash right into Jupiter itself.

◀ This Hubble Space Telescope image of NGC 1052-DF2 shows the blob-shaped galaxy's diffuse nature — it has so few stars and is so sparse that background galaxies are visible through it.

GALAXIES

A Galaxy Without Dark Matter?

ASTRONOMERS HAVE LONG thought you couldn't have galaxies without dark matter, just as you can't have a cup of coffee without the cup. But the fluffy galaxy NGC 1052-DF2 contradicts this picture. Combining ground- and space-based observations, Pieter van Dokkum (Yale University) and colleagues have found that this diffuse galaxy has 400 times less dark matter compared to other systems of similar mass. In fact, it might not have any dark matter at all.

The peculiar object is part of a group of galaxies 65 million light-years away that's dominated by the beefy elliptical NGC 1052. Astronomers already knew NGC 1052-DF2 existed, but its appearance in images from the team's Dragonfly Telephoto Array puzzled the researchers. Follow-up revealed the galaxy is so sparse that it's see-through.

Ten strangely big and bright globular clusters surround the galaxy. By measuring how quickly they orbit DF2, the astronomers estimated the galaxy's mass, which they found to be surprisingly low — roughly equal to the mass visible as stars, with essentially no dark matter. No other objects in DF2's class of so-called *ultra-diffuse galaxies* show this paucity of dark matter.

It's unclear how the galaxy came to exist. One possibility is that the elliptical had stripped DF2 of its dark matter when it passed too close, causing the remaining stars to "puff up." But the Dragonfly team doesn't see signs of disturbance around the galaxy, which it thinks disfavors this scenario. The researchers suggest a few other possible origins for DF2 in the March 29th *Nature*, but nothing fits perfectly.

That the coffee can exist without the cup indicates that the cup and coffee are both real entities, the team concludes. If the presence of dark matter were only an illusion, arising because we're using the wrong theory of gravity, then we'd always see signs of it in galaxies. But if the dark matter can be sometimes there and sometimes absent, then dark matter must exist. This result therefore undermines alternative approaches, including *modified Newtonian dynamics* (MOND), a theory of gravity that does without dark matter by suggesting gravity works slightly differently than in Einstein's framework, the team says.

MOND expert Stacy McGaugh (Case Western Reserve University) isn't so sure. He agrees that MOND predicts that DF2's globulars should move faster than they do. But he's squeamish about tweaking the fraction of dark matter in any given galaxy just to make sense of its stars' motions — that's an inference, not a prediction that can be proved or disproved, he says.

The Dragonfly team continues to look for more galaxies like DF2, and they've found three potentially similar objects for further study. With more than one such galaxy in hand, astronomers might be able to say more about how these galaxies form and what they mean for dark matter.

■ **CAMILLE M. CARLISLE**

SOLAR SYSTEM

Is 'Oumuamua Pancake-Shaped?

A NEW ANALYSIS of 818 telescopic observations suggests that our first known interstellar visitor could have the shape of a flattened disk.

Small-body specialist Michael Belton (Belton Space Exploration Initiatives) and colleagues pooled brightness estimates from nearly a dozen major instruments — including the Hubble Space Telescope — in order to unravel the details of 1I/'Oumuamua's shape and spin. Their conclusions appear in the April 1st *Astrophysical Journal Letters*.

◀ A new, pancake-shaped artist's concept of 'Oumuamua.

Belton and coauthor Karen Meech (University of Hawai'i) say that 'Oumuamua is tumbling, spinning every 54.48 hours with a pronounced wobble that takes 8.67 hours to complete. However, it's unclear if the object is rotating mainly end-over-end or if the primary spin axis is close to its long axis, like a wobbling, badly thrown football. How it spins determines our

NGC 1052-DF2: P. VAN DOKKUM / R. ABRAHAM / STSCI; 'OUMUAMUA: © WILLIAM K. HARTMANN

SPACECRAFT

James Webb Telescope Delayed Until 2020

NASA OFFICIALS HAVE announced that the launch of the James Webb Space Telescope will be delayed until approximately May 2020, slipping more than a year from its previous goal between March and June 2019.

To date, the agency has spent $7.3 billion on Webb's development. If the mission's development costs go over the $8 billion maximum that Congress set in 2011, Congress will need to reauthorize the project. An independent review will nail down the changes in cost and schedule, and NASA will report its assessment to Congress in late June.

The pieces of Webb are all complete; what's costing time and money is the often unpredictable "integration and testing" phase. NASA officials admit that the initial schedule for this phase was optimistic.

Some of the technical challenges faced were instructive. For example, the complex sunshield was torn during testing, so engineers made changes to its storage and deployment. Preventing damage is crucial, as the shield protects the telescope's sensitivity at near-infrared wavelengths.

There were also avoidable errors: A transducer was incorrectly powered and had to be replaced, resulting in a three-month delay, and an incorrect solvent was run through the propulsion system, damaging valves and seals and necessitating their replacement. To avoid future mistakes, NASA officials outlined plans to monitor contractor Northrop Grumman more closely.

▲ This 2017 image shows all five tennis-court-size, membranous layers of Webb's sunshield, displayed in Northrop Grumman's clean room in Redondo Beach, California. These will have to fold into the Ariane 5 rocket fairing.

NORTHROP GRUMMAN CORPORATION

Webb is a top priority within the astronomical community and represents NASA's largest international space science project. Once it launches, the 6.5-meter near-infrared telescope will orbit the Sun at the Lagrangian point L_2, 1.5 million km farther out than Earth. The telescope will peer farther back in cosmic time than Hubble to see the universe's first stars and galaxies. Astronomers will also use Webb to characterize nearby exoplanets.

The delay will have a broad impact on the astronomical community, notes associate administrator Thomas Zurbuchen, both in terms of perception and actual cost. Nevertheless, he insists, he doesn't want the agency to shy away from large, complex projects: "I want us to have ambition."

■ MONICA YOUNG

---

understanding of its shape, which Belton's team concludes could be anything from a cigar to a fat pancake. For the moment, either shape is equally likely.

'Oumuamua's overall spectrum and apparent lack of outgassing imply that it's rocky, which could mean that it was ejected from the inner region of its host solar system. Yet Sean Raymond (University of Bordeaux, France) and others argue in the May 21st *Monthly Notices of the Royal Astronomical Society* that too few asteroidal fragments would be ejected to make it statistically likely for one to reach us, unless it was ejected from a two-star system.

'Oumuamua may keep its secrets, but chances are we'll find another interloper soon: Calculations by Aaron Do (University of Hawai'i) and colleagues suggest that there are likely several of these objects in the inner solar system at any given time.

■ J. KELLY BEATTY

IN BRIEF

Update on the Aurora Named STEVE

For years amateur astronomers have seen and photographed a thin, faintly pink- or purple-colored ribbon that runs east-to-west southward of the northern lights. (To read about the discovery, visit **https://is.gd/aurorasteve**.) Eventually dubbed "Steve," neither amateurs nor researchers knew what the phenomenon was. Analyzing data from the European Space Agency's Swarm A satellite, which flew directly through a Steve ribbon in 2016, Elizabeth MacDonald (NASA Goddard) and colleagues suggest in the March 14th *Science Advances* that the amateurs had spotted the *subauroral ion drift* (SAID), a rapid flow of charged particles through Earth's atmosphere that's associated with brightening aurora. However, scientists had never known of visible emission from SAIDs, and the radiation mechanism remains unclear. In the meantime, the visual phenomenon gets to keep its name: STEVE, short for Strong Thermal Emission Velocity Enhancement.

■ MONICA YOUNG

Tiangong 1's Remote Reentry

China's first space station, Tiangong 1 (Chinese for "celestial palace"), reentered Earth's atmosphere over the South Pacific on April 2nd after almost seven years in space. No humans reported witnessing the reentry, but NASA and the European Space Agency mounted a campaign to remotely monitor the space station in an effort to better model future reentries. The reentry location was largely unknown beforehand, complicated by the vehicle's uncertain mass: While the media often cited it as 8.5 metric tons, that number assumed a ton of fuel still onboard. Tracking the reentry impressed upon scientists the sensitivity of predictions to solar activity, the state of Earth's thermosphere, and atmospheric drag.

■ DAVID DICKINSON

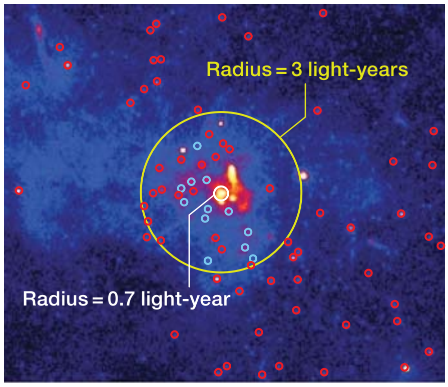
MILKY WAY

Galaxy's Center Is Home to Many Black Holes

A NEW X-RAY STUDY has uncovered a dozen potential stellar-mass black holes within 3 light-years of the supermassive black hole lurking in our galaxy's core — and these might be just the tip of the proverbial iceberg.

We've long known that a supermassive black hole lurks in the Milky Way's center. Now, a study published in the April 5th *Nature* makes the case that up to 10,000 or so stellar-mass black holes could be keeping it company.

Beginning with 16 days' worth of observations that the Chandra X-ray Observatory had collected over the past 12 years, Charles Hailey (Columbia University) and colleagues analyzed 26 sources that remain unresolved at X-ray wavelengths and lie within 3 light-years of the supermassive black hole. Typically, most X-ray emitters found near our galaxy's center are white dwarfs in binary systems, which siphon gas off of their ordinary stellar companions and radiate more of their energy at *lower* X-ray energies. But 12 of the 26 sources the team found are relatively brighter at *higher* X-ray energies. They also appear to be binaries, but with more massive neutron stars or black holes instead of white dwarfs. Hailey and colleagues argue that the sources are more likely to be black holes, as long-term monitoring of the galactic center should have found all neutron star binaries by now via their outbursts.



▲ A Chandra X-ray image of the Milky Way's center is overlaid with circles around unresolved X-ray sources. Red circles indicate white dwarf binaries, while blue circles denote likely black hole binaries.

If there are a dozen stellar-mass black hole binaries that we can see, then many more isolated (and therefore invisible) black holes might exist in the galactic center. Exactly how many depends on the binaries' origin. If they formed when the stellar remnants captured old, low-mass stars — instead of beginning life as a pair of stars — then there could be as many as 10,000 black holes in the galaxy's core.

But whether all 12 sources are black holes and how they got there remain uncertain. Hailey and his team acknowledge that as many as half of their X-ray sources could be *rotation-powered millisecond pulsars*: fast-spinning neutrons stars that exhibit fewer outbursts. Then there might be several hundred instead of thousands of black holes in the galactic center. Daryl Haggard (McGill University, Canada), who wasn't involved in this research, notes that future radio studies could distinguish between black holes and neutron stars, which would help astronomers pin down the number and origin of massive objects in our galaxy's core.

■ MONICA YOUNG

STARS

Astronomers Catch Cache of "Fast Supernovae"

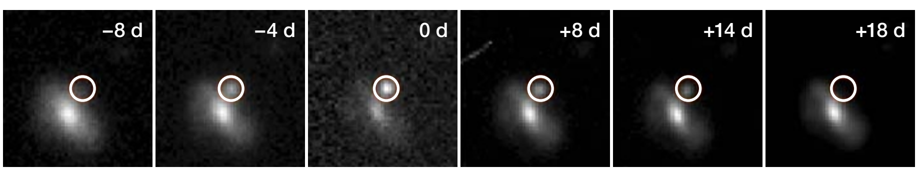
THE DARK ENERGY SURVEY'S SUPERNOVA (DES-SN) Program has detected 72 fast and furious explosions, Miika Pursiainen (University of Southampton) announced at the European Week of Astronomy and Space Science 2018 in Liverpool, UK. These *fast-evolving luminous transients* (FELTs) have the energy of a regular supernova explosion, but they brighten and fade within days or weeks rather than months or years.

A few dozen of these "fast supernovae" were already known, but their origin remained unclear. With DES data in hand, Pursiainen and colleagues conclude that the emission from a typical FELT comes from a hot, expanding shell of material — possibly a dense cocoon around an exploding star. The shell may span anywhere between a few and 100 astronomical units (the average distance between Earth and the Sun), with a temperature between 10,000K and 30,000K.

These findings agree with another recent result from NASA's Kepler mission. In 2015 Kepler spotted a FELT known as KSN 2015K, measuring its brightness every 30 minutes over a three-week period. In the March 26th *Nature Astronomy*, Armin Rest (Space Telescope Science Institute) and colleagues report that KSN 2015K's rise to peak brightness occurred in just 2.2 days, before it faded by a factor of two over 5 days. The richly sampled light curve enabled the team to exclude all but one viable scenario: A giant star had shed a huge amount of gas and dust less than a year before it went supernova. When it ultimately exploded, the star's outer layers slammed into the thick cocoon, turning most of the kinetic energy into heat and light.

Pursiainen and Rest agree that it's unclear whether this cocoon model would apply to all 72 DES-SN supernovae. Future DES observations will doubtless reveal more FELTs, and studying larger numbers will help elucidate their true nature.

■ GOVERT SCHILLING



▲ One of the 72 fast-evolving luminous transients (FELTs) observed by the Dark Energy Survey

STARS

Supergiant Runaway Star

ASTRONOMERS HAVE SPOTTED a rare supergiant star speeding through the Milky Way's neighboring galaxy, the Small Magellanic Cloud, at 300 km/s (700,000 mph). Kathryn Neugent (University of Washington) and colleagues present the results in an upcoming issue of *Astronomical Journal*.

The sighting is unique not only because of the star's high speed but also its advanced phase of evolution. The star, J01020100-7122208, appears to be a yellow supergiant, a phase that lasts only 10,000 to 100,000 years before the star balloons into a red supergiant.

"It's unexpected to find a very rare object in a very rare phase," says Warren Brown (Harvard-Smithsonian Center for Astrophysics), who wasn't involved in this study. "The joint probability is unlikely, so the implication is that runaways are quite common."

A runaway star moves significantly faster than other stars from its birthplace. Most known runaway stars are in the Milky Way; this yellow supergiant is only the second known evolved runaway in another galaxy. Neugent and colleagues suggest the star became a runaway when its stellar companion exploded in a supernova, ejecting mass from the system and enabling the star to fly away at high speed.

■ ELIZABETH HOWELL

Integral Shape Filament in Orion Nebula

ESO / H. DRASS / ALMA (ESO / NAOJ / NRAO) / A. HACAR

Star-forming Braids in the Orion Nebula

New ALMA observations reveal fiber-like structures within a longer, well-studied filament of dense gas within the Orion Nebula. These fibers will eventually form massive stars.

Back in 2015 Mario Tafalla (National Astronomical Observatory, Spain) and Alvaro Hacar (now at Leiden University, The Netherlands) studied a 30-light-year-long gaseous filament in a region forming low-mass stars. They found that the filament was like a rope made of smaller bundles of "fibers" (*S&T:* Oct. 2015, p. 28). The denser fibers were each typically 1½ light-years long. The seeds of future stars — compact areas that will eventually collapse into stars but haven't yet — can be seen as knots in these braids.

Hacar thought fibers might act as the fundamental building blocks of star formation, with more massive stars requiring more fibers. But it was unclear whether the bundle-of-fibers scenario would apply in denser environments, like the Orion Nebula, where high-mass stars come together. Other teams had suggested that the fibers in such regions would be more massive rather than more numerous.

High-mass stars are rare and typically far away, making their birthplaces difficult to observe. So Hacar and colleagues used the Atacama Large Millimeter/submillimeter Array to zoom in on the 20-light-year-long Integral Shape Filament, which crosses massive star-forming regions in the Orion Nebula. The team found a network of 55 fibers that braid into the single, larger filament, a result that fits into the pattern of more fibers in more massive star-forming regions. The only difference is that Orion's fibers are typically only ½ light-year long, on average three times shorter than the ones the researchers spotted in the low-mass star-forming region.

■ MONICA YOUNG

IN BRIEF

Hubble Images Most Distant Star

It's difficult to resolve stars in galaxies outside our own, but with the help of some cosmic lensing, the Hubble Space Telescope has imaged a star that existed when the universe was less than a third of its current age, at a redshift of 1.49. Hubble's optics were aided by two of the universe's own lenses: The first was the presence of a foreground galaxy cluster known as MACS J1149-2223, whose immense gravity bent and magnified the light from the background star. The second was something closer to the star, with three times the Sun's mass — perhaps another star, a neutron star, or a stellar-mass black hole — that gravitationally tweaked the starlight in what's known as a *microlensing event*. The combination of the two gravitational lenses magnified the star's light more than 2,000 times, making it visible to Hubble. The star itself is a blue supergiant much bigger, brighter, and hotter than the Sun. The results appear in the April 2nd *Nature Astronomy*.

■ MONICA YOUNG

Nearby Relic of Ancient Universe

NGC 1277 is a stunted galaxy, largely ungrown since the universe's early years, observations by Michael Beasley (Canary Islands Institute of Astrophysics, Spain) and colleagues confirm in the March 12th *Nature*. The galaxy, which lies 240 million light-years away in the center of the Perseus Cluster, is a dense "red nugget" — although it has twice as many stars as the Milky Way, it's about a quarter of our galaxy's size and filled with old stars that formed early on. Astronomers already suspected that NGC 1277 was frozen in time, but Beasley's team decided to test the idea. They hypothesized that, if NGC 1277 were really a relic, all its globular clusters would be rich in heavy elements because they had formed when the galaxy first coalesced. The team's Hubble Space Telescope observations confirm NGC 1277 has almost no young globular clusters, so NGC 1277 hasn't grown much by accreting other galaxies. The relic offers astronomers access to a relatively nearby example of early systems that are much more difficult to study.

■ CAMILLE M. CARLISLE

Advancing the SETI Quest

Hope, perseverance, and the courage of their convictions sustain those seeking hints of alien civilizations.

Seven days a week, the SETI Institute uses the Allen Telescope Array in California for its searches.

SETH SHOSTAK / SETI INSTITUTE

IN MARCH I ATTENDED a SETI Institute workshop, where a multidisciplinary group of astronomers, neuroscientists, anthropologists, philosophers, and historians pondered new approaches to expanding the search for extraterrestrial intelligence. Discussions ranged from the physics of planet formation, through the origin and evolution of life and the prospects for complex life and intelligence, to coming hunts for both biosignatures and "technosignatures" on exoplanets.

To me, the way these topics flowed together at the meeting served as a reminder that the distinction between astrobiology and SETI is completely artificial. It might exist in terms of bureaucracies and funding streams, but intellectually the quest to know how we — and living things in general — fit into the universe is all part of the same nested series of questions:

How does matter turn into living cells? Is this unlikely or inevitable? What is required of a planet to support this and the subsequent transitions to differentiated cells, multicellular life, cognition, curiosity, and technology? What planetary transitions accompanied, enabled, or were caused by these biological leaps? Should these have occurred on other types of planets that we know or suspect exist, and how would we recognize them?

For the future of SETI, the practical questions are, regrettably, as vexing as the intellectual ones. Few would deny how far-reaching success would be, but how do you maintain funding and scientific interest in a field where the payoff in any given year (or even decade) is so uncertain?

Not long ago, many deemed exobiology, along with SETI, as a fringe field, which "serious" researchers must keep at arm's length. In the 1990s, anti-intellectual budget cutters in Congress discontinued all federal government support for SETI. In 1998, attitudes changed. This came about largely due to the discovery of possible microfossils in a meteorite from Mars and the subsequent flurry of scientific and public excitement. It turned out to be a false alarm, but exobiology was rechristened as "astrobiology" and suddenly became acceptable, well-funded, and even thought central to NASA's mission.

In terms of government backing, however, SETI remains out in the cold. Maybe it needs its own highly credible false alarm! In the meantime, how do SETI researchers, year in and year out, remain engaged and positive?

At the workshop, you couldn't help but notice that among the most engaged and positive participants were the now "retired" SETI pioneers Frank Drake and Jill Tarter. Their enthusiasm doesn't depend upon immediate gratification. Both clearly believe, as do I, that we are not alone, that these efforts will ultimately pay off, and that whether we live to see it or not, we're contributing to something extremely important and larger than ourselves.

With new technologies and search strategies coming into play, with all the exoplanets that astronomers will soon bring into focus, and with people like Tarter and Drake willing to spend their entire careers on the quest — the odds be damned — I believe we have many reasons to be hopeful.

■ **DAVID GRINSPOON** gave a paper at the SETI workshop entitled, "Cognitive Planetary Transitions: An Astrobiological Perspective on the 'Sapiezoic Eon.'" He coined the term to denote a theoretical time when cognitive processes become integrated into a planet's functioning.

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 by Bruce Jakosky

Mars's LOST atmosphere

FLOOD LINES Scientists think that catastrophic flooding carved Osuga Valles, the central portion of which is shown here. The floor has been grooved by fast-flowing water. In some places, Osuga Valles plunges 900 m (3,000 ft) deep. It sits at the eastern edge of the Valles Marineris canyon system.

NASA's MAVEN mission has confirmed how our planetary neighbor lost its protective gas envelope.

Mention anything about the potential for life on Mars, and you'll get people's attention. The conversation often centers on water. Life as we know it requires liquid water, and the evidence that Mars has had liquid water in various forms throughout its history means that it could have supported life.

But Mars is a frozen, desert planet today, with a thin atmosphere and temperatures typically well below the melting point of water ice. So why do we think Mars had abundant liquid water in the past? And what caused the climate to change to one unfriendly to life?

The evidence that Mars once had liquid water came initially from orbiter images. Thanks to them, we've known for decades that Mars has systems of valleys that look like they formed via water runoff. We've seen what appear to be deposits of sediments carried by water as it flowed into the enclosed basins of impact craters. We've also observed that the oldest surfaces look worn down, and that few impact craters smaller than about 10–15 km wide mar the landscape, which combined tell us that significant erosion has occurred — with erosion by water runoff being the favored explanation.

Starting with the Mars Pathfinder landing in 1997, we also began observing small-scale surface features that suggested water once flowed. We've identified sediment deposits that bear all the hallmarks of having been laid down in liquid water. And we've seen small, round deposits formed by the buildup of waterborne material, called *concretions*, and even specific minerals that require liquid water in order to form.

By estimating dates for these various features, planetary scientists have put together a rough timeline for water on Mars. It reveals that the strongest signs of liquid water tend to be very old. In fact, all of the geological and geochemical evidence points toward Mars having had a climate that allowed liquid water to be widespread on the surface up until about 3.5 to 3.7 billion years ago. Conditions then changed rapidly (geologically speaking), and whatever allowed water to be present disappeared over a period of only a few hundred million years, leaving behind a colder and drier planet.

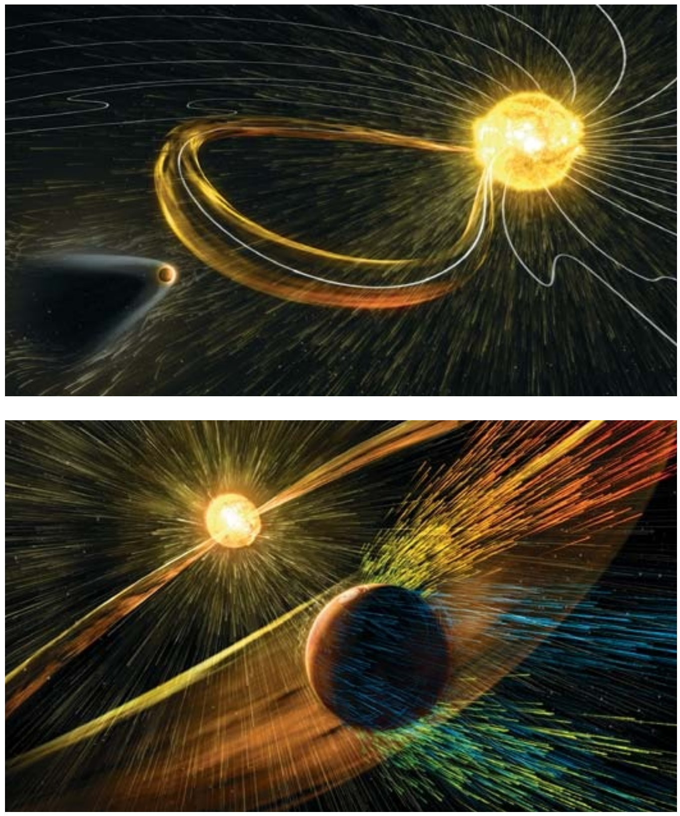
There is some evidence for water in later epochs — large flood channels that appear to have been formed by the catastrophic release of water from the subsurface, very recent (within the last couple million years) gullies that may involve water — but not as an abundant, stable liquid. These later features would all involve subsurface sources and do not require a different climate than what we see today.

What would the climate on early Mars have looked like? We expect that the average temperature likely was near 0°C or higher in order to support extensive liquid water. This compares to today's average temperature of around −60°C. The simplest explanation for the higher earlier temperatures is the presence of an abundant greenhouse gas that would trap the heat from the Sun and raise the global temperature. Carbon dioxide is the best greenhouse gas candidate, and it's the primary component of Mars's current, thin atmosphere. Scientists have not worked out the details of this ancient warming — whether CO_2 alone could raise the temperatures or whether another greenhouse gas such as hydrogen or methane would have been required — but most expect that a thicker atmosphere early in Mars's history will turn out to be the right explanation.

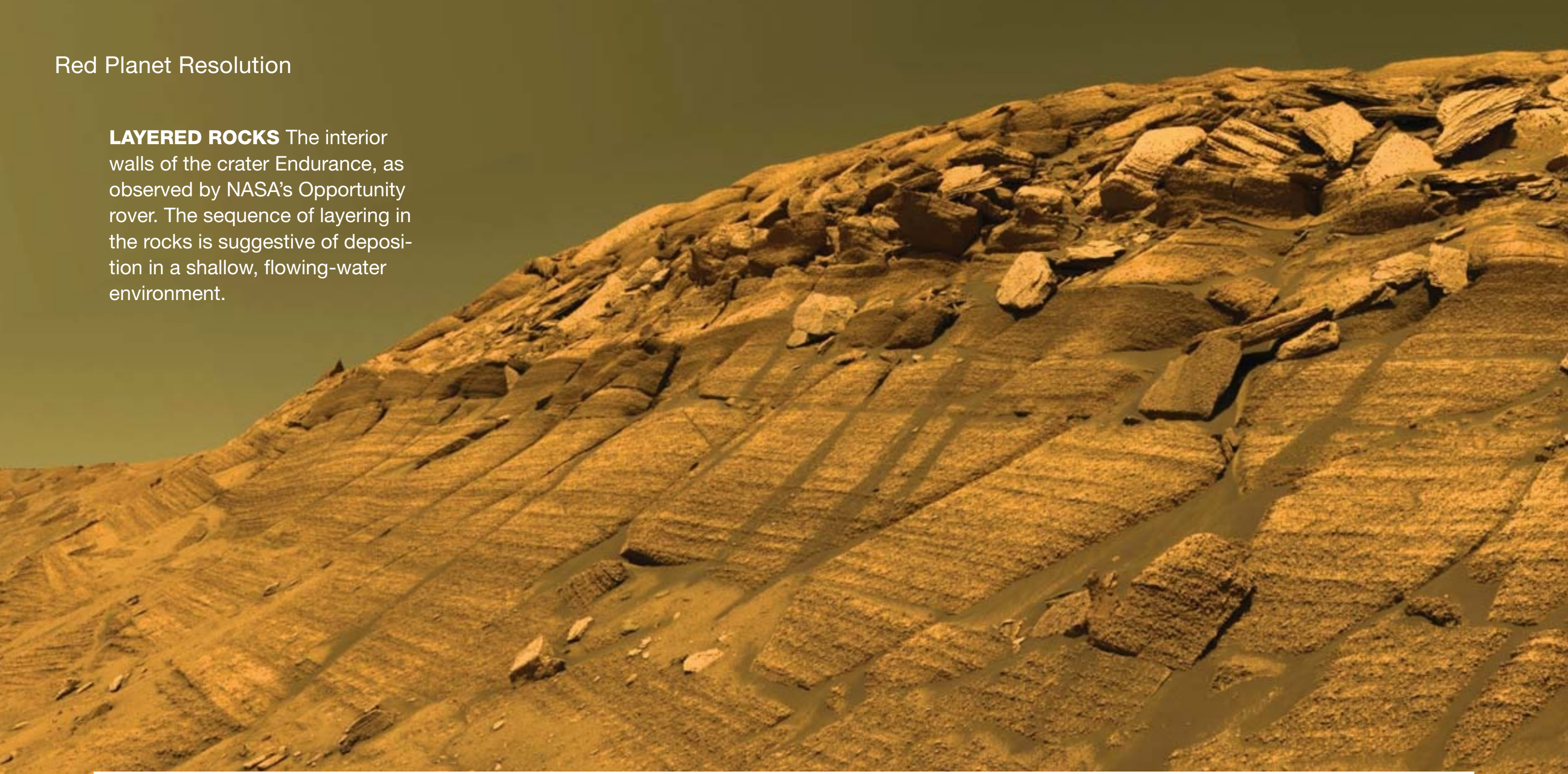
This is the picture we had prior to the Mars Atmosphere and Volatile Evolution (MAVEN) mission, which launched in 2013: that there must have once been a thicker atmosphere and that CO_2 played a role (*S&T:* Sept. 2014, p. 20). How did that atmosphere disappear? That is the mystery we sent MAVEN to solve.

Chemistry Clues

My fellow planetary scientists and I had already spent many years thinking about where the CO_2 could have gone. Observations had revealed CO_2-derived minerals (such as



▲ **POOR MARS** *Top:* The Sun strips Mars of its atmosphere, both via its ever-present wind of charged particles (streaks) and occasional violent eruptions (brownish band). *Above:* Close-up, with atmospheric escape.



LAYERED ROCKS The interior walls of the crater Endurance, as observed by NASA's Opportunity rover. The sequence of layering in the rocks is suggestive of deposition in a shallow, flowing-water environment.

carbonates) in small amounts on the surface. In theory, these minerals could contain CO_2 that had come from the atmosphere. However, scientists had spent the previous two decades looking for a carbonate reservoir on the surface or in the crust that was large enough to hold all the gas from a thick atmosphere, and they hadn't found it.

If atmospheric CO_2 had not gone into the surface or subsurface, then it might have escaped to space. We knew that at least some atmospheric gas had been lost to space: Measurements from the European Mars Express spacecraft, launched in 2003, showed ions from the planet's ionosphere being carried away by the solar wind. Although these measurements ultimately gave us a pretty good estimate of how much gas is being lost today, we didn't have enough information on the physical processes involved to estimate with any certainty how much atmosphere Mars had lost over time. We knew that the Sun's ultraviolet light and the solar wind, which together drive escape, both had been more intense in the past, but without details on the role that each of the potential mechanisms contributed to gas's removal, we couldn't extrapolate the loss rates back through time.

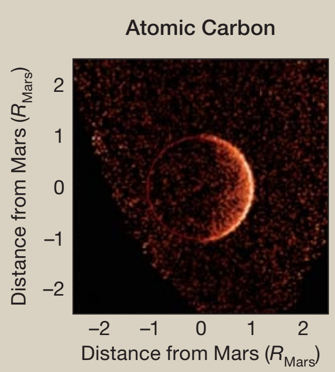
Also, we had chemical measurements from the Viking mission, from Earth-based telescopes, and from Martian meteorites collected on Earth that all strongly suggested that atmospheric loss to space had occurred. This evidence comes from isotopes, the different forms of an element that are distinguished by the number of neutrons in their atomic nuclei. The ways that gas is removed from the atmosphere into space preferentially take the lighter isotope of a pair — normal hydrogen is removed more efficiently than the heavier deuterium, nitrogen-14 over nitrogen-15, and argon-36 over argon-38 — leaving the gas that is left behind enriched in the heavier isotope. Measurements of each of these isotopic pairs in the atmosphere showed just such an enrichment. This meant that loss to space probably was an important process for changing the atmosphere. However, without detailed knowledge of the composition and structure of the upper atmosphere, going from that enrichment to an estimate of the total amount of gas lost involves a lot of guesswork.

And that's where MAVEN came in. We wanted to make measurements that would tell us how much gas is escaping to space today, what the specific processes are that are removing it, and how we could extrapolate back in time to get the total amount lost throughout Martian history. Then we could determine whether atmospheric loss to space had been the dominant process in changing the Martian climate, only one important process among several, or instead a relatively unimportant process.

Making these measurements was no easy task. The many ways that the upper atmosphere and the solar wind could interact, not to mention the ways *these* ways could interact, make the work similar to unraveling the proverbial Gordian knot. Mars is a complex planet. Goings-on in its deep interior, surface, atmosphere, upper atmosphere, and solar

▶ **HALOS** MAVEN has detected coronae of atomic oxygen and carbon around Mars that are en route to escaping. More dramatically, an extended cloud of hydrogen atoms (blue image) extends at least 10 Mars radii beyond the surface. The red circle marks Mars's location.

▶▶ **SEASONAL CHANGES** Mars loses the most atomic hydrogen to space during the northern hemisphere's late autumn and winter.



wind all link together, sometimes strongly, and we have to understand the interactions between each of the components in order to understand the system as a whole.

Missing Suspects

First, we needed to measure the solar properties that drive gas's escape from the Martian atmosphere and the specific ways the upper atmosphere's composition and structure respond. With its nine science instruments, MAVEN measures the amount of solar ultraviolet light hitting the planet; the solar wind speed, density, and magnetic field; and the solar energetic particles that are emitted from the Sun by solar storms. On the receiving end of the physical system, MAVEN also measures the basic state of the upper atmosphere's temperature, neutral-gas composition, and ion composition, as well as the electron properties in the ionosphere. Recently, we've been able to add measurements of the neutral and ionic winds in the upper atmosphere, too.

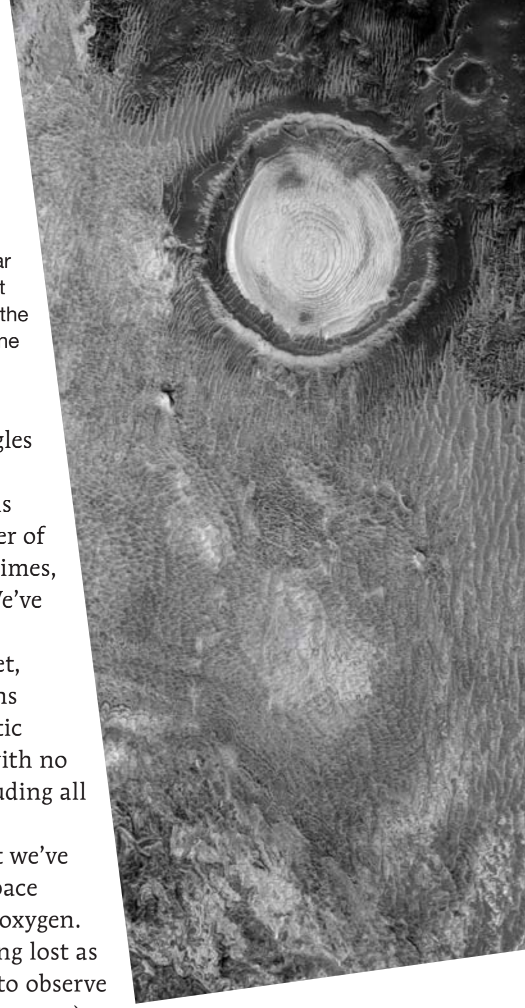
We're also determining how much gas Mars is losing today, following the clues in the upper atmosphere most likely to be important:

- The ions in the atmosphere that are being picked up and stripped away by the solar wind;
- The ions that are swept up and then flung back into the atmosphere, knocking other atoms into space in a process called *sputtering*;
- The properties of the ionosphere that tell us how much gas is being removed by photochemical processes; and
- The hydrogen distribution in an extended "corona" surrounding Mars that tells us how much hydrogen is escaping to space.

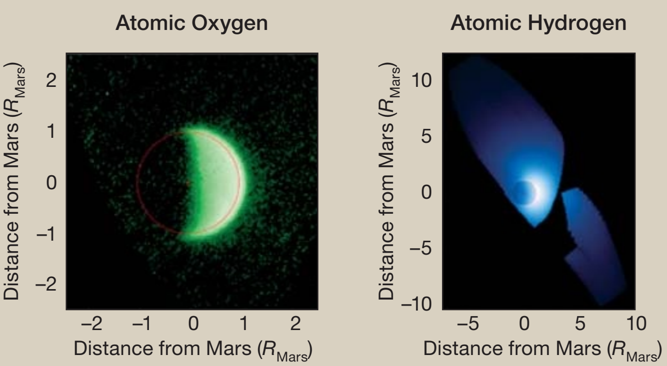
Together, these measurements enable us to follow the chain of evidence to determine the importance of each of the likely loss processes.

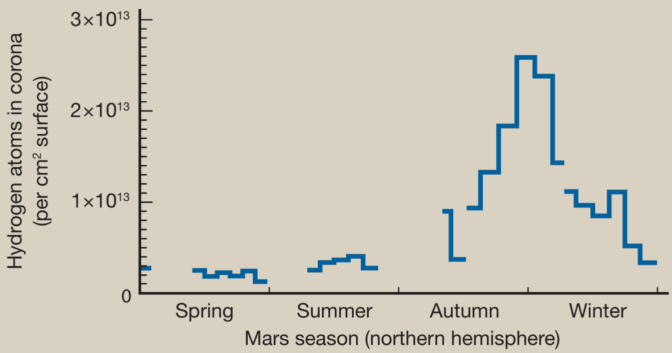
MAVEN entered orbit in September 2014. With it, we've collected measurements for longer than a full Martian year, and we've seen Mars at all seasons. During this time, we've seen several tens of solar storms hit Mars, including a couple big ones, and we've also seen the intensity of the solar ultraviolet light change significantly as the Sun has gone through part of its 11-year cycle. We've made observations at essentially all solar zenith angles (the angle between the Sun and the spacecraft as measured from the center of Mars), at all local solar times, and at most latitudes. We've observed at a wide range of locations on the planet, including over the regions of strong crustal magnetic fields and over regions with no magnetic field, and including all geological provinces.

The major atoms that we've observed being lost to space today are hydrogen and oxygen. (Other elements are being lost as well, but they're harder to observe than hydrogen and oxygen are.) These come from H_2O and CO_2, broken apart by the Sun's ultraviolet light. Hydrogen is leaving by *thermal escape*, which means that the gas is hot enough that some of the hydrogen atoms naturally move fast enough to escape Martian gravity. The hydrogen isn't being lost at a constant rate, however — we see a factor-of-ten variation in the escape rate throughout the Mars year, with the greatest loss rates occurring during the seasons when the atmosphere is the dustiest. We think that the dust increases the atmospheric temperature, allowing the water molecules that are the source of hydrogen to rise to higher altitudes, where they can be broken apart more easily and where escape is possible. Recent work with data from the Mars Reconnaissance Orbiter supports this picture.

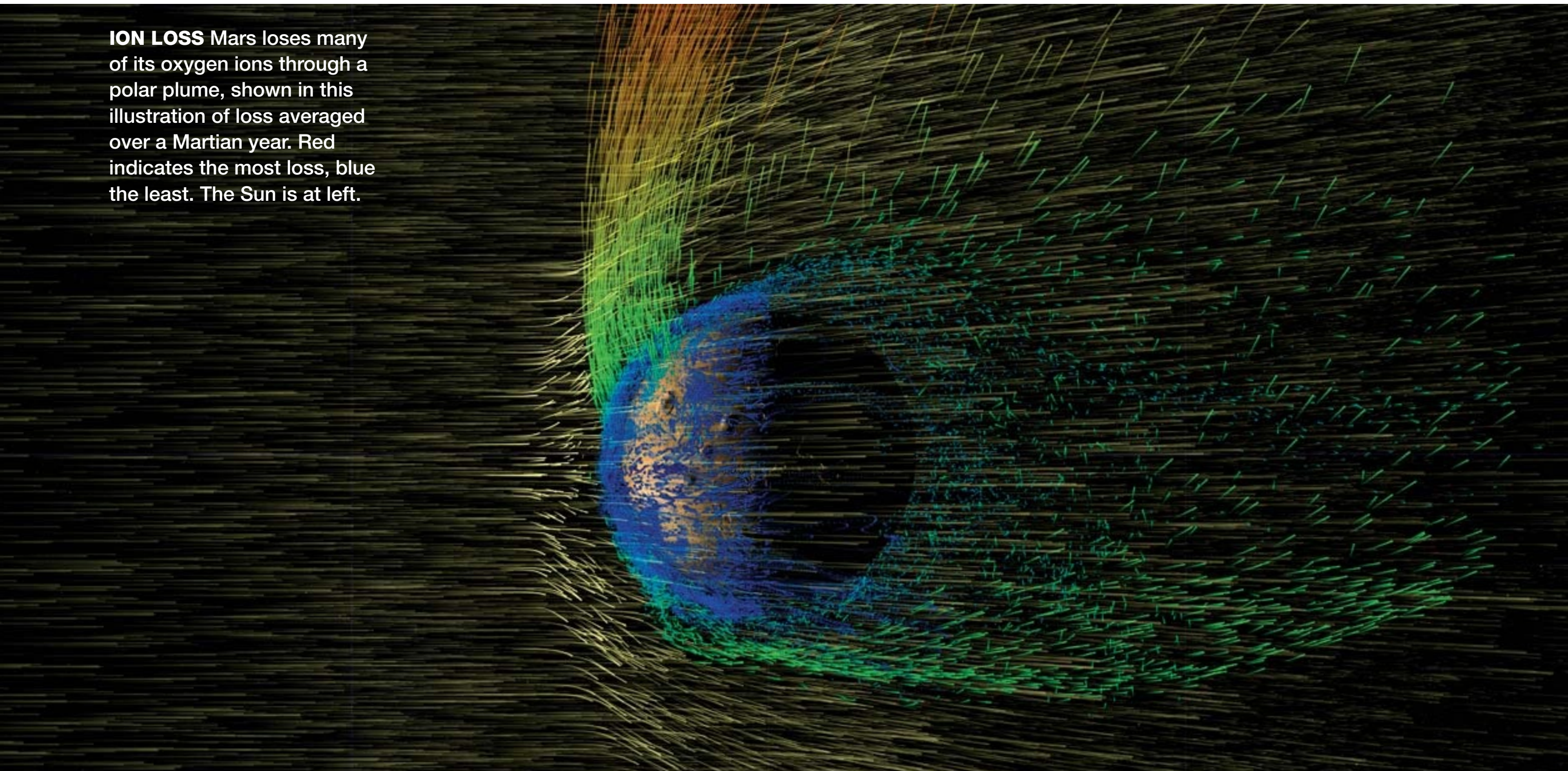


▶ **CONCENTRIC RINGS** Layered sediments fill this 2-km-wide crater, which lies inside the larger, equatorial crater Schiaparelli. It's unclear if the layers formed from dust or volcanic ash settling from the atmosphere, or as water-borne deposits built up over time.





LAYERED ROCKS: NASA / JPL / CORNELL; CONCENTRIC RINGS: NASA / JPL / UNIV. OF ARIZONA; HALOS: MAVEN TEAM / UNIVERSITY OF COLORADO / NASA; SEASONS GRAPH: GREGG DINDERMAN / *S&T*, SOURCE: AUTHOR



ION LOSS Mars loses many of its oxygen ions through a polar plume, shown in this illustration of loss averaged over a Martian year. Red indicates the most loss, blue the least. The Sun is at left.

The major way Mars loses oxygen today is by what's called *photochemical loss*. In this process, an ionized oxygen molecule (O_2^+) collides with an electron and recombines to form a neutral molecule. This recombination releases enough energy to break the molecule into two separate oxygen atoms and give them enough energy that, if one is moving upwards, it will escape into space (if it doesn't hit anything else first).

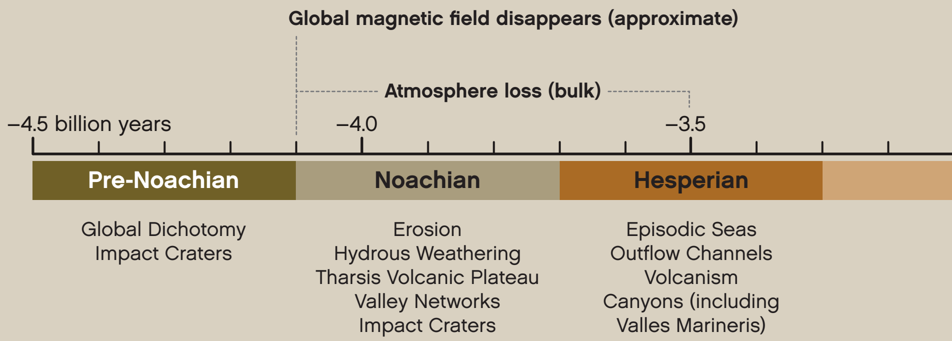
Adding these losses up, we've discovered that Mars is losing gas to space at a rate of about 2 to 3 kg/second. That's 10 million billionths (10^{-16}) of the total atmosphere lost each second. That may not sound like much, but it's enough of a trickle that, over the more than 4 billion years of Martian history, it could have removed enough oxygen and hydrogen to create a global layer of water a few meters thick. Equivalently, the oxygen that has been lost would have made enough CO_2 to produce an atmosphere ten times thicker than the present one of 6 millibars atmospheric pressure.

We don't think that the loss rate has been constant in time, however. The Sun's ultraviolet radiation and its wind of energetic particles were both more intense early in our solar system's history and would have driven greater gas loss. Now that we know the specific processes involved, though, we can calculate how much loss would have occurred earlier in Martian history if these same processes were at work.

Using these extrapolations, it appears that more than a half bar of CO_2 could have been lost to space. This is roughly 100 times the amount of CO_2 that is in today's atmosphere, and it is enough to have produced significant greenhouse warming. Given that the young Sun might have unleashed solar storms more often than it does today, even more CO_2 could have been stripped away.

This result might sound a bit hand-wavy, but we can determine the total loss more directly, too, thanks to argon. Argon's heavier isotope naturally settles lower in the Martian

▶ **HISTORY OF MARS** Planetary scientists divide the Red Planet's history into three periods, the Noachian, Hesperian, and Amazonian (sometimes with the prequel Pre-Noachian). Mars likely lost its global magnetic field around 4.1 billion years ago. Assuming that's when the solar wind began stripping off the atmosphere, then Mars lost the bulk of its atmosphere by 3.5 billion years ago. This period overlaps with the planet's transformation from widespread hydrous and volcanic activity to a global freeze-out.



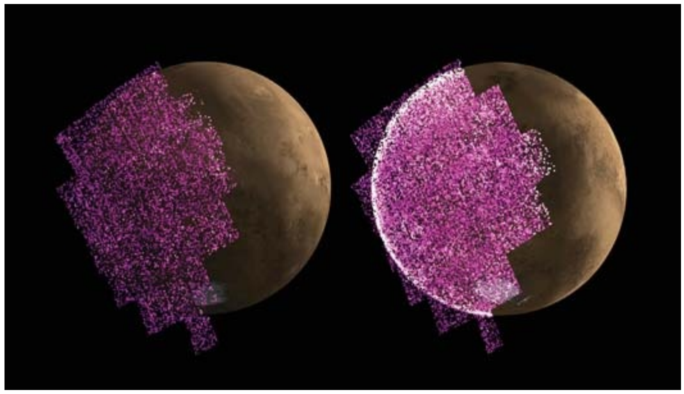
ALL BUT GONE
Mars has lost about 98% of its original atmosphere — it's both been lost to space and locked up in surface minerals and ice.

air than the lighter one, creating a predictable ratio of argon-36 to argon-38 in the upper atmosphere. This ratio will be different at the surface, where things are well mixed. The argon ratio at the ground has been measured most accurately by the SAM instrument on the Mars Curiosity rover. Combining Curiosity and MAVEN measurements with the argon ratio seen on other solar system objects tells us that Mars has lost to space about two-thirds of the argon that had ever been in its atmosphere.

Argon also reveals *how* it was lost. Because argon is a noble gas, it can't be removed by chemical processes such as interacting with the surface and forming mineral deposits there, as carbon dioxide forms carbonates. Only the physical sputtering mechanism will work. If Mars lost a lot of argon via sputtering, it probably lost similar amounts of carbon dioxide that way, too. Other processes, such as photochemical loss, would have removed even more of the CO_2, giving us confidence that our extrapolations from current oxygen and hydrogen loss aren't totally off the mark.

Following the trail of evidence from MAVEN and what we know about the Sun, the majority of this loss would have occurred early in the planet's history, when the solar ultraviolet light and the solar wind were most intense. In the very earliest epochs, Mars's global magnetic field likely protected the atmosphere from stripping — the field would have kept the solar wind standing off at a greater distance, as happens on Earth today. Based on magnetic records in the planet's surface, we think the global magnetic field turned off roughly 4 billion years ago. That switch would have allowed the solar wind to hit the upper atmosphere directly, triggering significant atmospheric loss to space. The bulk of Mars's atmosphere then would have been lost within a few hundred million years. As the solar radiation and wind calmed down later in history, loss would have slowed to a gradual leak, but the damage would have been done. The loss we see occurring today would be the tail end of that slow leak.

This timing of the Sun's stripping of the atmosphere will sound familiar: It matches the timing of the climate change inferred from the geologic features left by water. That's not by our design; it's the result of totally different lines of evidence converging on the same picture. Scientists suspected that the bulk of the Martian atmosphere has been lost to space, but MAVEN has confirmed it. This means that escape to space was the major process responsible for changing the Martian climate from its early, potentially warm and wet environment to the cold, dry planet that we see today.

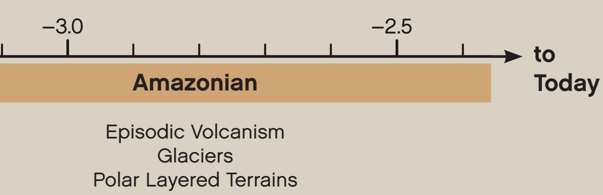


▲ **GLOBAL AURORA** Unlike on Earth, Mars has planet-wide auroral events, and the one in September 2017 was 25 times brighter than any aurora previously seen on Mars. An image before the event (left) shows just noise; the right-hand image shows the event at its peak.

Not Quite a Closed Case

Where do we go from here? Our results are based on one Mars year so far. But not every year is the same on Mars. The lower atmosphere's water cycle and the behavior of dust there can vary significantly from one year to another and can affect the supply of gas to the upper atmosphere. MAVEN hasn't observed the effects of a global dust storm yet. The planet's dust storm season begins this summer, though, so perhaps we'll get lucky.

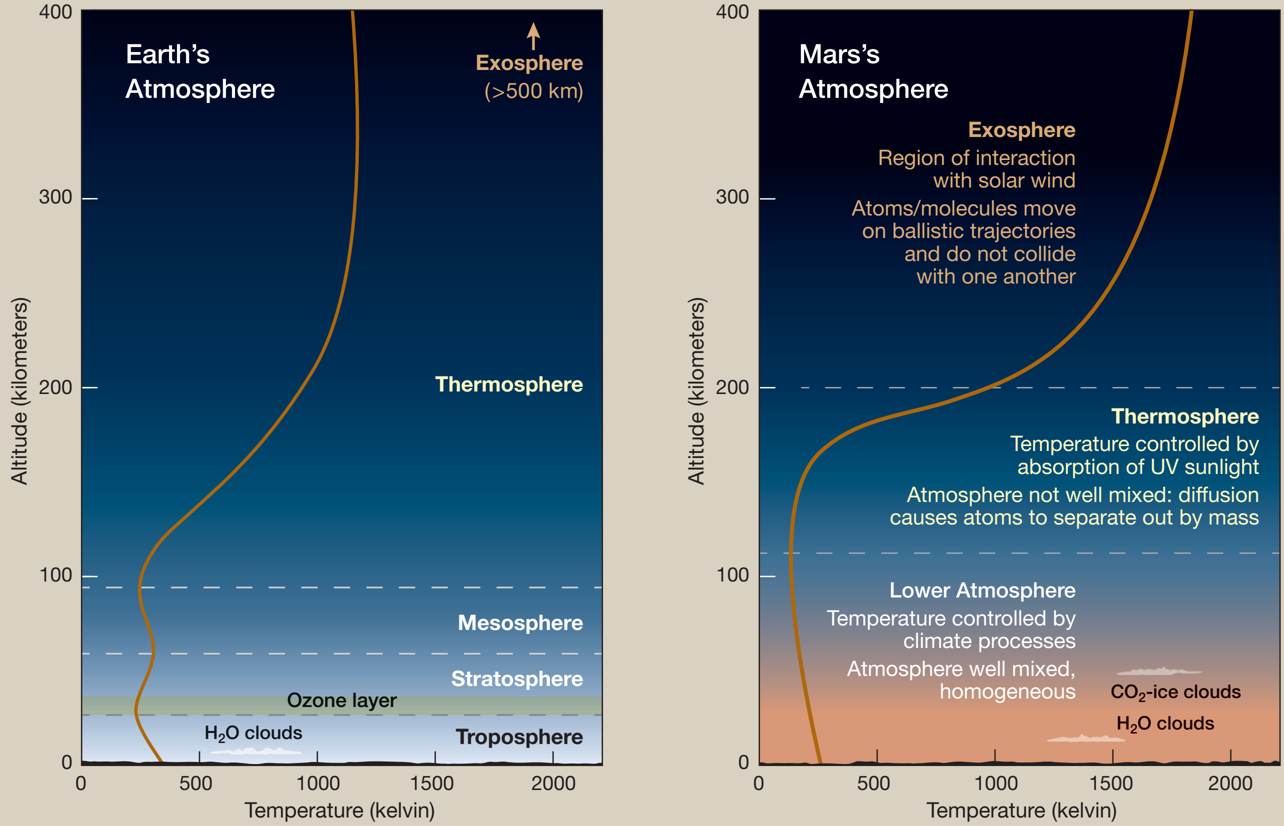
In addition, the Sun goes through an 11-year cycle of behavior, which changes the properties of the solar wind and our star's ultraviolet output. MAVEN arrived just after solar maximum in the current cycle and was able to see how a moderately active Sun affects Mars's atmosphere, but it was a very weak solar maximum, with only a few strong solar storms hitting the planet. We aren't entirely sure yet what the



MARTIAN ATMOSPHERIC LOSS

Present-day loss rate	Oxygen lost after 4.2 billion years at present rate	Actual oxygen loss after 4.2 billion years (lower limit)
1.6–11×10²⁶ atoms/sec Hydrogen	**2.5 meters** Expressed as equivalent global H_2O layer	**16 meters** Expressed as global H_2O layer
~6×10²⁵ atoms/sec Oxygen	**0.078 bar** Expressed as equivalent CO_2 loss (in atmospheric pressure)	**0.46 bar** Expressed as CO_2 loss

IONS: NASA'S SCIENTIFIC VISUALIZATION STUDIO / MAVEN SCIENCE TEAM; AURORAS: NASA GSFC / UNIVERSITY OF COLORADO; TIMELINE: TERRI DUBÉ / S&T

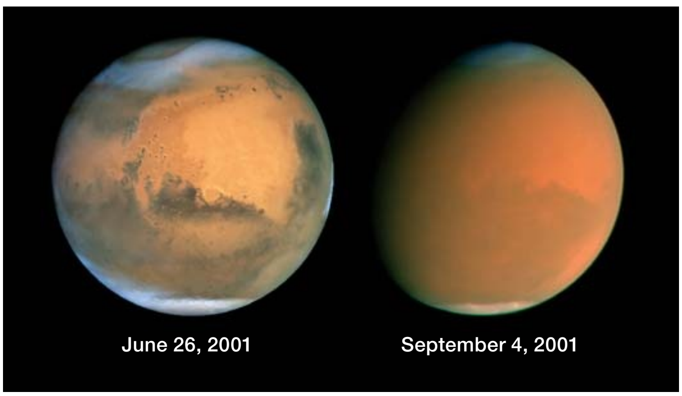


▲ **MARS'S ATMOSPHERE** Temperatures in the Martian atmosphere decline steadily with height for the first 100 km or so — unlike on Earth, where the temperature decreases, then increases, then decreases again (in part due to the ozone layer, which creates rising temperatures in the stratosphere). Above both worlds' lower atmospheres, temperatures rise steadily due to absorbed sunlight (thermosphere) and the solar wind (exosphere).

"most common" behavior of the modern atmosphere is. This means that the extrapolation of present-day loss rates into the past carries some uncertainty.

The spacecraft and all of its science instruments continue to operate nominally (a wonderful word to hear for anybody involved in the spacecraft world!). We plan to continue

▼ **GLOBAL STORM** A dust storm enveloped the Red Planet with the onset of southern hemisphere spring in 2001, shown here just before (left) and two months after the storm began. Airborne dust absorbs sunlight and warms the atmosphere, enabling water vapor to rise to higher altitudes and escape to space.



observations in coordination with the European Mars Express mission, which has been in orbit for more than a decade. And we'll coordinate with future observations from other spacecraft: The European/Russian Trace Gas Orbiter has finally settled into its circular, near-polar orbit at Mars and is beginning science observations, and the United Arab Emirates Hope orbiter will launch in 2020 to study how the lower and upper atmosphere connect (*S&T:* Nov. 2017, p. 14).

MAVEN's current extended mission runs through September 2018, but it has enough fuel that we think it can survive until 2030. We plan to continue our science observations as long as possible, along with serving as a communications relay between Earth and rovers and landers on the Martian surface. It's our hope that, in addition to what we've already learned from MAVEN, teaming it up with current and future spacecraft will teach us even more about Mars's atmosphere and the history of habitability on this small, frozen world.

■ Planetary scientist and MAVEN Principal Investigator **BRUCE JAKOSKY** is Associate Director of the Laboratory for Atmospheric and Space Physics at the University of Colorado, Boulder. He has been exploring Mars since the Viking missions in the 1970s.

ATMOSPHERE ILLUSTRATIONS: GREGG DINDERMAN / *S&T*; SOURCE: AUTHOR; DUST STORM: NASA / J. BELL (CORNELL UNIV.) / M. WOLFF (SSI) / HUBBLE HERITAGE TEAM (STSCI / AURA)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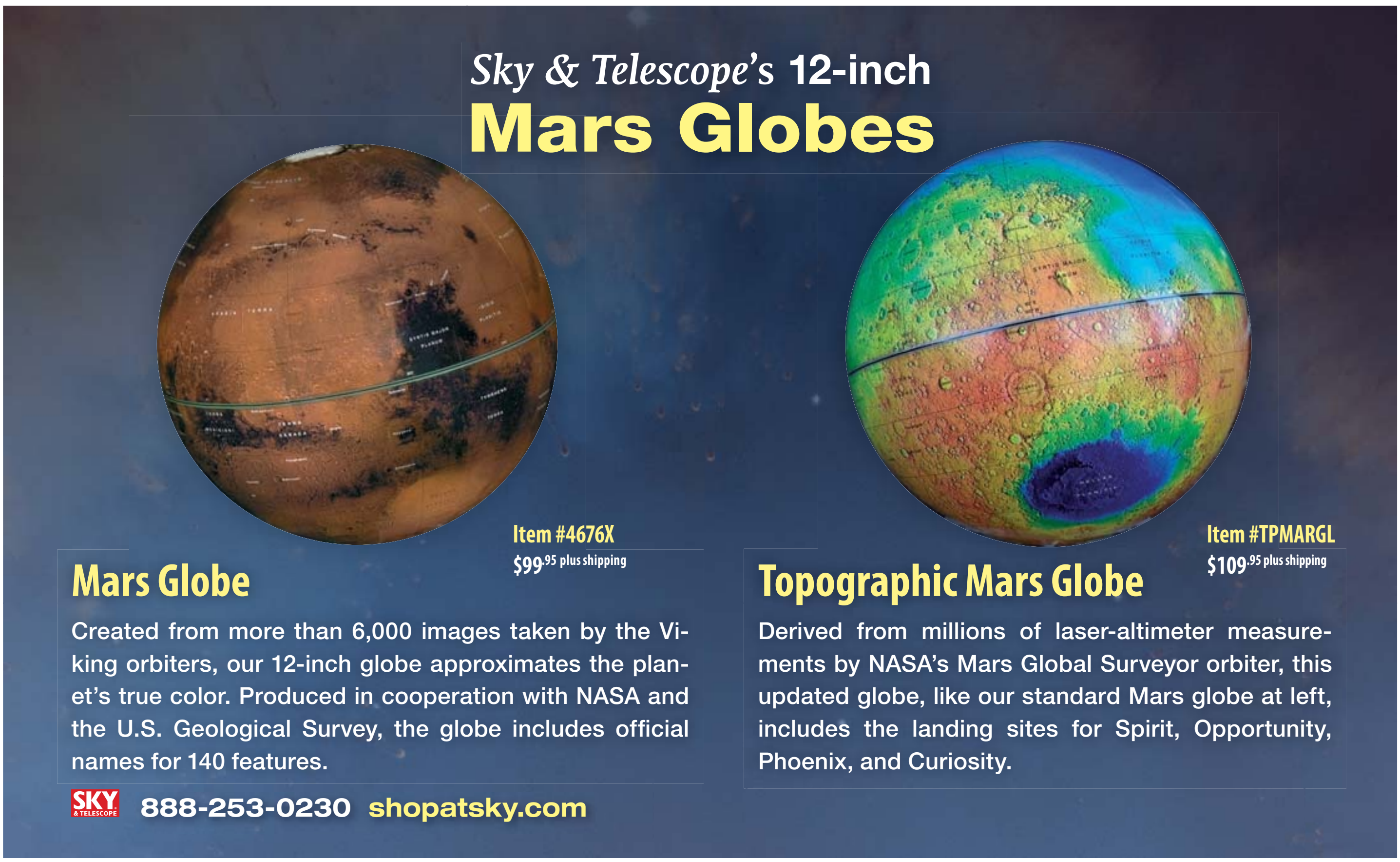
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Mars the MIGHTY returns

Wonder what to see now that the Red Planet is at its biggest and brightest? Read on for the best tips.

We've waited 15 long years and now it's time to party. Mars reaches perihelic opposition — an opposition when a planet is at its closest point to the Sun — on July 27th. This is the first perihelic opposition of Mars since August 2003, meaning that it's bigger and bolder in the night sky than it's been in more than a decade. Are you as eager as I am to roam its deserts and poles with a telescope? Maybe even track a dust storm or catch sight of clouds capping mighty Olympus Mons?

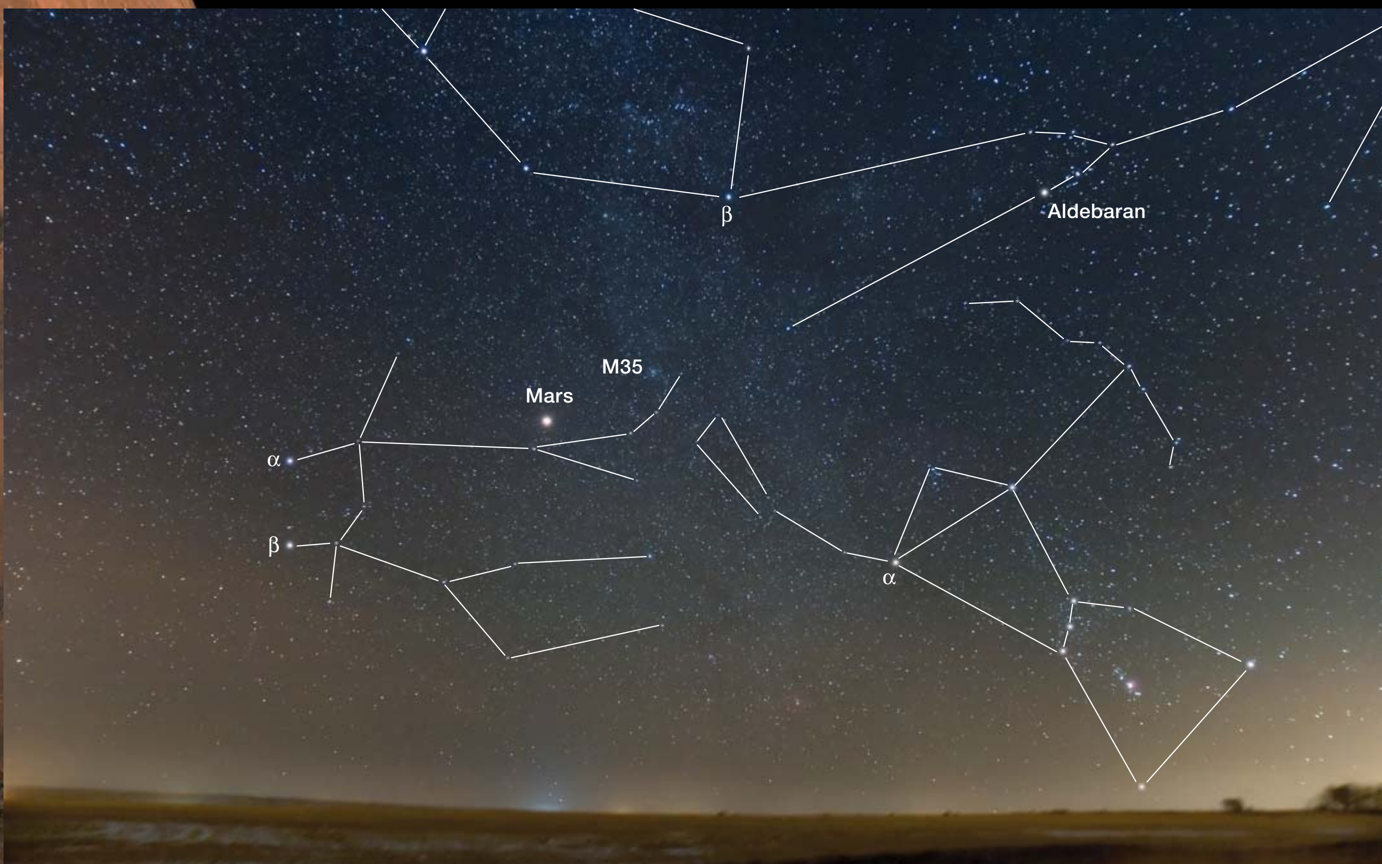
Mars, a planet that requires the patience of marble, has a more eccentric orbit than most denizens of our solar system. At approximately two-year intervals, Earth lines up with Mars at opposition, but a majority of those alignments occur at the same time Mars is relatively far from the Sun. Not this year. Mars is almost at perihelion at the same time as opposition, so it will be a snug .38 au (57.6 million kilometers) away from Earth, close enough for telescopic observers to have a field day ferreting out dark surface markings and changeable weather.

On the night of opposition, in the company of the waxing gibbous Moon, the Red Planet will burn an intense magnitude –2.8, equaling Jupiter at peak brightness. That's a lot of light to muster for a tiny planet only twice the size of our Moon. It just goes to show how distance trumps size when it comes to things celestial.

At the same time, the planet's disk will balloon to 24.3″ (arcseconds), only 0.8″ smaller than during the 2003 opposition when Mars came its closest to Earth in 59,635 years. Because Mars won't arrive at perihelion until September, its closest approach to Earth is slightly delayed, occurring on July 31st. After that date, the two planets begin to part ways.

June opens with Mars already 15.5″ across and shining at magnitude –1.2, nearly the equal of Sirius. Even users of small telescopes should have no problem seeing the south polar ice cap and numerous dark albedo markings. By July 1st, it fills out to 21.1″ and reaches its greatest size at month's end as the polar cap continues to shrink.

Despite its glorious girth, northern observers will pay a price during this juicy Mars apparition. At most perihelic oppositions, including this one, the planet retreats to the belly of the ecliptic low in the southern sky. On July 27th, Mars gleams from southwestern Capricornus at declination –25° 34′ and at culmination stands only 23° high from Chicago and 13° from London. Low altitude often means more air layers to peer through, resulting in increased turbulence, poor seeing, and soft images.



▲ **WINTER VISITOR** Astrophotographer Alan Dyer captured Mars *(center)* as it looped through Gemini during its 2007–2008 apparition. Gemini rises above the eastern horizon. To the right of the Twins, Orion raises his club and shield to challenge the red-eyed bull, Taurus.

MARS: NASA / JPL-CALTECH; PHOTO: NASA / ESA / ALAN DYER

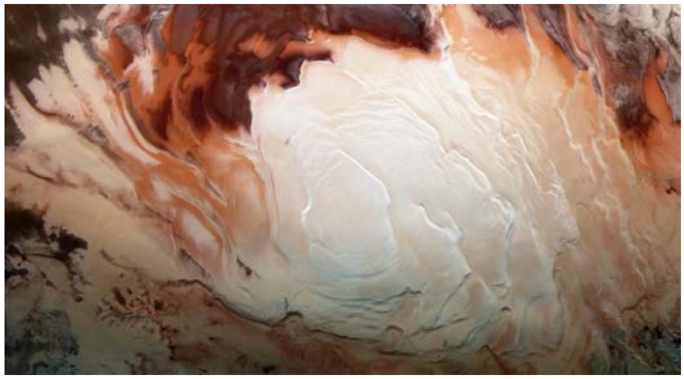
Your best strategy is to observe the planet as often as possible to maximize the chance of getting a sharp look during infrequent spells of excellent seeing, when all dross falls away and the planet looks as real as being there. Remember to allow your telescope's optics to cool to the outside temperature, so they don't become their own source of "boiling" air. Mars won't be this close to Earth again until September 2035, a simple fact that motivates many a Mars-watcher to put eye to eyepiece every clear night around opposition.

The Red Planet remains in Capricornus throughout the summer and early fall, making a brief foray west into neighboring Sagittarius near the end of its retrograde loop in late August. Minimum declination of –26° 33′ occurs on August 15th before the planet finally comes up for air in the middle of October. When the kids knock on doors for Halloween candy, Mars will still be in negative magnitudes, 12″ across, and perched at declination –17°.

What to See

The south polar cap (SPC) will highlight the first half of the apparition. Tipped in our direction, this frozen CO_2 button will appear big and bright as it emerges from its winter hood of clouds in late April and May. Watch it gradually shrink and rift as opposition approaches. We'll also see part of the north polar hood (NPH), a dull, diffuse cap of clouds shrouding the north polar cap (NPC). Look for it along the planet's northern limb throughout the summer and early fall. The NPH is often confused with the much brighter, more distinct true cap, but that won't be visible until mid-winter 2019.

Spring in Mars's southern hemisphere occurs on May 22nd with the cap at maximum extent. North of the SPC, keep a wary eye out for another polar cap look-alike, the 2,300-kilometer-wide impact basin Hellas. In June, Hellas may be still be coated with frost or hidden under a blanket of clouds, mimicking the appearance of a polar cap, but you can tell the two apart — Hellas is distinctly north of the SPC and appears duller. Even small scopes should provide great views of these polar features.

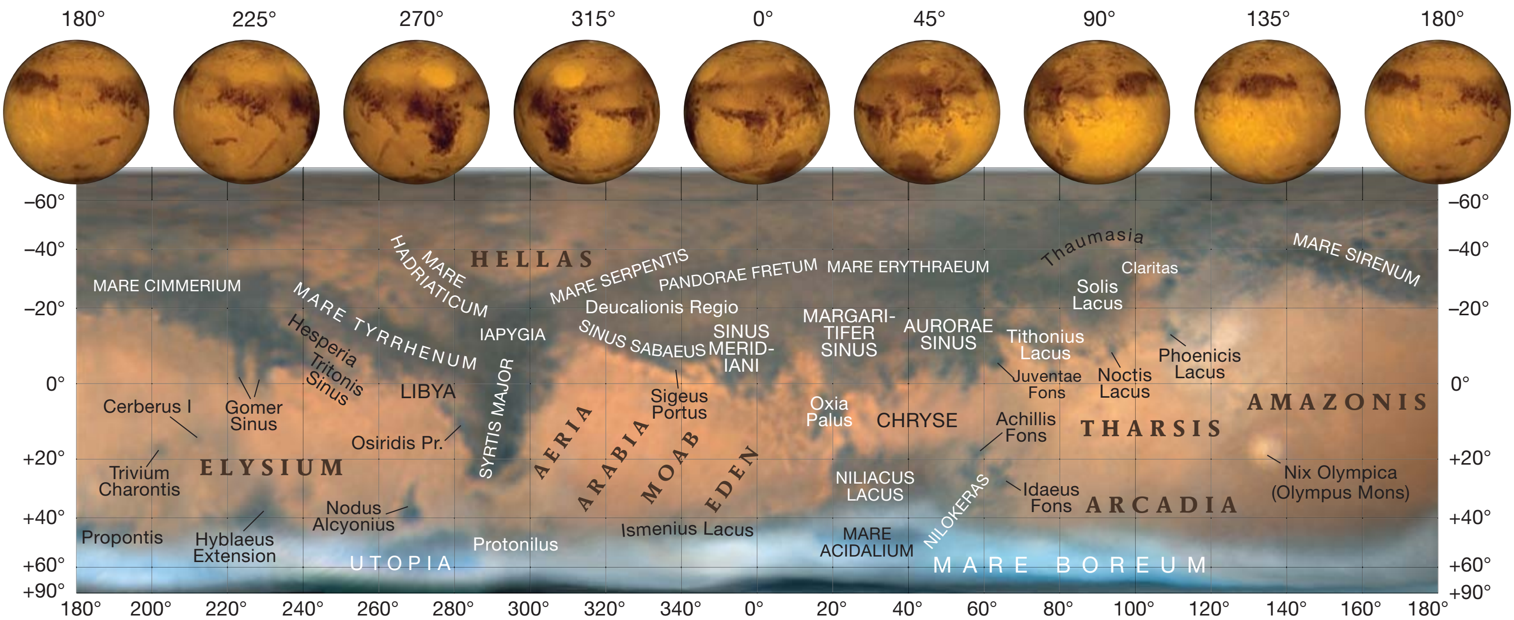


▲ **SOUTHERN ICE** The south polar cap, which reaches 3 km deep in places, is made up of frozen water and carbon dioxide.

To see all these wonderful features best, you'll need to observe around the time of dawn when the planet is high enough above the muck for a good look. Mars won't be conveniently placed for evening viewing until early August.

Albedo Markings

Like the Moon, Mars readily reveals surface features called *albedo markings* across its orange globe. Some change shape with the seasons or from apparition to apparition depending



▲ **PRACTICE MAKES PERFECT** The more often you observe Mars, the easier you'll find it to detect albedo markings. Use this map to identify them. Damian Peach assembled this map from images he took during 2009–2010. The globes, tipped correctly for the current apparition, are from the software program WinJupos. Each globe displays the central meridian longitude that is directly below it on the map. Moderate telescopes will show only the darkest, largest regions. South is up.

COME CLOSER As it approaches Earth, Mars will swell from a small apparent disk to a maximum diameter of 24.3″ on July 31st, the date of closest approach. Opposition occurs on July 27th. The images show Mars at 0^h UT, with the planet's declination and distance from the Sun noted in astronomical units (au). South is up.

Date	Feb. 12	Mar. 25	Apr. 20	May 9	July 31	Oct. 31	Nov. 21	Dec. 21	Feb. 6
Diam	6″	8″	10″	12″	24.3″	12″	10″	8″	6″
Dec	–23.4	–23.5	–23.4	–22.4	–25.8	–16.8	–11.7	–3.5	9.8
AU	1.566	1.173	0.938	0.781	0.385	0.781	0.932	1.169	1.570

MARS CALENDAR

May 22
Equinox marks the start of northern autumn and southern spring. Mars shines at magnitude –1.0, with a diameter of 13.9″.

June 28
Retrograde (westward) motion begins. Mars shines at magnitude –2.0, with a diameter of 20.2″.

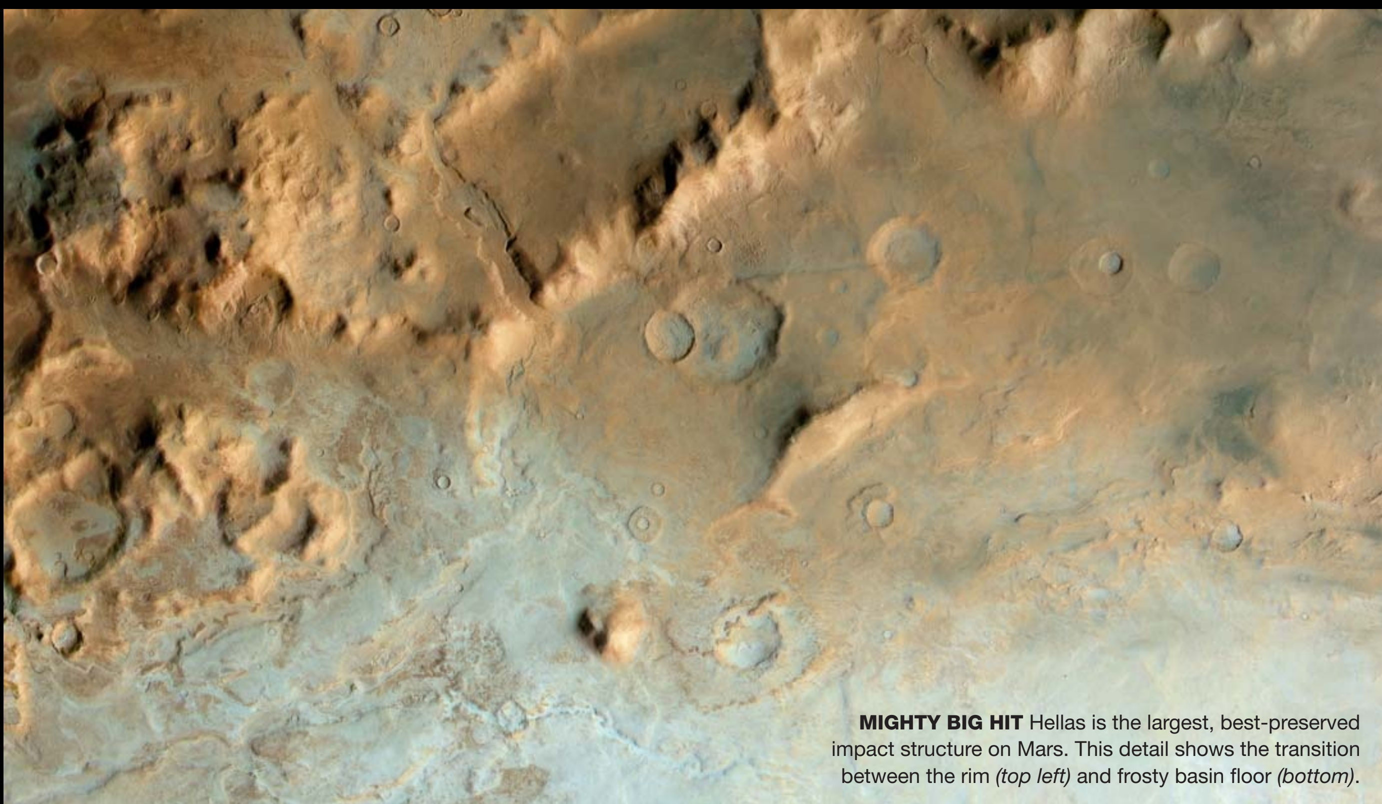
July 27
Mars reaches opposition. Mars shines at magnitude –2.8, with a diameter of 24.3″.

July 31
Mars makes its closest approach to Earth.

Aug. 28
Retrograde motion ends, direct (eastward) motion resumes. Mars shines at magnitude –2.2, with a diameter of 21.6″.

Sept. 16
Mars is at perihelion. Mars shines at magnitude –1.7, with a diameter of 18.3″.

Oct. 16
The solstice marks the start of northern winter. Mars shines at magnitude –0.9, with a diameter of 13.6″.



MIGHTY BIG HIT Hellas is the largest, best-preserved impact structure on Mars. This detail shows the transition between the rim *(top left)* and frosty basin floor *(bottom)*.

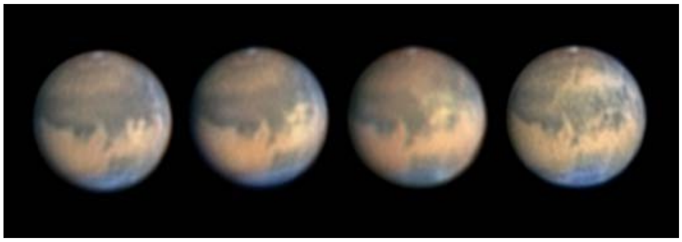
SOUTH POLE: ESA / DLR / FU BERLIN / BILL DUNFORD; ALBEDO MARKINGS: DAMIAN PEACH / GREGG DINDERMAN (S&T); APPARITION: ALPO; HELLAS: ESA / DLR / FU BERLIN / CC BY-SA 3.0 IGO on how the Martian winds move bright surface dust around. The most obvious southern hemisphere features include Syrtis Major, an ancient shield volcano shaped like the subcontinent India; the "chicken drumstick" combination of Sinus Sabaeus and Sinus Meridiani (east of Syrtis Major); the great bands of Mare Tyrrhenum and Mare Cimmerium that stretch west of Syrtis Major; the vast and amoebic Mare Erythraeum-Aurorae Sinus complex; and the dark eye of Solis Lacus. In the northern hemisphere you can't miss the dark thumb of Mare Acidalium and Niliacus Lacus located at the same longitudes as Mare Erythraeum.

But identifying albedo markings can take time. Most are subtle and difficult to pick out against the glaring orange landscape, but with practice, they become easier to see until you recognize them like continents on a globe. To make the task easier, observe the planet with as much magnification allowed by the seeing conditions. I've always found a red #23A filter a big help in boosting their contrast.

This is especially true when viewing Mars's "boring" hemisphere, located between about longitudes 110° and 240°, which includes the narrow polar-hugging stripe of Mare Sirenum and the low-contrast volcanoes of the Tharsis Plateau. Orographic clouds often cover Olympus Mons, the planet's largest extinct volcano, making it look like a pale, white pustule in the ochre desert.

Clouds, Hazes, and Dust Storms

One of the most exciting aspects of observing Mars is discovering its similarities to Earth. Both planets have their share

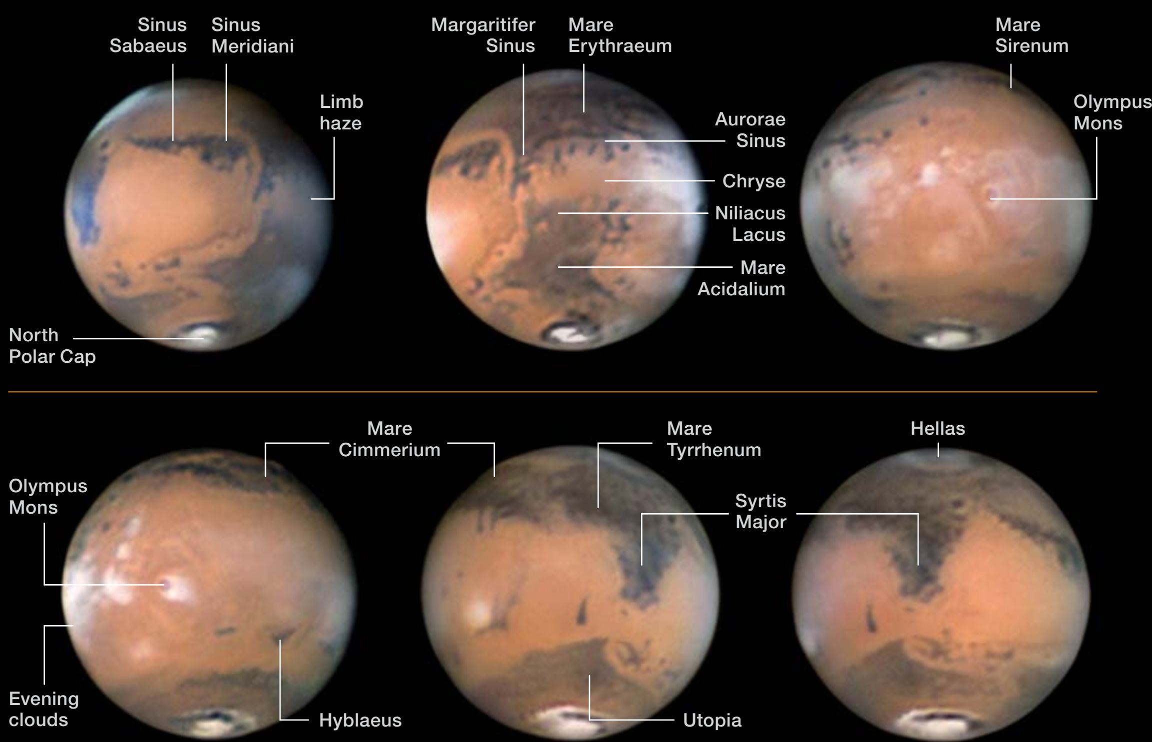


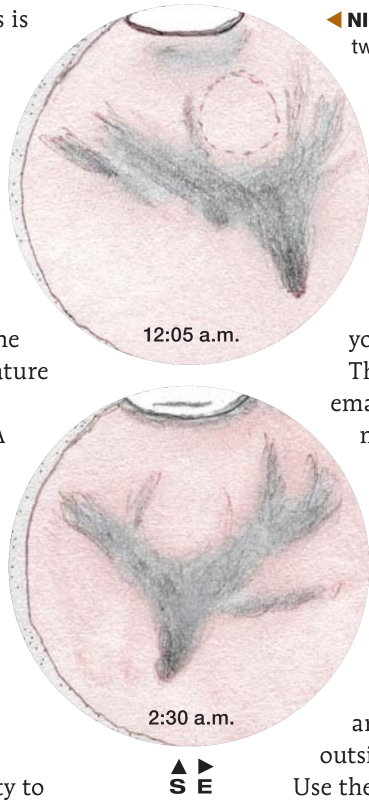
▲ **YELLOW STORM RISING** With frequent observing, you can detect changes in the day-to-day appearance of Mars. For example, a dust storm erupted on the planet in October 2005. By recording images each night, *S&T* Equipment Editor Sean Walker was able to track the progress of the yellowish clouds as they traveled across the planet's dark surface. South is up.

of clouds, fog, and mist. On Mars, these often appear as narrow bands of white haze along either the morning or evening limb where the Sun is just rising or setting. In my experience, these are the most common clouds visible in amateur telescopes, but watch for isolated puffs and high-altitude clouds that hug Martian volcanoes. A blue #80A filter will enhance their visibility.

In the opposite hemisphere, autumn will be underway during Earth's summer and fall, with clouds forming over the north polar cap (NPC) and beyond to create the NPH. By October, the NPH may extend as far south as latitude 50° north, giving the "top" of Mars a diffuse, off-white cast as if it had been dipped in milk. Isolated clouds can appear anytime, especially as the SPC shrinks through the summer and fall.

SHARPEST VIEW These images captured during the planet's 2012 apparition show many of Mars's dark albedo markings. The planet rotates every 24 hours, 38 minutes. Since that's very similar to Earth's rotation, we view nearly the same hemisphere from night to night. If you observe Mars at 11 p.m. from the same place night after night, the planet will appear to rotate in retrograde (backward) over a period of about six weeks. If you see Syrtis Major front and center at 11 p.m. the first night, you will see it in that same spot about six weeks later. To see a different side of the planet, you need to observe Mars at a different time of night or from a different longitude. South is up.





◀ **NIGHT WATCH** The author drew two sketches of Mars, two hours apart, as viewed with a 10-inch telescope at 256× on August 4, 2003 UT. The sketches show the planet's rotation as well as several of its most prominent features, including the dark "finger" of Syrtis Major and the south polar cap. In the bottom view, a dark rift shows in the cap. Such rifts appear as the cap shrinks.

One of the most dramatic events to witness is a dust storm — as long as it doesn't expand to become a planet-encircling event! This last occurred in June 2007, when, within a few weeks, dust had blanketed nearly every feature from view. Fortunately, such planet-wide events are uncommon, with just 10 recorded over the past 130 years.

The more often you observe Mars, the more familiar you'll be with any changes in the appearance of albedo features that mark the onset of a dust storm. Watch for a familiar feature to disappear or a light area to appear. Visually, dust storms appear as bright, yellow patches. A #23A red filter will brighten and enhance the view and serve to confirm that you're seeing dust and not water vapor clouds.

Dust storms are common during the Martian southern summer, which begins in mid-October. Good spots to keep an eye on include the Chryse region and Hellas-Noachis from late August through November.

Phobos and Deimos

Close oppositions provide a perfect opportunity to observe the Martian moons, Deimos and Phobos. Without the planet nearby, even a 3-inch telescope would be up to the task: their 2018 opposition magnitudes are 11.5 and 10.5, respectively. But Deimos strays just 1.2′ (arcminutes) and Phobos only 21″ from the planet at best, so you'll need at least a 10-inch instrument and careful planning. First and foremost, make your attempt around opposition when the moons are brightest and their angular distance from Mars is at maximum (see page 52).

I saw both moons during the 2003 perihelic opposition of Mars in an 11-inch Schmidt-Cassegrain telescope by hiding the brilliant planet behind an occulting strip made of aluminum foil taped across the field stop of an ancient orthoscopic eyepiece. With Mars safely hidden and a magnification of 233× applied, Deimos was an obvious pinpoint of light in the glare. Phobos, though brighter, orbits much closer to the planet and proved much more challenging.

Go for it and surprise yourself. Several planetarium-style software programs including the free Stellarium (**stellarium.org**) display the moons, allowing you to plan your observing session when either is at maximum elongation from the planet.

Be a Planetary Ambassador

Finally, don't forget to get the public involved. Who could forget the internet rumor started in 2003 about Mars appearing as big as the full Moon at opposition? I won't quote the full e-mail that bounded from inbox to inbox, but surprisingly, its content was mostly true, as it claimed Mars through a 75× eyepiece would look as large as the full Moon to the naked eye. Since the post referred to its apparent diameter, it was correct. Multiply 25″ × 75 and you get 31′, the full Moon's apparent diameter. Then an unfortunate thing happened. As the email made the rounds, the reference to "at a modest 75-power magnification" was left out, leading neophyte skywatchers to expect a frighteningly large, Moon-sized Mars casting a rusty specter over the landscape. Like a mosquito you hear but forever fail to swat, the description has popped up at every subsequent opposition. Watch for it to reappear on schedule this apparition, and when friends ask what's up, patiently explain and then direct them to the real thing right outside their window.

Use the hype that will inevitably spin out of social media to your advantage to share Mars and the joys of looking up with those new to the hobby. And it won't hurt one bit if you mention how important minimizing light pollution is for a great dark-sky experience.

■ Contributing Editor **BOB KING** has been an avid observer since childhood. He's a long-time member of the American Association of Variable Star Observers (AAVSO) and author of multiple observing guides, including *Wonders of the Night Sky You Must See Before You Die*. Visit his blog at **astrobob.areavoices.com**.

USEFUL RESOURCES

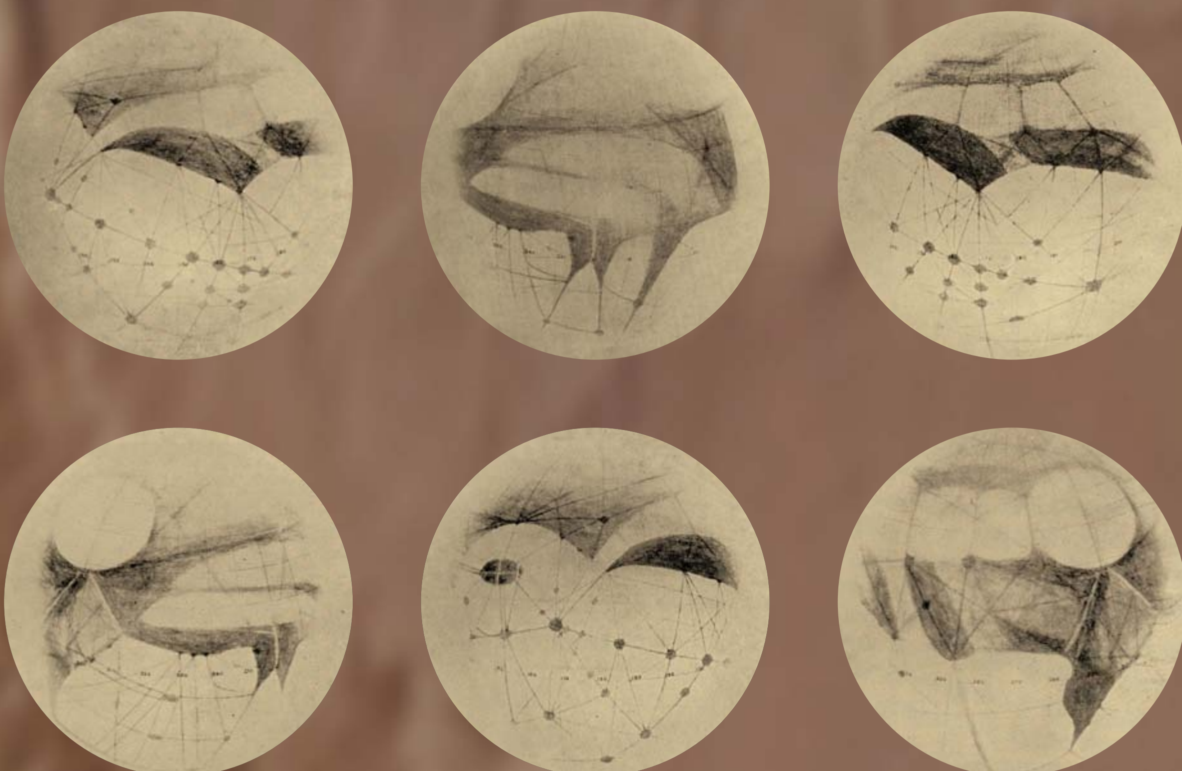
Though the internet is often a tool for rumormongering, it can also provide good information for planetary observers. Here are a few sites to visit during this opposition of Mars.

- *Sky & Telescope* Mars Profiler (**https://is.gd/marsprofiler**)
- Association of Lunar and Planetary Observers (ALPO) Mars Section (**alpo-astronomy.org/marsblog**)
- The Red Planet (**https://mars.nasa.gov/#red_planet/**)
- The 2018 Perihelic Opposition of Mars (**alpo-astronomy.org/jbeish/2018_MARS.htm**)
- How to Make An Occulting Bar (**https://is.gd/OccultingBar**)
- Mars Observers Yahoo Group (**groups.yahoo.com/group/marsobservers**)

ALBEDO MARKINGS: DAMIAN PEACH; SKETCHES: BOB KING

Canal MANIA

Earthly events influenced how astronomers perceived the Martian landscape a century ago.



BACKGROUND: ESA / DLR / FU BERLIN, CC BY-SA 3.0 IGO; SKETCHES: PERCIVAL LOWELL / WIKIMEDIA COMMONS / PUBLIC DOMAIN

▲ **CELEBRATED CONTROVERSY** Percival Lowell was perhaps the most vocal proponent of intelligent life on Mars. His famous observations of linear "canals" on Mars inspired the literary works of H. G. Wells and Edgar Rice Burroughs.

Few notions captured the public imagination more at the turn of the 20th century than claims made by celebrated and controversial astronomer Percival Lowell. He was convinced that Mars was inhabited by an advanced civilization of intelligent beings in the process of building a planet-wide system of canals. Based on his observations at his newly established observatory in Flagstaff, Arizona, Lowell delineated an extensive network of canals on the Red Planet. He maintained that putative Martians used these to tap water from the planet's polar caps and channel it to the warmer equatorial regions. He wrote and lectured extensively on the subject, publishing three best-selling books detailing his theories and interpretations. Although astronomers ultimately debunked and derided these claims, Lowell clung to them until his death in 1916.

In his book *Planets and Perception: Telescopic Views and Interpretations, 1609-1909*, noted astronomy historian William Sheehan analyses the reasons many past astronomical claims and observations proved illusory. While the supposed Martian canals were clearly that, and, as depicted by Lowell, were beyond the resolving power of a 24-inch telescope, there's much more to the story.

Lowell often stopped down his achromatic telescope to 6 inches or less, mostly to minimize chromatic aberration, the bane of classical doublet refractors, as well as to decrease glare and lessen the effects of bad seeing. Unfortunately, this practice might also have produced ophthalmoscope-like reflections of Lowell's retina, or generated so-called subjective contours, the tendency of the eye to perceive linear connections where none exist. Others have ascribed his fanciful observations to pareidolia, a psychological phenomenon in which the mind perceives a familiar pattern where none exists.

Sign of the Times

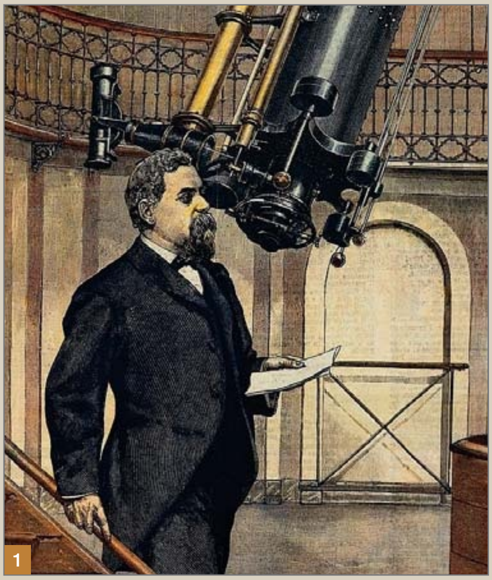
Before totally dismissing Lowell's notions and theories as pure fantasy, fraud, or self-deception, it's instructive to consider the social and technological setting in which they were formulated. During the Industrial Revolution of the 18th and 19th centuries, large-scale engineering projects were undertaken in much of the world, including extensive construction of shipping and irrigation canals.

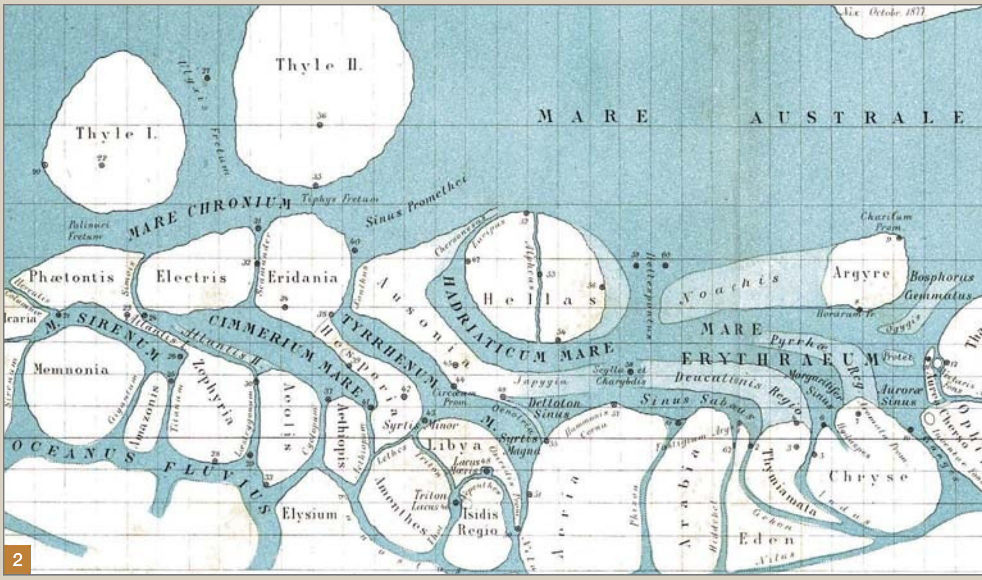
Between 1790 and the mid-1800s, some 6,000 kilometers of shipping canals crisscrossed Great Britain alone, while the Suez Canal connecting the Mediterranean and Red Seas opened in 1869. The term "canal mania" was widely in use at the time. Similar projects in Canada and the United States produced dozens of artificial waterways, including the Lachine, Welland, and Erie Canals. Finally, the construction of the Panama Canal in the early 1900s had the most profound impact on the American public's imagination. Canals greatly altered the social and economic life of the world.

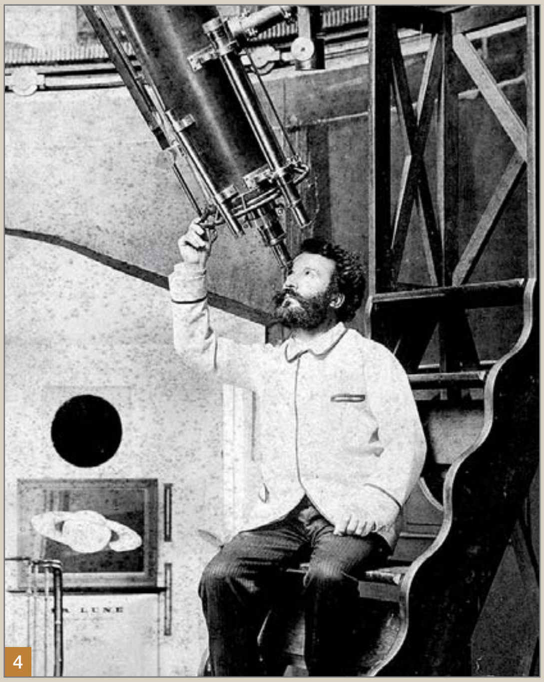
Given these developments, it's perhaps not surprising that Lowell and many of his contemporaries were quite open to the idea that intelligent beings inhabited Mars, and that canals might exist on the most Earth-like planet in the solar system. Well before Lowell established his observatory in 1894, many other astronomers had fallen prey to Martian "canal mania." One only has to peruse the abundant drawings, reports, and discussions in Camille Flammarion's epic 1892 *La planète Mars et ses conditions d'habitabilité* (available

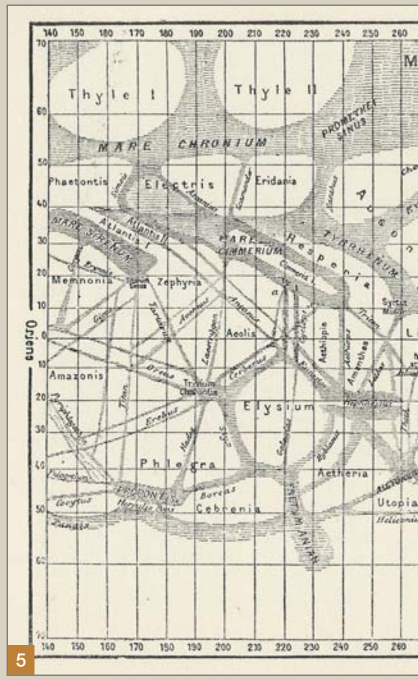
◀ **MARTIAN ROMANCE** Inspired by Flammarion's *La planète Mars*, Percival Lowell founded his observatory in Flagstaff, Arizona, and dedicated himself to the study of Mars. His earliest drawings, like the samples at left from 1896, depicted numerous linear features he was convinced were the work of intelligent inhabitants of the Red Planet.

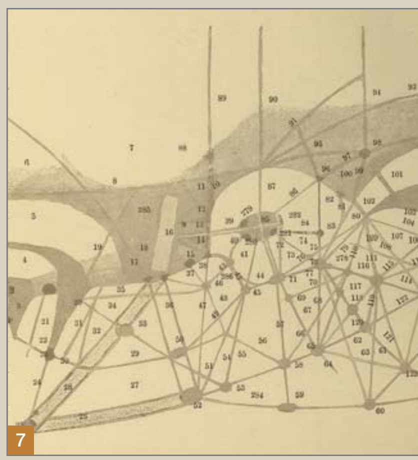
▼ **DIGGING THROUGH** The U.S. experienced its own epoch of "canal mania" with the construction of the Panama Canal. Begun in 1904, it firmly established giant canals in the public's imagination.











1. PLANTING THE SEED Italian astronomer Giovanni Schiaparelli first used the term *canali* to describe linear features he observed on Mars during the opposition of 1877. Although the word in Italian means "channels," it was mistranslated into English as "canals," encouraging speculation about intelligent life on the Red Planet.

2. ALBEDO AS OCEANS Schiaparelli's map of Mars, based on his observations throughout the apparition of 1877, depicted the darker albedo features as oceans and seas, with many linear *canali* throughout the northern hemisphere (south is up).

3. REFINED CANALS Following the Mars apparition of 1879, Schiaparelli published a new map featuring more refined, linear canals.

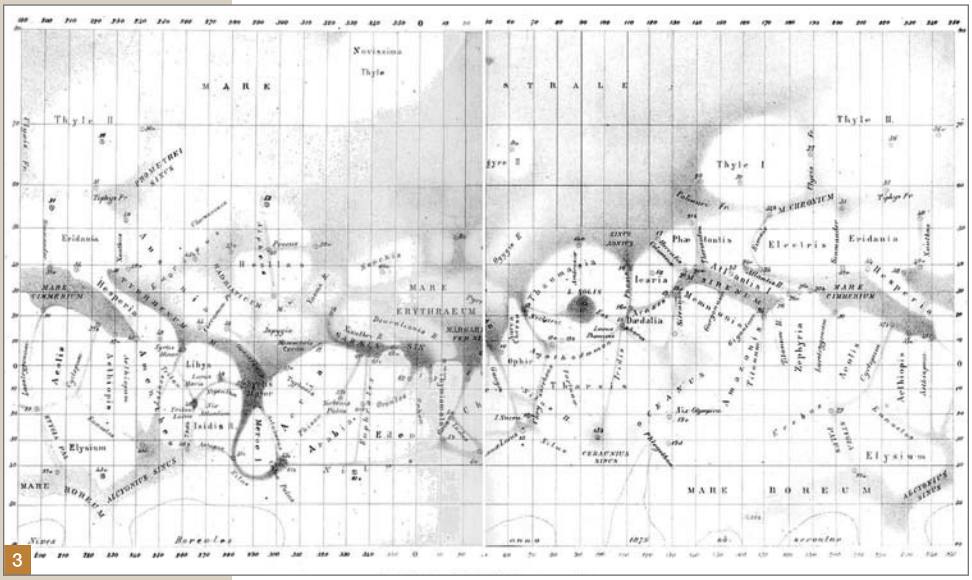
4. POWERFUL PROPONENT French astronomer and publisher of the journal *L'Astronomie* Camille Flammarion also claimed to see linear canals on Mars from his private observatory and believed the planet to be in the last stages of habitability.

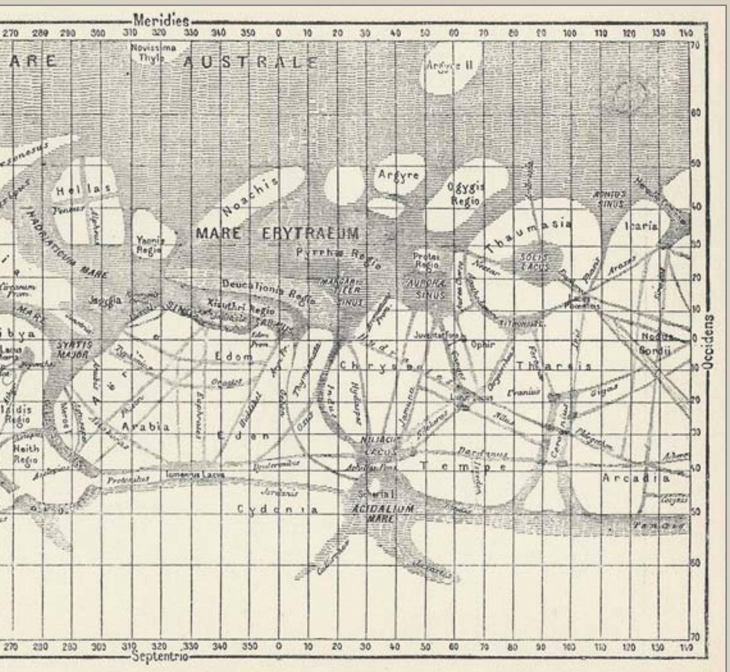
5. DOUBLING DOWN By the 1890s, Flammarion published a refined map based on Schiaparelli's recent observations that depicted many double canals.

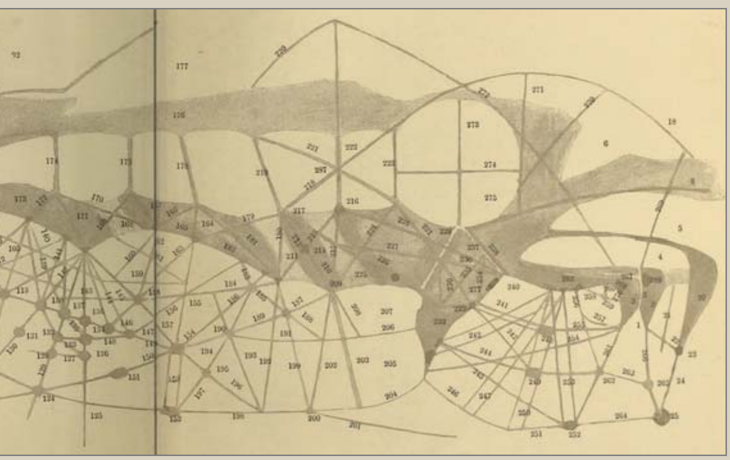
6. SUGGESTIVE VIEW Immediately following the commissioning of his 24-inch refractor, Lowell sketched delicate linear features connecting the larger albedo markings on Mars.

7. CANAL HIGHWAY Lowell's first map of Mars, published in 1895, depicted more canals than most observers had reported before.

1: ACHILLE BELTRAME; 2,3: G. V. SCHIAPARELLI / WIKIMEDIA COMMONS / PUBLIC DOMAIN; 4: WIKIMEDIA COMMONS / PUBLIC DOMAIN; 5: G. V. SCHIAPARELLI / WIKIMEDIA COMMONS / PUBLIC DOMAIN; 6: LOWELL OBSERVATORY ARCHIVES; 7: PERCIVAL LOWELL / WIKIMEDIA COMMONS / PUBLIC DOMAIN







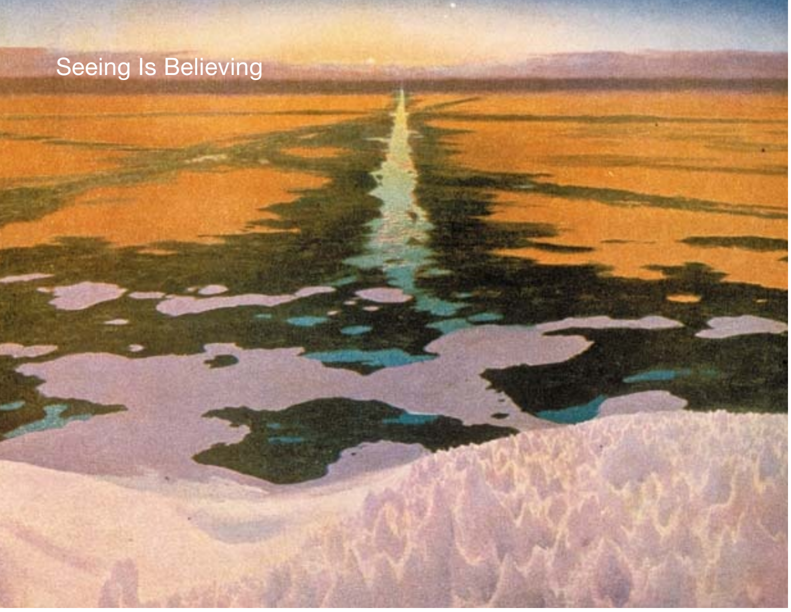
today in English as *Camille Flammarion's the Planet Mars*) and his popular magazine *L'Astronomie*, covering the oppositions of 1887 to 1894, to fully appreciate just how widespread the notion of canals and Mars's habitability was.

Schiaparelli's Influence

It all began with the very favorable Martian opposition of 1877, during which famed Italian astronomer Giovanni Schiaparelli set out to accurately map the planet's albedo features. Working with an 8.6-inch Merz refractor at Brera Observatory in Milan, Schiaparelli had earned distinction by establishing a link between Comet 109P/Swift-Tuttle and the Perseid meteor shower, discovering the asteroid Hesperia, and conducting excellent double-star studies. He was not the first to show linear features on the planet, however, nor to call them "*canali*" (meaning channels). Italian astronomer Father Angelo Secchi first used that term in association with Mars in 1858.

Schiaparelli was the first, though, to map an extensive network of seemingly linear features crisscrossing the planet throughout the apparition of 1877. It was widely assumed at the time that some of the dark features were seas and lakes while the polar caps were composed of water ice, and the planet's atmosphere was far denser and more Earthlike than in actuality. That, coupled with seasonal changes in the polar caps and darkening of many albedo features, was taken as evidence as early as the 1860s that Mars was geologically quite similar to Earth and probably harbored intelligent life. Elias Colbert, director of Dearborn Observatory near Chicago, exemplified this view when he wrote, in 1871, "Mars is, therefore, adapted as a residence for rational beings, like ourselves; and that the Martians had likely attained a higher state of mental development than we have . . ."

This conviction was also in keeping with the popular doctrine of "the plurality of worlds" during the 18th and 19th centuries, which asserted that most celestial bodies are inhabited. This idea was based on teleological rather than



▲ **LINGERING BELIEF** While most astronomers came to doubt their existence, belief in Martian canals lasted until the mid-20th century. Space artist Chesley Bonestell produced this view of a water-filled canal stretching away from one of the planet's polar caps for Willy Ley's 1949 book *The Conquest of Space*.

scientific grounds — namely, that God would not have created anything in the universe without purpose. Advocates of this doctrine included prominent astronomers such as Christian Huygens, William and John Herschel, and Isaac Newton.

In the late 1800s, there was probably no stronger advocate for extraterrestrial life than the prolific French author and astronomer Camille Flammarion. His massive 1862 tome *La pluralité des mondes habités* provides an imposing overview of humankind's place in the universe in relation to presumptive inhabitants of other worlds, all within an optimistic philosophic and spiritual setting.

It is most revealing in this regard to read Flammarion's reports on the 1894 opposition of Mars in *L'Astronomie*. He comments on some exciting new observations, such as sudden flashes of brightness along the planet's terminator reported by several notable observers, including Edward Holden at Lick Observatory, Percival Lowell, Flammarion himself, and Greek astronomer Eugène Antoniadi. Copious discussion followed as to whether these flashes were reflected sunlight off mountaintops, clouds, auroras, or even intentional signals by the Martians themselves. A review in the prestigious English journal *Nature* that same year included the following statement: "If we assume the light to be on the planet itself, then it must either have a physical or human origin; so it is to be expected that the old idea that the Martians are signaling to us will be revived." It seems most likely that conjectures like this inspired H. G. Wells's classic 1897 novel *The War of the Worlds*.

After Schiaparelli's 1877 announcements of extensive networks of *canali* on Mars, a virtual race ensued among others to glimpse, analyze, and classify them. In 1879 he published a second chart of Mars showing an increasingly detailed network of *canali*, many narrower and more delicate in appearance than depicted in 1877. Flammarion enthusiastically wrote about this in *La planète Mars* and *L'Astronomie* between the oppositions of 1877 and 1892. Many reports by other observers at the time described these canals, and discussions flourished as to their nature and difficulty or ease of detection, as well as speculation that many canals appeared now appeared as pairs! Although some of Schiaparelli's contemporaries eagerly confirmed claims of new and double canals, controversy began to emerge, particularly as new and larger telescopes came on line.

Canals: Natural or Artificial?

By the time Percival Lowell arrived on the astronomical scene in 1894, the canal debate was in full swing. That year respected astronomer E. E. Barnard, using the new 36-inch refractor at Lick Observatory, stated that he could not verify Schiaparelli's contiguous linear canals. Even under the best seeing conditions, he saw them as irregular, broken features. Ironically, during that same opposition Eugène Antoniadi was working with Flammarion at his observatory in Juvisy-sur-Orge using a 240-mm (9.45-inch) refractor and recorded no less than 39 of Schiaparelli's *canali*.

Other observers in France, Germany, England, and Italy reported numerous canals, many of them double. Such confirmatory reports were no doubt more reflective of the high esteem in which Schiaparelli was held than of a truly objective evaluation of his claims. This was amply demonstrated in Flammarion's introduction to Schiaparelli's observations of the 1877 opposition:

> *The illustrious Director of the Milan Observatory — as skillful in observation as in calculation — to whom Science owes more than one brilliant discovery . . . undertook studies of Mars which were more successful and more fruitful than any previously undertaken, and which eclipsed those of all his predecessors.*

The debate really heated up after Lowell published his 1894 observations and those of subsequent oppositions, showing incredibly fine and complex networks of canals and their putative intersection points or "oases." His most controversial theories about "intelligent creatures, alike to us in spirit but not in form," were outlined in each of his books on the Red Planet. Lowell's contention was that the canals, as seen from Earth, were not just waterways but agricultural zones fed by water from the planet's polar caps.

Although Schiaparelli believed that Mars bore life, he was less convinced the *canali* were artificial. In his 1893 book *La vita sul pianeta Marte*, he states:

> *Rather than true channels in a form familiar to us, we must imagine depressions in the soil that are not very deep, extended in a straight direction for thousands of kilometers, over a width of 100, 200 kilometers and maybe more. I have already pointed out that, in the absence of rain on Mars, these channels are probably the main mechanism by which the water (and with it organic life) can spread on the dry surface of the planet.*

◀ **PHOTOGRAPHIC INTERPRETATION** Although great strides occurred in the improvement of astronomical photography in the 20th century, film emulsion never surpassed the resolving capacity of the human eye. Earl C. Slipher, who worked at Lowell Observatory from 1909 until his death in 1964, compiled the most comprehensive photographic record of Mars, spanning 50 years. He never gave up his belief in the canals, going so far as to publish drawn interpretations of his photographs.

From the start, however, even scientists who accepted Schiaparelli's reports of channels on Mars favored natural explanations. A sobering review by Dublin astronomer J. R. Holt in the September 1894 issue of *L'Astronomie* summarizes it eloquently:

The overall opinion is that the Martian canals are fissures on the planet's surface created when Mars transitioned from a liquid to solid phase and consequently are older than the seas. On the other hand, some astronomers believe them to be artificial, or rivers and canals redirected by the inhabitants for irrigation purposes.

He concludes that the canals were probably caused by fluvial erosion, in part due to shrinkage of the ancient seas:

It is likely that the oldest "continents" are mostly deserts, and that life, if it does exist, is relegated to terrains only recently laid bare by retreat of the waters and the canals. It must also be said that the fluvial erosions must have been massive, if these rivers have indeed [flowed] *for millions of years along these same basins.*

This seems remarkably prescient given the poor state of knowledge about Mars at the time.

Finally, what was known of the physical and geological conditions on Mars in the late 1800s? Spectroscopy and photography were just coming of age as powerful new astronomical tools, as were increasingly larger telescopes. The first spectroscopic studies of the Martian atmosphere compared it to that of the airless Moon and incorrectly concluded it contained water vapor. That finding no doubt fueled the debate about canals and life on Mars. By 1894, however, Lick astronomer William Campbell showed that the water-vapor signature in the Martian spectrum was actually due to the Earth's atmosphere.

Likewise, astronomical photography, which had vastly improved by the turn of the 20th century (*S&T:* March 2014, p. 68), did not convincingly record the network of canals. Despite Lowell astronomers Carl Otto Lampland and later Earl C. Slipher's determined efforts to do so, their very best images only revealed broad, diffuse linear features, very similar to those drawn by Eugène Antoniadi using the 32.6-inch refractor at Meudon Observatory in Paris. Antoniadi's sketches, in fact, correspond quite closely to modern charts of the major geologic features on the planet as revealed by orbiting spacecraft.

So, in the end, were all of the Red Planet's presumptive canals imaginary? Not quite, but they were decidedly not artificial. As Mars expert William Hartmann points out in his engaging book *A Traveler's Guide to Mars*, while many consider that Lowell and his followers let their imaginations get the best of them, were they really so crazy? The answer seems to be no. As Hartmann says, "Proof that some of Schiaparelli's and Lowell's much-criticized canals were based on real features can be found in a Martian region known as Xanthe Terra."

As we now know, this extensive desert region contains two large craters with dark, windblown dust streaks and the gigantic canyon Valles Marineris. All three features were portrayed as canals by many 19th-century astronomers and given various names. For example, Lowell's canal Coprates corresponds to Valles Marineris. Other canals that correspond to actual Martian features include Cerberus, named by Schiaparelli, a prominent fracture zone now called Cerberus Fossae. Similarly, many other canals are dark linear streaks caused by windswept dust on the Martian surface, which gradually changed from one opposition to the next, especially as seen with Earth-based telescopes.

▲ **CLOSING THE BOOK** Today, Mars has been explored by numerous spacecraft, landers, and rovers, which have conclusively shown that no artificial canals exist on the Red Planet.

The Lingering Romance

As Sheehan and others have pointed out, Lowell, Schiaparelli, and Flammarion, as well as many of their contemporaries, set the stage for a hopeful if not overly romantic notion of Mars as an abode of life, especially in the public mind. Talk of "intelligent beings" disappeared in the early 20th century as new data emerged on the tenuous nature of the Martian atmosphere, its desiccated, frigid surface conditions, and its lack of liquid water. Even after NASA's historic Mariner 4 spacecraft flyby in the mid-1960s, such luminaries as Carl Sagan and Gerard Kuiper argued that the shrinking polar caps and darkening of adjacent landscape on Mars might be evidence of lichen-like organisms consuming water vapor released by melting frost. While we now know this isn't the case, the quest for past or even present life on Mars remains a major scientific goal of current space exploration. And so the romance continues.

■ **KLAUS BRASCH** is professor emeritus of biology at California State University, San Bernardino, and docent in the public program at Lowell Observatory.

 by Jonathan McDowell

LITTERBUGS This artist's representation of space debris in low-Earth orbit is based off of actual data but exaggerates the size of individual objects so that they will be visible at this scale.

LITTER IN ORBIT:

How to Clean Up Space Junk

GEO 35,800

Thousands of pieces of debris orbit Earth, and it's going to take a coordinated effort to solve the problem.

Sixty-some years ago, Sputnik became Earth's first artificial satellite. But it wasn't the only thing launched that day — the main rocket stage of the launch vehicle also ended up in orbit. There are now more than 9,000 metric tons in orbit around Earth, and 80% of that is orbital debris — "space junk."

Space is famously big, so you might think that even tens of thousands of orbiting objects would have plenty of room to themselves. Indeed, the average distance between debris at any moment is hundreds of miles. But each of those objects is flying around Earth at swift speeds: 28,000 km/hr (17,400 mph) in the lowest, fastest orbits. They sweep through so much space in the course of a short time that the occasional cosmic collision is not only likely but inevitable.

On February 10, 2009, a half-ton communications satellite, Iridium 33, smashed into a dead Russian satellite at a relative speed of 41,940 km/hr and an energy of 54,000 megajoules. (A single megajoule is the energy of a one-ton truck hitting you at 100 mph.) In a fraction of a second, both satellites were reduced to thousands of pieces of shrapnel, many of which remain in orbit today and pose a threat to other space traffic.

As the amount of space junk increases, we risk what's called the *Kessler syndrome*, in which collisions become so frequent that a chain reaction gradually reduces the near-Earth satellite population to aluminum confetti and makes space travel impractical.

In the Kessler syndrome collisions become so frequent that a chain reaction gradually reduces the near-Earth satellite population to aluminum confetti and makes space travel impractical.

Debris Demographics

We can distinguish two main kinds of junk: Deliberate littering includes dead satellites, expended rocket stages, and discarded parts such as covers and lens caps. Debris can also result from destructive events, such as rocket explosions, satellite collisions, and antisatellite tests. As the number of satellites has gone up, the number of different types of space junk has also increased over time. In the classic Space Race years of the 1960s, only a few dozen satellites were operating at any one time, but today there are almost 2,000 — and the amount of orbital garbage has ballooned accordingly. The junk increased dramatically in 2007, when China tested an antisatellite missile and destroyed one of its weather satellites, and again in 2009, thanks to the Iridium collision. A handful of incidents have undone decades of efforts to reduce the amount of space junk.

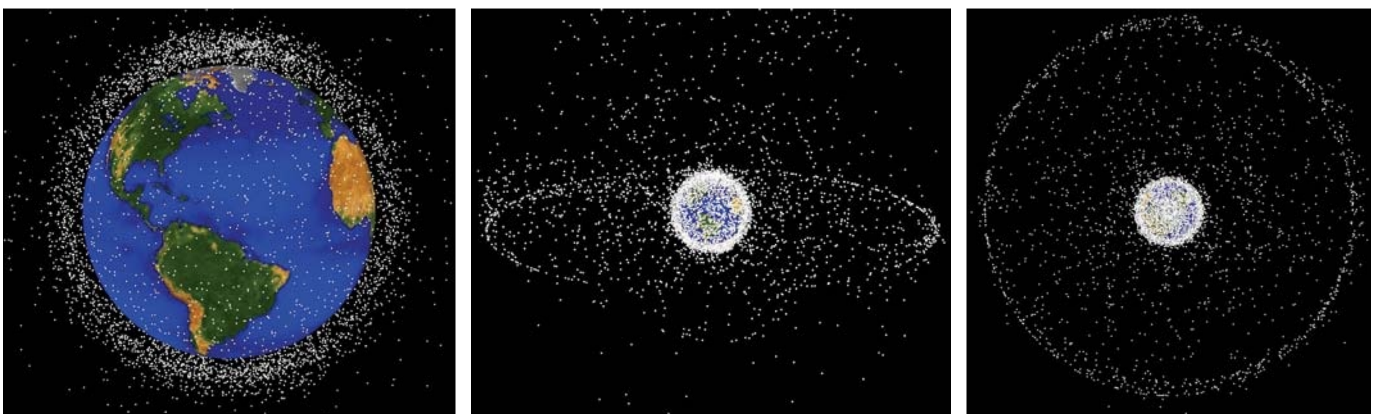
Any piece of debris orbits Earth in a path similar to that of the satellite that made it. Most satellites are either in *low-Earth orbit* (LEO), between 200 and 1,700 km above the surface, or in the 35,800-km-high *geostationary orbit* (GEO), where satellites take 24 hours to circle the planet in order to stay in the same location on the sky as seen from Earth. GEO is mostly used for communications and television-broadcasting satellites, although low-power communications payloads used for cellphone and email traffic can be found in LEO, too.

A special set of near-polar orbits within LEO are known as *Sun-synchronous orbits* (SSO), where satellites pass over the same part of Earth at roughly the same local time every day. Here you can find the satellites that image Earth, both for civilian mapping and government surveillance purposes.

At intermediate heights (*medium Earth orbit*; MEO) between LEO and GEO, the intense Van Allen radiation belts make it harder for satellites to operate. Nevertheless, GPS navigation satellites are among those that operate here in 12-hour orbits.

MEO

▼**JUNK NEAR EARTH** The vast majority of debris exists in low-Earth orbit (*left*), but a significant number of objects are in or near geostationary orbit *(center)*, which, aligned with Earth's equator, allows satellites to match our planet's spin. A polar perspective *(right)* provides a different view of the density of objects in LEO and GEO orbits. View the debris in motion at **https://is.gd/spacedebrismovie**.



LITTERBUGS: ESA; JUNK NEAR EARTH: NASA (3)

1,700

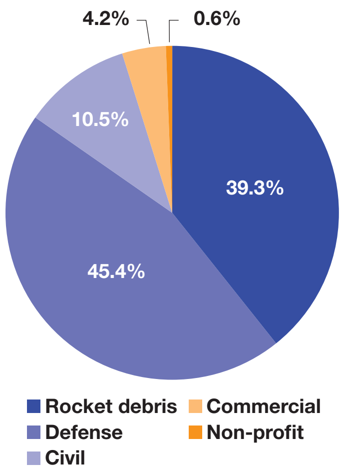
LEO

200 km

All of these orbits are roughly circular — relatively few satellites operate in *highly elliptical orbits* (HEO), where the low and high points (perigee and apogee) are very different from each other. But a lot of junk lies in HEO, mostly from rocket stages, which were left there while delivering a satellite to GEO.

Still, most of the known junk is in LEO, and thanks to the 2007 Chinese military weapons test, the majority of that is in SSO.

That distribution may be an illusion, though, as it's much harder to detect small debris in the higher orbits farther from Earth. The same object in a 10 times higher orbit is 1/100 as bright to optical telescopes and appears 1/10,000 as bright to radar reflection. We'll know better what the high-orbit debris situation is in a few years, when new satellites dedicated to mapping high-altitude space debris give us the true picture. It's likely to be depressing news.



◀ **WHO'S LITTERING?** The littering by civilian and commercial satellites is relatively minor compared to the debris generated by military satellites (medium purple) and exploded rocket stages (dark purple).

Litter Prevention

The major spacefaring nations are now taking steps to lower the risk of a Kessler cascade. Although no international law controls space littering, informal agreements exist between the world's major space agencies. The Inter-Agency Space Debris Coordination Committee provides a forum for these agencies to set recommendations — for example, how high above GEO you should boost your dying satellite so it won't bump into operational ones. The leading centers for research on debris are the Orbital Debris Program Office at NASA's Johnson Space Center in Houston, Texas, and the European Space Agency's Space Debris Office in Darmstadt, Germany, which also hosts regular international conferences on the problem.

These groups have found that there's no one-size-fits-all solution when it comes to space junk. Different kinds of junk need different approaches.

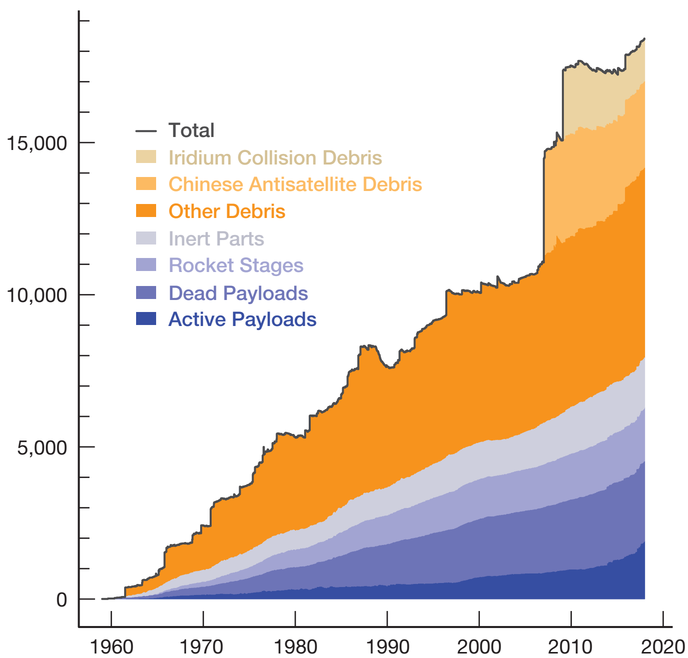
Active satellites are "passivated" at the end of their missions. This neologism indicates that the owners try to get rid of all energy sources that might cause the satellite to blow up at a later date — usually, by venting all rocket propellant and all the fluid from any batteries. In the past, battery explosions had been another significant contributor to space junk.

If the satellite is in a low orbit, it will be lowered toward Earth as much as possible before getting rid of its rocket fuel. The idea is to make it vulnerable to atmospheric burn-up. Getting the satellite to reenter immediately is best, since you can then control where it burns up, but there may not be enough fuel to do this. Even reducing the perigee a bit will help, since the atmosphere gets much denser the lower you go, and atmospheric drag will become more effective in bringing the satellite down, perhaps in months instead of decades.

For satellites in GEO, it wouldn't be practical to bring the satellite down from that high. Instead, they go into a so-called "graveyard orbit," a few hundred kilometers above the geostationary belt. Satellites placed here will stay out of the belt for hundreds of years, even with the perturbing gravity of the Moon and Sun.

Such actions mark a drastic change from 30 years ago, when most low-orbit satellites didn't have the ability to change their orbits at all. A rocket put them in space, and they orbited solely under the influence of gravity and air drag. Nowadays, most satellites with a mass of more than a few hundred kilograms have their own rocket-propulsion systems to alter the orbit at mission's end.

But recent years have brought us a new problem: Since 2003 nanosatellites (less than 10 kg) have become common, most using a standard design known as a CubeSat (*S&T:* Nov. 2013, p. 64). More than 500 CubeSats are now in orbit, and almost none of them have their own rocket engines, posing a challenge for other satellites. Even if a CubeSat is still operating, if it can't get out of the way it might as well be space debris as far as an approaching satellite is concerned. Until recently many CubeSats were launched to low orbits with



▲ **A GROWING PROBLEM** The amount of space junk has increased dramatically over a few decades. Most debris comes from accidental rocket explosions or deliberate military tests. Single collision events, such as the deliberate Chinese test or the accidental Iridium/Cosmos crash, can worsen the situation significantly. Littering of inert parts, rocket stages, and dead satellites makes up most of the rest. Active satellites (dark purple) are only a small fraction of the orbital traffic.

GREGG DINDERMAN / S&T; SOURCE: J. MCDOWELL (2) short lifetimes to perform technology demonstrations. But as CubeSat systems mature, operational constellations are being designed to stay up longer.

In the past couple of years, a wave of new experimental CubeSats have been built to test various ways to get out of LEO cheaply once they're done working. One company is advocating tiny solid rocket motors, but an early test fired in the wrong direction. Most of the current experiments use some variation of *drag brakes*: Either a balloon or parachute pops out of the tiny satellite at the end of its mission and inflates to a much larger size. Friction with the upper atmosphere then decelerates the satellite, ensuring reentry within a few weeks or months.

A bunch of older rocket stages are still in orbit as ticking time bombs.

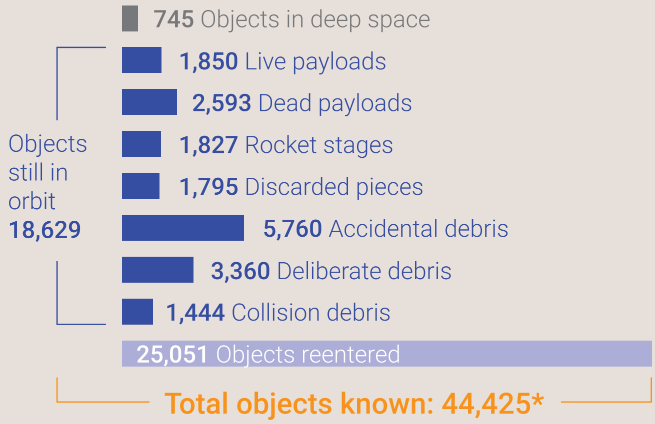
To address the longevity of both CubeSats and larger items, Japan has shown an interest in electrodynamic space tethers, launched coiled up and then unreeled. Earlier U.S. experiments demonstrated tethers many kilometers long. As the tether passes through Earth's magnetic field, currents run along the wire, converting the satellite's orbital motion into heat. As a result, the satellite slowly drops out of orbit. Unfortunately, space tethers have seen a variety of problems in deployment and implementation, which makes it unlikely that they will ever see wide use.

Rocket stages present a slightly different challenge, since they usually run on batteries that last only a few hours. But disposing of them uses the same general idea as for large satellites. When the rocket completes its mission of delivering a satellite, its tanks won't be entirely empty — technicians always leave a little extra in reserve. And since there's no air in space, the rocket also carries an extra tank of oxidizer to help it burn the fuel. As long as the leftover fuel and oxidizer are kept separate, there's no problem. But if the gaskets in the plumbing erode, perhaps months or years after the mission, the two can mix and you can get a large bang. (Of course, in space, no one hears it explode.)

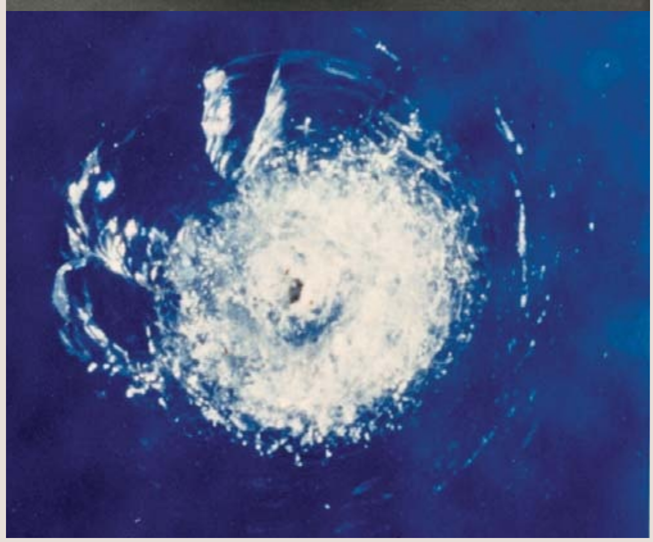
Most modern rockets are designed so that the engine can restart at the end of the mission and use up all the leftovers, preferably making the rocket stage reenter, too, so that it spends only hours instead of years in space. But a bunch of older rocket stages are still in orbit as ticking time bombs: One type of Russian rocket motor, called SOZ, was responsible for four explosions over the past two years. In each case, the motor had been orbiting for about a decade.

Satellite operators have also learned to do less littering. In the early days of the space age, satellites would often jettison instrument covers that were no longer needed using springs or explosive bolts. Now such covers are often mounted on hinges so that they remain attached. It's more expensive and potentially less reliable, but avoids extra debris.

DEBRIS STATISTICS
(through December 25, 2017)



* Includes 43,086 cataloged objects and 1,339 objects that are known but not tracked.



▲▲ **"SHOTGUN" BLAST** This view shows a small hole that orbital debris created in a panel of the Solar Maximum Mission.

▲ **WINDOW CRACK** Orbital debris the size of a paint chip made this small pit in the window of the *Challenger* during NASA's 7th Space Shuttle mission.

NASA (2)

▶ **SPECTACULAR BREAKUP** A European Space Agency's unmanned cargo re-supply spacecraft, dubbed Jules Verne, burned up over the Pacific Ocean in 2008 after delivering supplies to the International Space Station. An observing campaign monitored the reentry to compare against computer modeling. Watch the breakup at **https://is.gd/julesvernebreakup.**

BIGGEST UNCONTROLLED REENTRIES (reentry mass in metric tons)

12.2
Zenit-2 rocket 11S772/ EPN 03.694
June 21, 1985
Pacific Ocean

13.2
UR-500 No. 207 (Proton-1 rocket)
September 18, 1965
Unknown

13.2
UR-500 No. 212 (Proton-3 rocket)
January 4, 1966
Unknown

13.2
UR-500 No. 209 (Proton-2 rocket)
August 21, 1966
Unknown

13.6
Saturn S-IVB-205 (Apollo 7 rocket)
October 18, 1968
Indian Ocean

14.5
Saturn S-IVB-204 (Apollo 5 rocket)
January 23, 1968
Off Australian Coast

14.6
Tselina-2 No. 3L/Zenit-2 11S772 rocket (Kosmos-1714)
February 27, 1986
Pacific Ocean

16.2
Apollo BP-13/ Saturn SA-6
June 1, 1964
Pacific Ocean

16.3
Almaz-1 space station (Salyut-2)
May 28, 1973
Pacific Ocean (near Fiji)

16.4
Apollo BP-15/ Saturn SA-7
September 22, 1964
Indian Ocean

17.0
N-6 No. 1 satellite (Proton-4)
July 24, 1969
Unknown

17.2
Saturn SA-5 rocket/ Jupiter nosecone
April 30, 1966
Brazil

18.5
DOS 3 space station (Kosmos-557)
May 22, 1973
Indian Ocean

39.0
DOS 6 space station/TKS-M module (Salyut-7/Kosmos-1686)
Feb 7, 1991
Argentina

45.1
Saturn S-II-13 (Skylab rocket)
January 11, 1975
Atlantic Ocean (west of Madeira)

75.7
Skylab space station
July 11, 1979
Australia

REENTRIES

One aspect of the space junk problem that tends to get media attention is what happens when larger chunks reenter Earth's atmosphere.

While a lot of the debris pieces are made of aluminum, which melts during reentry, some denser and hardier parts survive the fiery descent and reach Earth's surface. In the 60-some years since Sputnik, though, no one has been hurt, and there has been no serious damage from things falling from the sky. In 1962 the service module of Sputnik 4, the prototype Vostok spaceship, reentered over the U.S. — a piece of it was found in the middle of a street in Manitowoc, Wisconsin, but there wasn't even a crater.

The most notorious reentry was also the biggest ever: the 77-ton Skylab space station, which broke up harmlessly over Australia in 1979. Since then, most large spacecraft have been brought down under control using rocket engines, usually in the so-called "spacecraft cemetery" in the central southern Pacific Ocean.

Nowadays, when even a moderate-size spacecraft does make an uncontrolled reentry, like the 7.5-ton Chinese Tiangong 1 space lab on April 2nd, it makes headlines (see p. 9).

▲ **LONE STAR** The main propellant tank of the second stage of a Delta 2 launch vehicle landed near Georgetown, Texas, on January 22, 1997. The approximately 250-kg tank is primarily made of stainless steel and survived reentry relatively intact.

Bad Behavior in Orbit

All of these techniques are working to keep space junk at a lower level, but they can't prevent deliberate explosions and collisions. These have been another big source of debris historically, one that is completely avoidable. Soviet satellites often carried self-destruct packages to prevent them falling into American hands if they reentered. Unfortunately, sometimes these packages would go off by accident. The Soviet missile early warning system used one-ton infrared observatories called Oko (old Russian for "eye") to watch for American missile launches from orbit. These satellites only lasted a few years at best, remaining in highly elliptical orbits as space junk, and their self-destruct systems had a regrettable habit of activating months or years after the satellite's demise, strewing debris on a path ranging all the way from LEO to GEO altitudes.

The U.S., USSR, and China have also all played with weapons designed to destroy an enemy's space systems. Fortunately, none of these weapons have been used against an opponent, but they've been tested against the country's own satellites. The weapons have usually been aimed at a dedicated target. But a U.S. Air Force test in September 1985 did use an F-15 to take out a still-operational U.S. Navy solar physics observatory, causing some bitterness from the Navy scientists whose data suddenly stopped coming in. (Wags at the time suggested the traditional Air Force/Navy rivalry had escalated to confusion about who their real enemy was.)

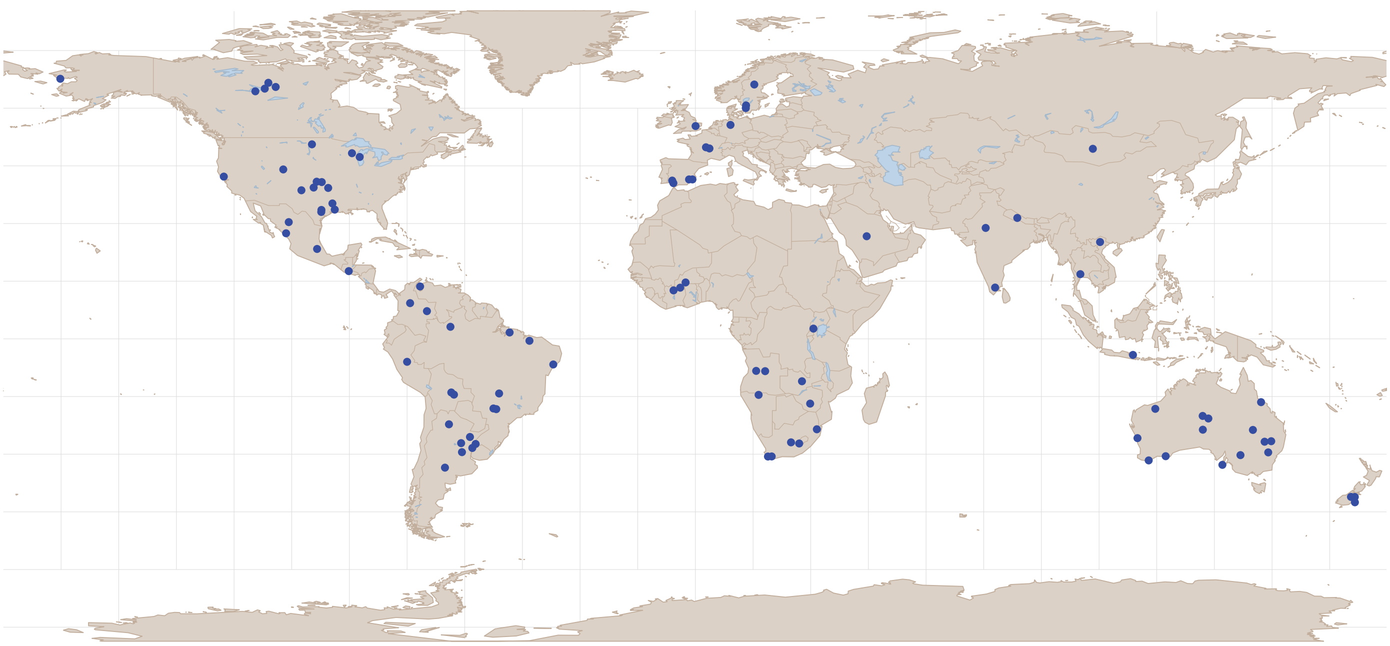
Deliberate collisions are simple to avoid: Let's just not do that sort of thing. But that still leaves the accidental ones. At the moment, the debris from accidental collisions is still a small fraction of all the space junk (only about 3%), so do we really need to worry about it? The problem is that if you have ten times the number of satellites, you typically make ten times the amount of all the other kinds of debris. But you get a hundred times as many collisions; the probability of an orbital crash goes as the square of how much traffic there is. So if we keep increasing our use of space, in a few decades the collisions are likely to surpass everything else and become the main space debris problem. Then we'll be in trouble — Kessler's prediction may come true.

So far, our efforts to reduce how much debris we generate have met with mixed success. Attention is now shifting to more active measures.

Space Garbage Trucks

With tens of thousands of small debris objects floating in near space, some fairly imaginative, and indeed desperate, ideas have been suggested. Powerful Earth-based lasers could melt small debris pieces. Or, a satellite could deploy a huge sticky net, perhaps covered in the aerogel used to collect solar wind samples, and act as a sort of space vacuum cleaner. (Of course, an actual vacuum cleaner wouldn't work in the vacuum of space!) Such devices go under the heading of *active debris removal*, the term of art for space garbage collection.

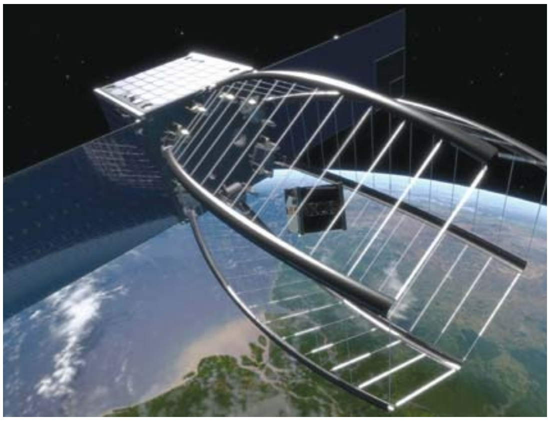
Perhaps these removal mechanisms aren't really needed, though, because it turns out the smallest objects aren't the worst problem. Most of them have a fairly large area-to-mass ratio: They're more like feathers than cannonballs, so they're strongly affected by atmospheric drag. In orbits below 500 kilometers, objects will usually reenter over the course of the solar cycle. Every 11 years, as our star reaches solar



▲ **REENTRIES AROUND THE WORLD** Debris fragments have been recovered on the ground worldwide. Even so, the hazards posed by reentering spacecraft and debris are extremely small. Space agencies and nation states typically aim for a casualty risk of less than 1 in 10,000 probability for a single uncontrolled reentry.

JULES VERNE: ESA / NASA; LONE STAR: NASA; MAP: GREGG DINDERMAN / S&T; SOURCE: ESA maximum, its wind stretches out Earth's atmosphere. As high-density air reaches higher altitudes, it clears out much of the LEO debris.

Further, simulations show that the biggest contributors to a Kessler cascade would be the largest satellites. The Iridium-Cosmos collision is a case in point — it's this sort of crash that makes the most debris. So maybe we should focus on getting rid of the monster space junk first; there's less of it, so that's an easier problem.



▲ **INVENTION OF NECESSITY** The Cleanspace One concept, which features a Pac-Man-like mechanism for capturing space junk, is one of many inventive ideas on the drawing board for dealing with orbital debris.

We will soon have the technology to do just that. Building on the collective experience in sending robotic cargo ships to the International Space Station (ISS), companies may soon build satellites to grab onto and repair or refuel communications payloads, even those that — unlike the ISS — weren't designed for visitors. Such space tugs could also move their prey to a different orbit, perhaps sending them down to controlled reentry over the ocean.

But whose stuff can you deorbit? NASA, for example, would be allowed to deorbit its own space junk, but the legality of grabbing onto someone else's dead satellite is questionable, even if it belongs to a country that no longer has a space program. Space lawyers are already talking about this issue!

Space tugs wouldn't come cheap, either. Different satellites fly at various orbital inclinations to the equator. Changing from one orbit to another would require too much fuel to be practical, so tugs would have to stay at a narrow range of inclinations.

Nevertheless, in the long run I expect we'll see a fleet of space garbage trucks sidling up to long-dead spacecraft and nudging them to their doom. Or, perhaps, sending them to very high orbits, where the low orbital velocities make it cheaper to change inclination. You could potentially collect billions of dollars of defunct high-tech material in an orbital scrapyard, where materials could be recycled.

At this point, the challenge has become more political and economical than technical. I believe that some kind of international tax on satellite operators will be needed to fund the orbital cleanup system. As usual with environmental problems, it's one thing to realize we have a disaster on our hands — it's quite another to agree to do something about it. Let's hope we still have space exploration a century from now!

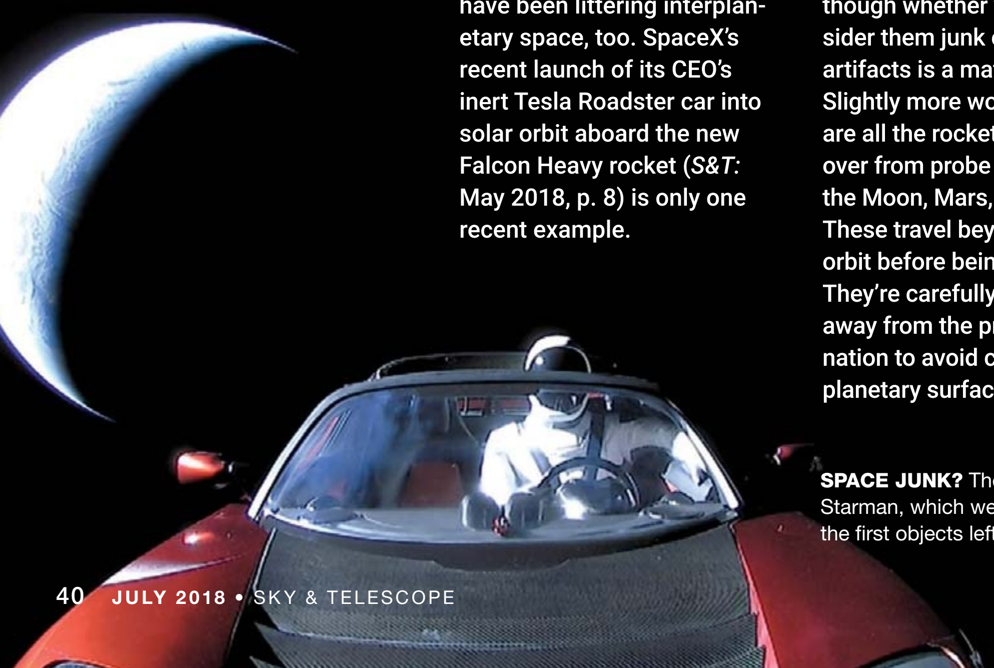
■ In addition to studying black holes and devising data-analysis software, astrophysicist **JONATHAN MCDOWELL** (Harvard-Smithsonian Center for Astrophysics) is an avid investigator of space history. His free online newsletter, *Jonathan's Space Report*, has provided technical details of satellite launches since 1989. Find out more at **planet4589.org**.

CLEANSPACE ONE: WIKIMEDIA COMMONS / CC ASA 4.0; TESLA ROADSTER: SPACEX

INTERPLANETARY SPACE JUNK

In this article I have concentrated primarily on the junk that orbits Earth. But humans have been littering interplanetary space, too. SpaceX's recent launch of its CEO's inert Tesla Roadster car into solar orbit aboard the new Falcon Heavy rocket (*S&T:* May 2018, p. 8) is only one recent example.

The surface of the Moon is scattered with the relics of the Apollo lunar missions – though whether you consider them junk or historical artifacts is a matter of taste. Slightly more worrisome are all the rocket stages left over from probe launches to the Moon, Mars, and Venus. These travel beyond Earth orbit before being discarded. They're carefully targeted away from the probe's destination to avoid contaminating planetary surfaces with any terrestrial microbes that might have hitched a ride on the vehicles. But that avoidance is only for the stages' first orbit around the Sun. Over the decades, centuries, and millennia to come, there's about a 10% chance that these abandoned rockets will end up smashing into one world or another. Although it's unlikely there will be any biological material left onboard to violate the planetary protection criteria by that point, they'd still make a big mess.



SPACE JUNK? The Tesla Roadster and its dummy occupant, dubbed Starman, which were launched into a solar orbit earlier this year, weren't the first objects left in interplanetary space.

1 DAWN: Look toward the southwest to see the waning gibbous Moon and rusty Mars, some 6° apart, slowly disappear from view as the sky brightens.

DUSK: Spot Mercury low on the western horizon shortly after sunset, where you will find the tiny world over the next 17 days. Bring binoculars.

6 EARTH is at aphelion, farthest from the Sun for 2018, at a distance of 152,095,566 kilometers.

9 EARLY EVENING: Venus accompanies Regulus at a separation of less than 1° as Leo, the Lion, sinks in the west.

10 DAWN: The thin sliver of the waning crescent Moon is in the Hyades, a mere ½° from Aldebaran, as they rise together in the east; an occultation of the red giant is visible in parts of Canada.

10–11 NIGHT: Jupiter arrives at its stationary point — look for it 2° right of the double star Alpha (α) Librae; henceforth, the giant planet slowly starts moving eastward against the backdrop of stars.

11–12 NIGHT: Mercury achieves a greatest eastern elongation of 26°; it then fades from view until re-emerging at dawn in late August.

15 DUSK: The waxing crescent Moon and Venus, less than 2° apart, trail Regulus by about 5° as they descend in the west.

20 NIGHT: The waxing gibbous Moon, giant Jupiter, and Alpha Librae form a compact triangle in the southwest.

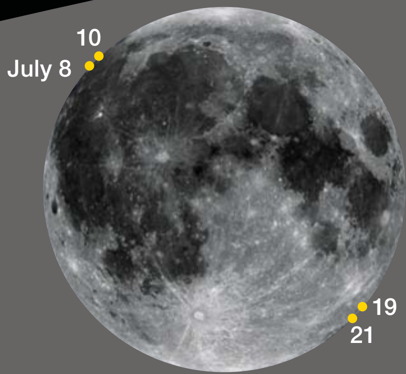
24 NIGHT: The fat waxing gibbous Moon visits Saturn in Sagittarius, where the ringed planet has lingered for the past few months.

26–27 ALL NIGHT: Mars arrives at opposition. Viewers in Europe, Africa, and Asia are well placed to witness an eclipsed Moon pass some 6° above the planet; see page 50.

30–31 ALL NIGHT: Mars comes closer to Earth than it has since 2003. Look in southwest Capricornus to see the Red Planet blazing at magnitude –2.8 and flaunting a disk some 24.3″ wide.

Gullies on Mars are commonly found at mid-latitudes, especially in the southern highlands. Carbon dioxide is thought to play a key role in their formation. Missions such as NASA's HiRISE, from which this image was taken, greatly help in our understanding of these features.

NASA / JPL / UNIVERSITY OF ARIZONA



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				

LAST QUARTER
July 6
07:51 UT

NEW MOON
July 13
02:48 UT

FIRST QUARTER
July 19
19:52 UT

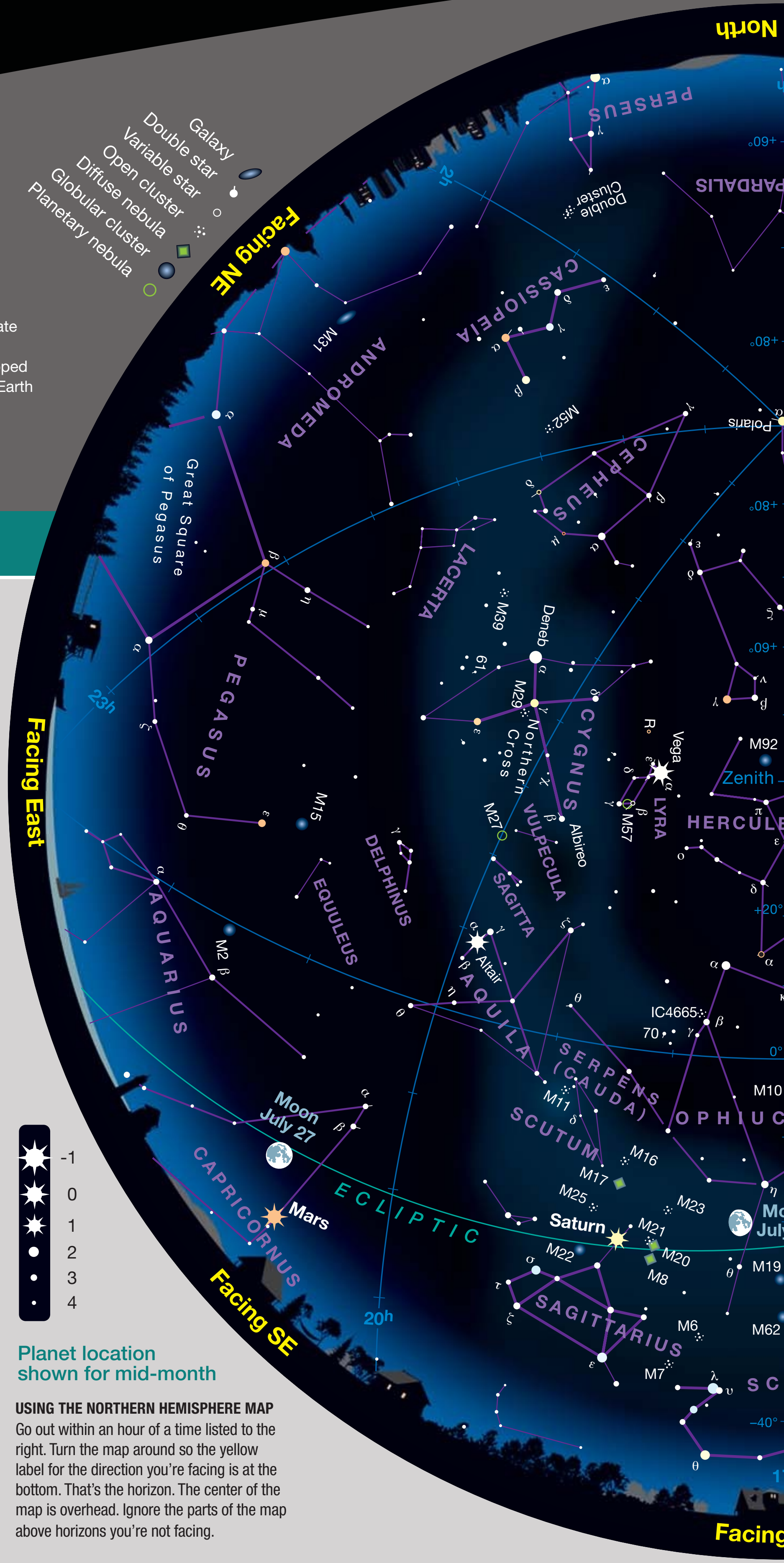
FULL MOON
July 27
20:20 UT

DISTANCES

Perigee	July 13, 08^h UT
357,431 km	Diameter 33′ 26″
Apogee	July 27, 06^h UT
406,223 km	Diameter 29′ 25″

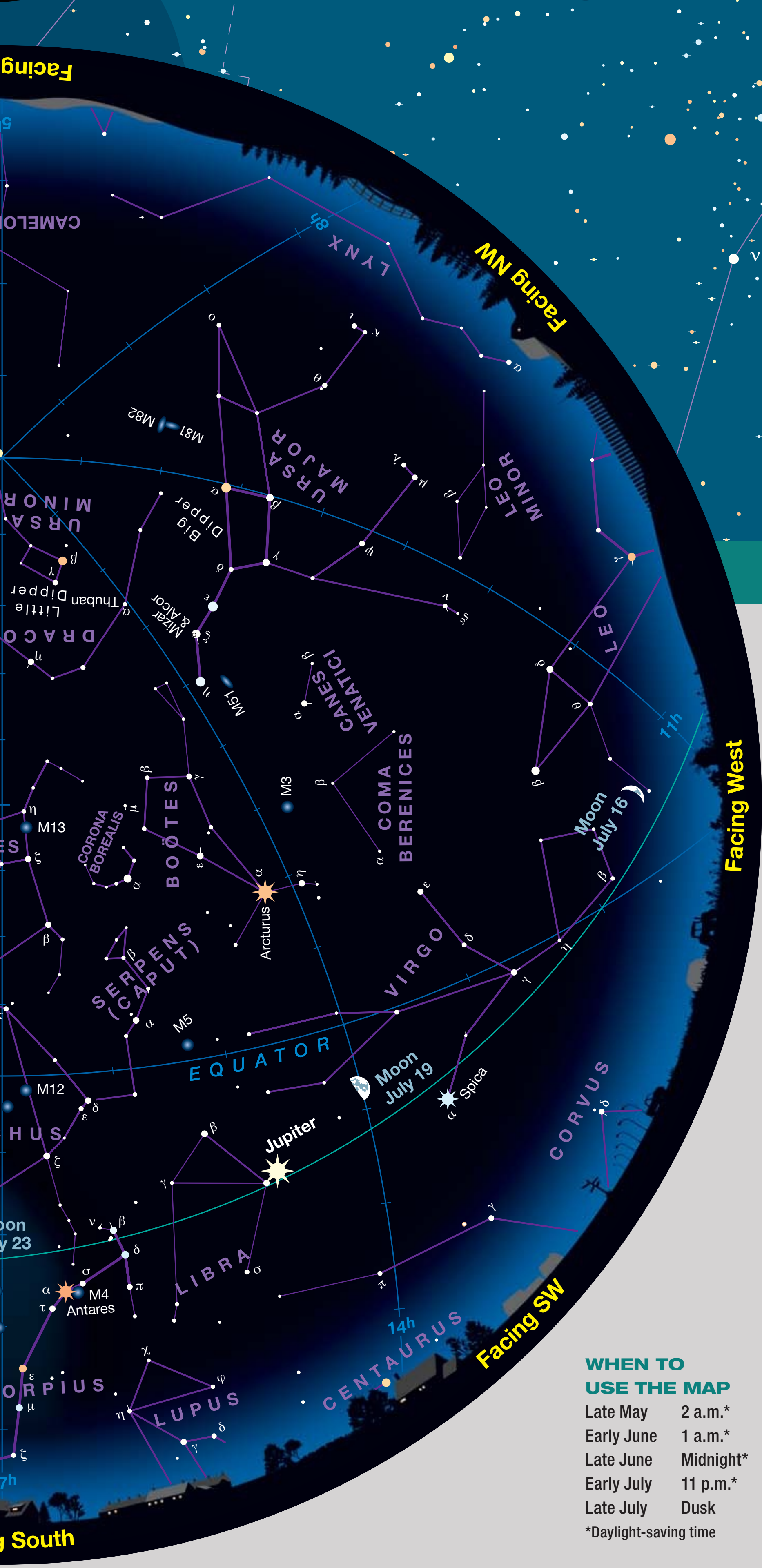
FAVORABLE LIBRATIONS

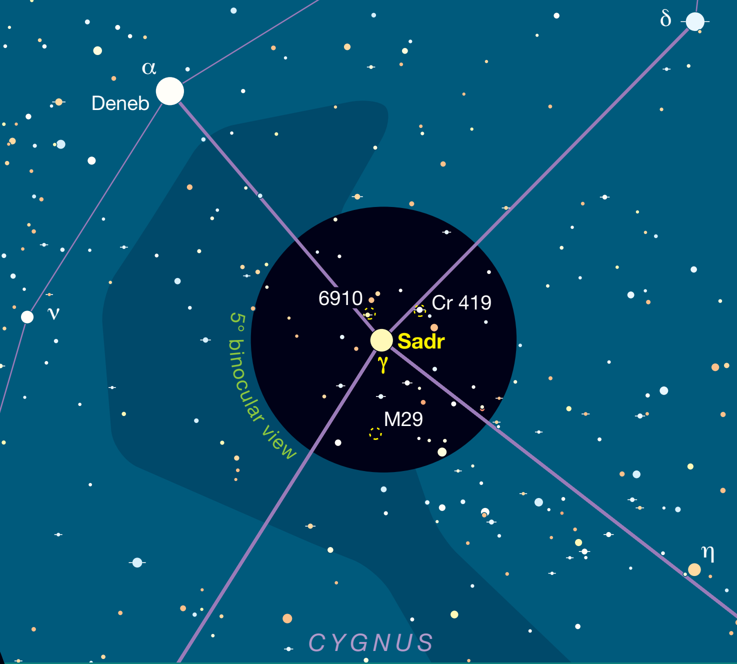
- Ulugh Beigh Crater July 8
- Repsold Crater July 10
- Jenner Crater July 19
- Oken Crater July 21



Planet location shown for mid-month

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





Binocular Highlight by Mathew Wedel

The Secret Heart of Night

The bright star **Sadr**, or Gamma (γ) Cygni, sits at the intersection of the Northern Cross asterism and the heart of Cygnus, the celestial Swan. Indeed, the name Sadr means "chest" or "heart" in Arabic. Of the various Arabic words for heart, *sadr* means the place where secrets are kept: an anatomical chest, but also a treasure chest.

Sometimes the ancient names for the stars are so uncannily perceptive that it makes my hair stand on end. Nowhere is that more true than of Sadr. The Heart of the Swan does indeed keep a secret from the naked eye: a surrounding ring of stars and star clusters, about 2° in diameter, which is bent inward at its northwest border to form the rough shape of a heart. Included in the heart-shaped ring are the open clusters NGC 6910 almost due north of Sadr, and Collinder 419 to the northwest. Both clusters are small, at 10 and 4 arcminutes across, respectively, and they can be rather challenging to pull out of the rich background star field.

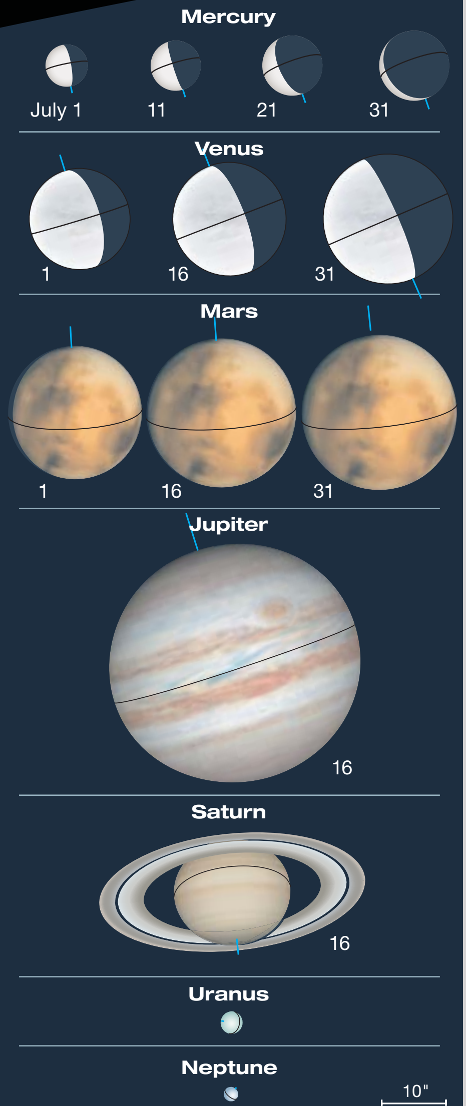
Sadr itself shines back at us across a gulf of 1,800 light-years, making it one of the more distant stars easily visible to the naked eye. An *F*-class supergiant, its mass is at least 12 times that of our Sun, its diameter between 150 and 180 Suns, and its energy output more than 30,000 Suns. The rate of fusion in the core of a star scales with the fourth power of mass, so Sadr can't keep this up for long. In a few million years at most, it will tear itself apart in a supernova, and then the heart of the night will burn very brightly indeed. So let's enjoy it while we can.

■ **MATT WEDEL** has a look at the heart-shaped ring around Sadr every chance he gets; it may be his most often observed object.

WHEN TO USE THE MAP

Late May	2 a.m.*
Early June	1 a.m.*
Late June	Midnight*
Early July	11 p.m.*
Late July	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 **Mercury:** visible at dusk through the 17th • **Venus:** visible at dusk • **Mars:** rises near sunset, highest after midnight • **Jupiter:** visible at dusk, sets near midnight • **Saturn:** visible at dusk, sets before dawn

July Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	6^h 38.7^m	+23° 08′	—	–26.8	31′ 28″	—	1.017
	31	8^h 39.7^m	+18° 23′	—	–26.8	31′ 31″	—	1.015
Mercury	1	8^h 20.0^m	+20° 57′	24° Ev	–0.1	6.6″	61%	1.023
	11	9^h 08.8^m	+16° 13′	26° Ev	+0.3	7.8″	45%	0.861
	21	9^h 34.8^m	+11° 56′	24° Ev	+1.0	9.4″	28%	0.718
	31	9^h 32.6^m	+9° 56′	15° Ev	+2.6	10.9″	10%	0.616
Venus	1	9^h 29.9^m	+16° 41′	41° Ev	–4.1	15.7″	70%	1.060
	11	10^h 13.3^m	+12° 32′	42° Ev	–4.1	17.0″	66%	0.984
	21	10^h 54.1^m	+7° 57′	44° Ev	–4.2	18.4″	62%	0.906
	31	11^h 32.7^m	+3° 06′	45° Ev	–4.3	20.2″	57%	0.826
Mars	1	20^h 50.8^m	–22° 52′	150° Mo	–2.2	20.9″	97%	0.449
	16	20^h 43.1^m	–24° 24′	165° Mo	–2.6	23.3″	99%	0.402
	31	20^h 27.2^m	–25° 53′	172° Ev	–2.8	24.3″	100%	0.385
Jupiter	1	14^h 44.5^m	–14° 45′	124° Ev	–2.3	41.4″	99%	4.759
	31	14^h 46.2^m	–15° 01′	96° Ev	–2.1	38.0″	99%	5.186
Saturn	1	18^h 23.1^m	–22° 29′	176° Ev	0.0	18.4″	100%	9.050
	31	18^h 14.5^m	–22° 36′	146° Ev	+0.2	18.0″	100%	9.209
Uranus	16	2^h 00.4^m	+11° 42′	81° Mo	+5.8	3.5″	100%	20.013
Neptune	16	23^h 10.1^m	–6° 24′	127° Mo	+7.8	2.3″	100%	29.317

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

The Sun and planets are positioned for mid-July; 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.

All My Mars at Once

The author shares a lifetime of encounters with the Red Planet.

Mars and the Moon shine in evening twilight.

STEFAN SEIP

When I was young the title of a science fiction story that I never even read caught my attention: "All the Last Wars at Once." Now, in this month's and next month's column, with Mars closer to us than at any other time in the 32 years between 2003 and 2035, I'd like to share a concentrated account of memorable Mars moments — mostly observational — from my lifetime. Like mine, your sights of mighty Mars this summer will be grounded in whatever past experiences you've had with this most fascinating of our solar system's planets, the world most like Earth.

My earliest Mars. I can't recall the very first time I knowingly saw Mars, but it was probably before I was 8 years old. Carl Sagan said he was 8 when he stared imploringly at what he thought (but wasn't sure) was Mars. "Imploringly" because he was hoping to be mystically transported to Mars by wishing for it like John Carter did in Edgar Rice Burroughs's early 20th-century tales of adventures on the Red Planet. I probably didn't read the John Carter books until I was a few years older. But actually my earliest encounter with Mars happened in the summer of 1954, when I was about minus-5 or minus-6 months old. My mother always told me she remembered how often and intensely she found herself watching Mars in that summer of a near-perihelic opposition of the planet when she was pregnant with me.

Mars and stars. This column is called "Under the Stars," so it seems appropriate to mention a few connections of Mars and stars that make the stars involved all the more wonderful.

Mars spends most of its time far enough from Earth for it to be outshined by close to 30 of the heavens' brightest stars. But then it remarkably kindles, doubling in brightness in some months, until, in a month like July 2018, it burns almost five magnitudes brighter, greatly outshining even Sirius.

The star most famously connected with Mars is, of course, the red giant Antares, whose name means "rival of Mars" — rival in color. Back in February, Mars passed fairly near Antares at similar brightness. But the perihelic oppositions of Mars typically occur when Mars has moved on to glow like a burning coal in the largely dim zodiac constellations of Capricornus or Aquarius.

Mars, Mebsuta, and me. Mars has a special connection with a much dimmer star: The planet periodically has very close conjunctions with magnitude-3.1 Epsilon (ε) Geminorum, the star also known as Mebsuta. But back in April 1976 the transparency was excellent and seeing good across much of the eastern U.S. for something much better: Mars's spectacular occultation of Mebsuta. A friend of mine who was (and still is) a gifted telescopic observer saw the star briefly twinkle through the thin Martian atmosphere.

Another person who observed the Mebsuta occultation was a 14-year-old. He had read about the upcoming event in the weekly astronomy newspaper column I had started with the coming of Comet West the previous month. (To this day I am still writing that column, though now every other week.) This bright young person contacted me about his observation, and we eventually met, observed together, and went on to become very close friends. In the June 2017 installment of the column you're currently reading, I discussed my 1977 trip to Stellafane with this friend, Chuck Fuller. Sadly, Chuck died last summer after a long fight with cancer.

Next month. I'll take an inside look at Martian lore, Viking at Mars, very special daytime observations of Mars, and the greatest meetings of Mars with other planets — including the conjunction of Jupiter and Mars at their best that happens only once every 143 years.

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

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

Mars and Its Supporting Cast

July is all about Mars, but the other planets put on a pretty good show, too.

This is the month that Mars comes dramatically nearer to Earth than at any time in the past 15 years. It comes about 12 million kilometers closer than in 2005 and a whopping 18 million kilometers closer than in 2016. By late July, Mars shines almost twice as bright as it did at 2016's fine opposition — in fact, almost twice as bright as Jupiter! — and its disk grows to 25% wider than it ever got in 2016.

There's no doubt that this is the best-in-a-generation month — and summer — for Mars. But Venus shines bright in the west until the end of July's long twilights, with Mercury still visible well to the lower right of Venus in the first half of July. Jupiter is near its highest in the south at nightfall, while Saturn is low in the southeast. And Saturn is followed, earlier and earlier in the evening as July progresses, by fiery Mars, the final attraction in what ends up being an all-night parade of bright planets across the sky.

DUSK

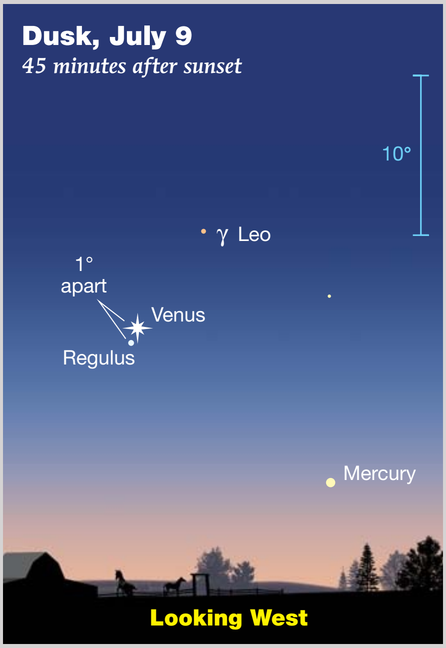
Venus glows fairly low in the west at nightfall, lower with each passing week even though its greatest elongation (46° east) from the Sun doesn't occur until August 17th. Telescopes show Venus's phase thinning from about 70% to 57% lit, while the overall diameter of its disk grows from 16″ to around 20″, less than that of Mars. Still, the much greater surface brightness of Venus makes it shine magnitude –4.1 to –4.3 this month, a lot brighter than Mars.

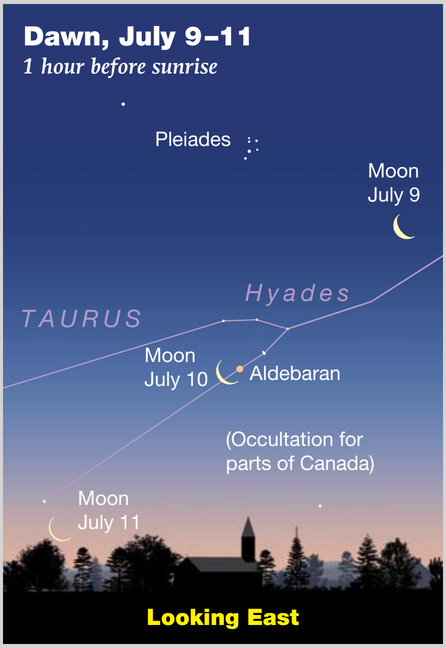
Venus has two exciting conjunctions this month. On July 9th, Regulus is about 1° to the lower left of fantastically brighter Venus. On July 15th, the waxing lunar crescent stands less than 2° lower right of Venus.

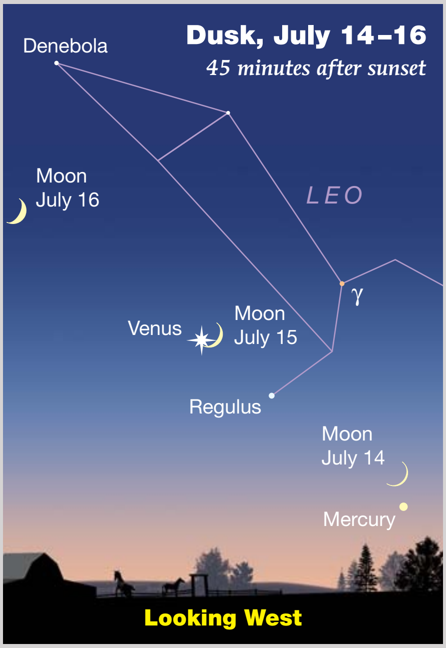
Mercury is a roughly zero-magnitude object about 15° lower right of Venus for the first half of July. Mercury reaches a greatest elongation of 26° east of the Sun during the evening and night of July 11–12 in the Americas. By July 17th Mercury has dimmed to magnitude 1.0 and is rapidly fading from view.

DUSK TO MIDNIGHT

Jupiter is near the meridian in the south soon after sunset in early July. The kingly planet this month fades from magnitude –2.3 to –2.1 and in telescopes shrinks from 41″ to 38″ wide. Jupiter shines 2° upper right of the wide double star Alpha (α) Librae







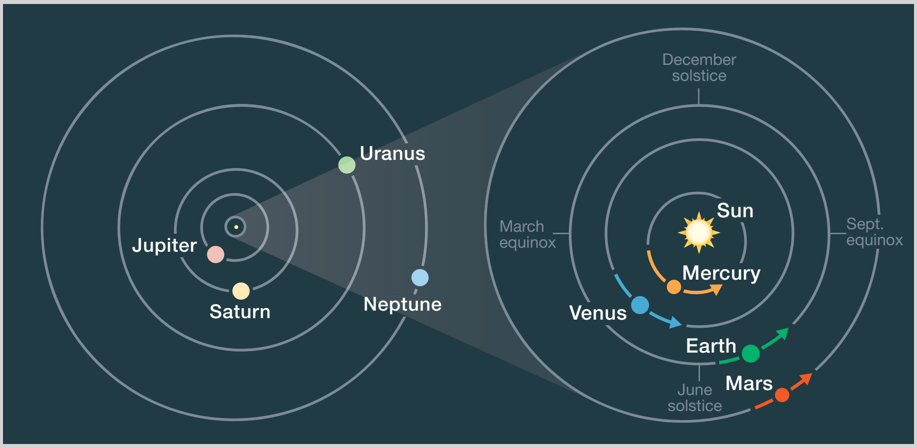
as the planet's apparent motion slows to a halt during the night of July 10–11. Then the planet resumes direct motion, creeping eastward against the background of the stars.

DUSK TO DAWN

Saturn was at opposition on June 27th and so starts July visible from dusk to dawn. Its magnitude fades from +0.0 to +0.2, but the golden planet continues to glow in the midst of the Sagittarius Milky Way, slowly retrograding west to within a few degrees of M8, the Lagoon Nebula, and M20, the Trifid Nebula. The globe of Saturn has an apparent equatorial diameter of about 18″ (similar to that of Venus a little after mid-month). The rings of Saturn gloriously remain open to 26°, nearly their maximum tilt. Saturn is highest around midnight or late evening this month.

Mars begins the month rising about two hours after sunset and already glaring at magnitude –2.2, ever so slightly dimmer than Jupiter. But the campfire-colored planet reaches opposition on the night of July 26–27, rising less than half an hour after sunset and peaking at –2.8 for the final week of July and opening nights of August. Mars comes closest to Earth on the night of July 30–31 and attains a diameter of 24.3″. Mars is more than 24″ wide from July 24th through August 8th and wider than 18.6″ (its maximum 2016 diameter) from June 20th to September 13th (virtually all summer).

Mars follows a little bit more than 30° behind ringed Saturn throughout July, retrograding just above faint Psi (ψ) Capricorni around mid-month. For detailed information on observing Mars (and its two moons), see the article on page 22 of this issue of the magazine and **skyandtelescope.com/marsprofiler.**



ORBITS OF THE PLANETS

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

DAWN

Neptune is almost at its highest in the south during July dawns, **Uranus** a few hours behind it in the sky (see **https://is.gd/urnep** for finder charts).

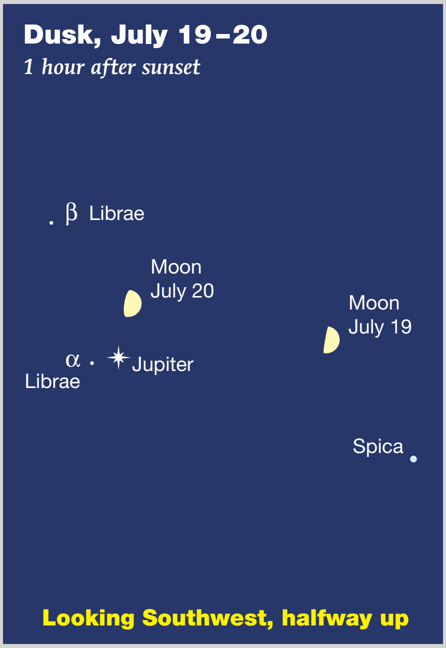
EARTH AND MOON

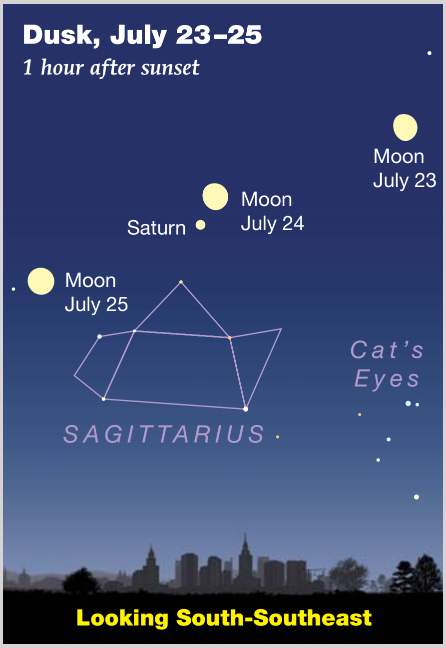
Earth reaches aphelion, its farthest from the Sun in space, at 1 p.m. EDT on July 6th, at 1.02 a.u. (152,095,566 km).

A thin waning crescent **Moon** is closer than 1° to Aldebaran at dawn on July 10th. An even thinner waxing crescent shines less than 2° above Mercury about 45 minutes after sunset on July 14th. It's 2° right of Venus the next night. The waxing gibbous Moon is some 3½° above Jupiter at nightfall on July 20th and 2° upper right of Saturn on July 24th.

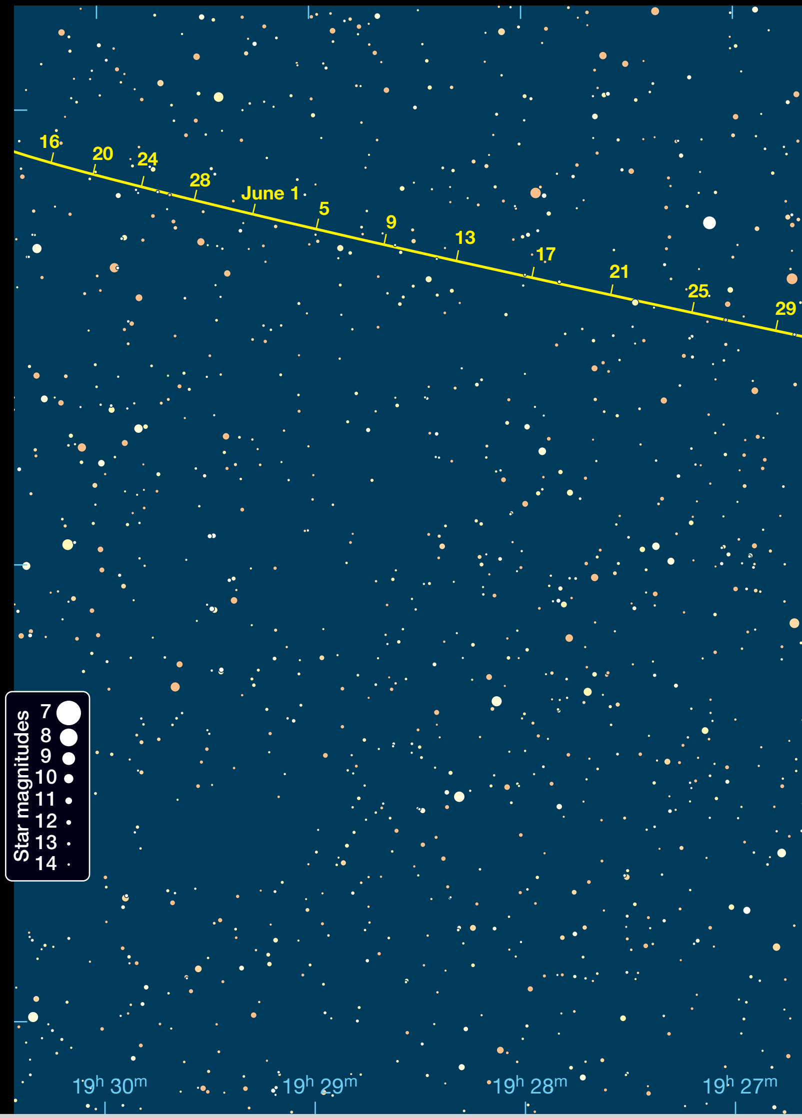
The full Moon is totally eclipsed in Europe, Africa, and Asia on July 27–28. Look for Mars lower left of the action (see page 50 for details).

■ Contributing Editor **FRED SCHAAF** welcomes your comments at **fschaaf@aol.com**.





◀ 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.



Pluto in 2018

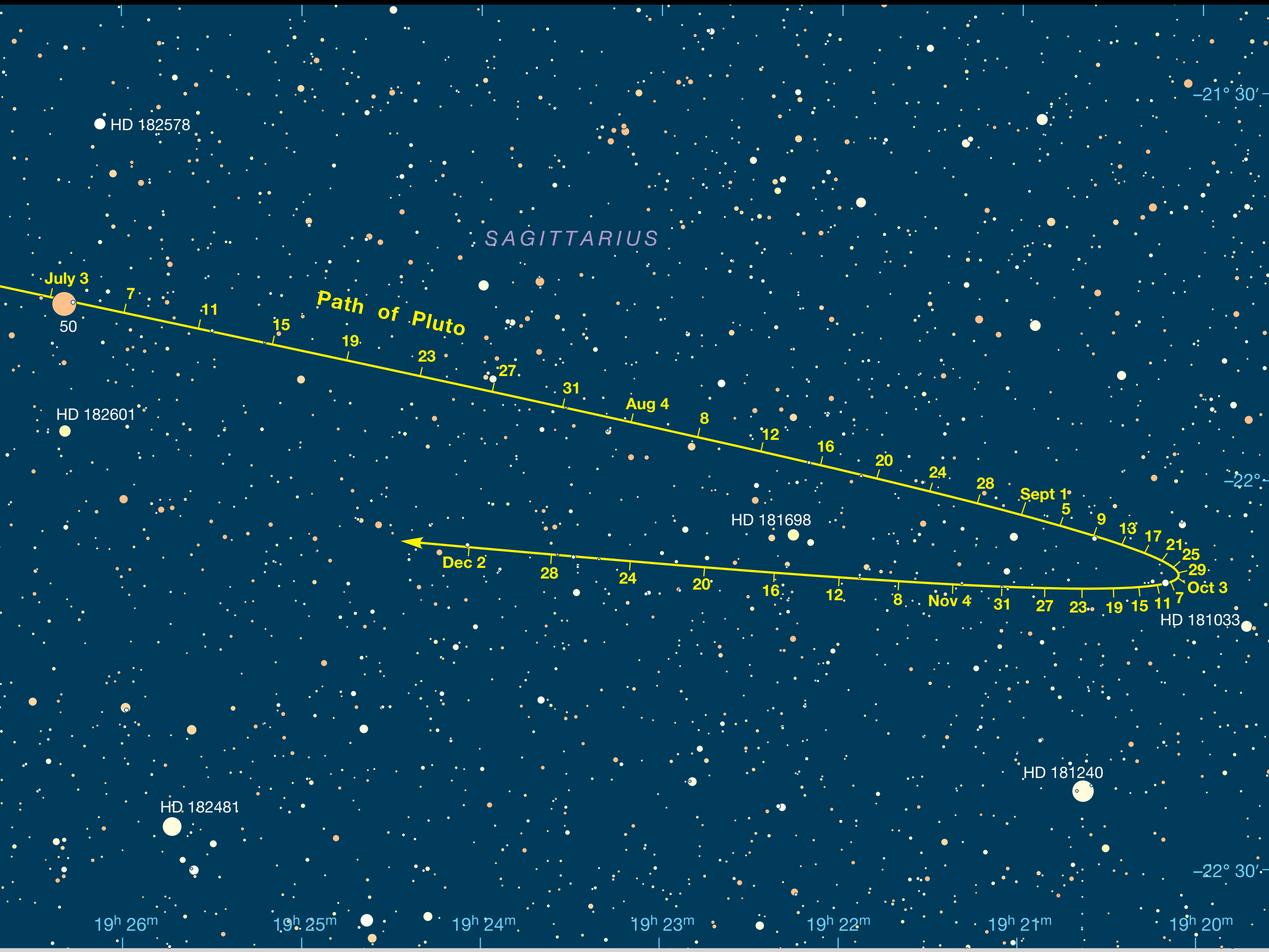
This intriguing little world is at opposition this month. Catch it while you can.

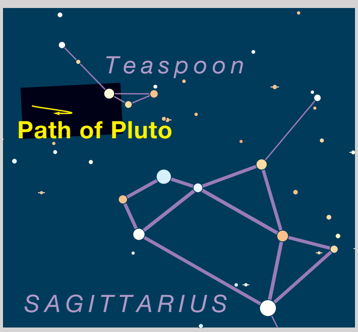
By the time this issue hits the newsstands, the third anniversary of NASA's New Horizons flyby of Pluto will be upon us. What have we learned about our tiny, distant neighbor in the past 36 months? Before New Horizons, scientists didn't know much about Pluto's surface, but data and images sent back by the spacecraft have helped transform Pluto from an astronomical object into a geological world. What appeared as a mottled orb through the eyes of the Hubble Space Telescope has resolved into a dynamic planet with faulted terrains, immense and active surface flows of nitrogen ice, glacially eroded highlands, jumbled mountains of water ice blocks, and possibly even a cryovolcano or two. The jury's still out as to the source of internal heat driving Pluto's geological activity, but data give every indication that it's there. Pluto may still be distant (about 32.6 au from us right now), and it may still be tiny (its radius is only 1,187 km), but we can no longer think of it as cold.

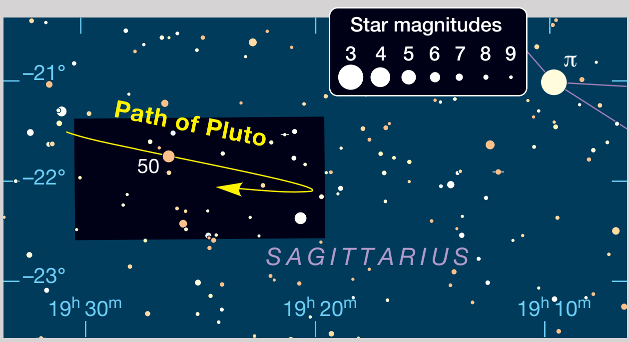
These are the kind of fun facts that compel amateur astronomers to track down this diminutive dwarf planet even if it doesn't look like much in the eyepiece. Because let's face it: Pluto is a challenging target. Not only is it dim, shining about magnitude 14.8 this season, it's traveling through a crowded region of the sky. You'll find it in northern Sagittarius, just below the Teaspoon asterism, as shown in the small charts opposite. The large chart is 1.2° tall and shows stars to magnitude 14.5, which gives some idea of how deep your search will go. The most obvious light in the field is 50 Sagittarii. On July 11–12, the night of opposition, Pluto is just 12′ from this *K*-class star, making 50 Sgr an obvious jumping-

▲ Methane ice dominates the high-altitude landforms at Pluto's equatorial region. The knife-like ridges, or "bladed" terrain, may have been formed by a sublimation cycle. In the extreme cold, methane freezes out of the atmosphere to form deposits hundreds of feet deep. Later, during warming periods, the methane ice evaporates to leave behind spectacularly sharp cliffs and crags.

NASA / JHU APPLIED PHYSICS LABORATORY / SWRI





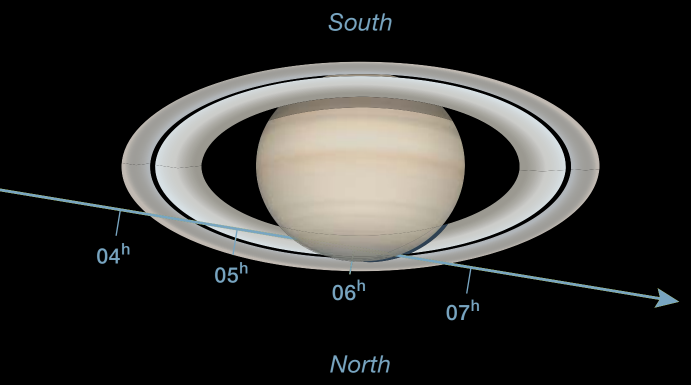


off point for the star-hop. The date ticks on the large chart are for 0^h Universal Time, which translates to late afternoon or evening hours of the date before for North America.

An added difficulty is Pluto's southerly position. It's at a declination of almost –22° right now, low enough to increase the threat of bad seeing (atmospheric turbulence) for most of us. The hunt is easier under dark, transparent skies. You may have some luck with smaller apertures, but using a 10- or 12-inch scope will make the night go more easily, especially if there's any hint of light pollution. Draw a sketch so you can return to the eyepiece on the next clear evening to confirm your observation.

Pluto dims about a tenth of a magnitude each year as it moves away from perihelion. It won't stop fading until it reaches magnitude 16 at aphelion in 2114. It continues to move southward each year as well, at least until 2030 when it nears declination –24°. All of this is to say that your best shot at getting to know this geological world is right here, right now.

A Star Behind Saturn



On the night of July 4–5 the star TYC 6277-323-1 follows this apparent track behind Saturn. The time it will reach a particular ring could vary up to 10 minutes or so, depending on your location. Subtract 4 hours from UT (tick marks) for EDT, 7 hours for PDT.

ON THE EVENING of July 4th or early in the morning of July 5th, depending on where you are in the Americas, Saturn occults a 10th-magnitude star in Sagittarius. Observers with large enough telescopes — say, 8-inch or larger — can watch as the star fades in and out as it passes behind the rings, gaps, and the planet itself.

The western edge of Saturn's rings hides the star TYC 6277-323-1 (also cataloged BD-22 4689) around 4:10 UT (12:10 a.m. EDT) July 5th. The time the star reaches a particular ring or gap can vary as much as 10 minutes or so, depending on your location, so plan to watch earlier than the predicted timings. It takes about 20 minutes for the star to reappear in the Cassini Division, where it should be visible for about 7 minutes. TYC 6277-323-1 winks out behind the planet around 5:17 UT and emerges on the eastern edge of the globe in just under an hour. Look for it in the Cassini Division around 6:18 UT and at the eastern edge of the rings about 20 minutes later.

None of Saturn's moons will occult the star, but around 1:45 UT, Tethys will be just 10″ away from it. That's too early for West Coast viewing and the darkest of darks won't have completely fallen on the East Coast. Plus, Tethys is a tough target made tougher when Saturn is low in the south. However, if you're observing from the eastern U.S. and you have transparent, steady skies, the pairing will still be worth a try.

The Red Planet Returns

◖Mars, fourth rock from the Sun, arrives at opposition at 05^{h} UT on July 27th. This is the apparition we've all been waiting for — at least since 2003, the last year we enjoyed such good looks at our near neighbor. This is a very southerly apparition, with Mars sitting about 7° below the ecliptic. For more on observing Mars this month, see page 22.

Action at Jupiter

JUPITER IS GIVING up its morning game, its setting time edging closer to midnight each night. It transits about 30 minutes after sunset at the beginning of July. As soon as you can tease it out of the gloaming, it's at the highest you'll see it that night — about 30° high on the 1st, and some 10° lower at the end of the month.

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.

June 1, 5:22, 15:18; **2,** 1:13, 11:09, 21:05; **3,** 7:00, 16:56; **4,** 2:52, 12:47, 22:43; **5,** 8:39, 18:34; **6,** 4:30, 14:25; **7,** 0:21, 10:17, 20:12; **8,** 6:08, 16:04; **9,** 1:59, 11:55, 21:51; **10,** 7:46, 17:42; **11,** 3:38, 13:33, 23:29; **12,** 9:24, 19:20; **13,** 5:16, 15:11; **14,** 1:07, 11:03, 20:58; **15,** 6:54, 16:50; **16,** 2:45, 12:41, 22:37; **17,** 8:32, 18:28; **18,** 4:24, 14:19; **19,** 0:15, 10:11, 20:06; **20,** 6:02, 15:58; **21,** 1:53, 11:49, 21:45; **22,** 7:40, 17:36; **23,** 3:32, 13:28, 23:23; **24,** 9:19, 19:15; **25,** 5:10, 15:06; **26,** 1:02, 10:57, 20:53; **27,** 6:49, 16:44; **28,** 2:40, 12:36, 22:31; **29,** 8:27, 18:23; **30,** 4:19, 14:14.

July 1, 0:10, 10:06, 20:01; **2,** 5:57, 15:53; **3,** 1:48, 11:44, 21:40; **4,** 7:36, 17:31; **5,** 3:27, 13:23, 23:18; **6,** 9:14, 19:10; **7,** 5:06, 15:01; **8,** 0:57, 10:53, 20:48; **9,** 6:44, 16:40; **10,** 2:36, 12:31, 22:27; **11,** 8:23, 18:19; **12,** 4:14, 14:10; **13,** 0:06, 10:01, 19:57; **14,** 5:53, 15:49; **15,** 1:44, 11:40, 21:36; **16,** 7:32, 17:27; **17,** 3:23, 13:19, 23:15; **18,** 9:10, 19:06; **19,** 5:02, 14:58; **20,** 0:53, 10:49, 20:45;

Total Lunar Eclipse

THE TOTAL LUNAR ECLIPSE of July 27–28, the second of the year, is well placed for viewers in Europe, Africa, Asia, and Australia. Africa and West Asia will see the entire eclipse, from first contact to last (weather permitting). The leading partial phase will already be underway by the time the Moon rises on the evening of the 27th for Europe, but all of totality will be visible. This is a good, deep eclipse, with the Moon passing through the middle of Earth's shadow. The total phase will last approximately 1 hour, 43 minutes.

East Asia and Australia observe the eclipse as the Moon sets on the 28th, with the Pacific edges of those continents seeing only the initial penumbral or partial stages. North America misses this one altogether, though South America sees the end of totality and later phases as the Moon rises in the evening.

GREGG DINDERMAN / S&T

21, 6:41, 16:36; **22,** 2:32, 12:28, 22:24; **23,** 8:19, 18:15; **24,** 4:11, 14:07; **25,** 0:02, 9:58, 19:54; **26,** 5:50, 15:45; **27,** 1:41, 11:37, 21:33; **28,** 7:28, 17:24; **29,** 3:20, 13:16, 23:11; **30,** 9:07, 19:03; **31,** 4:59, 14:55.

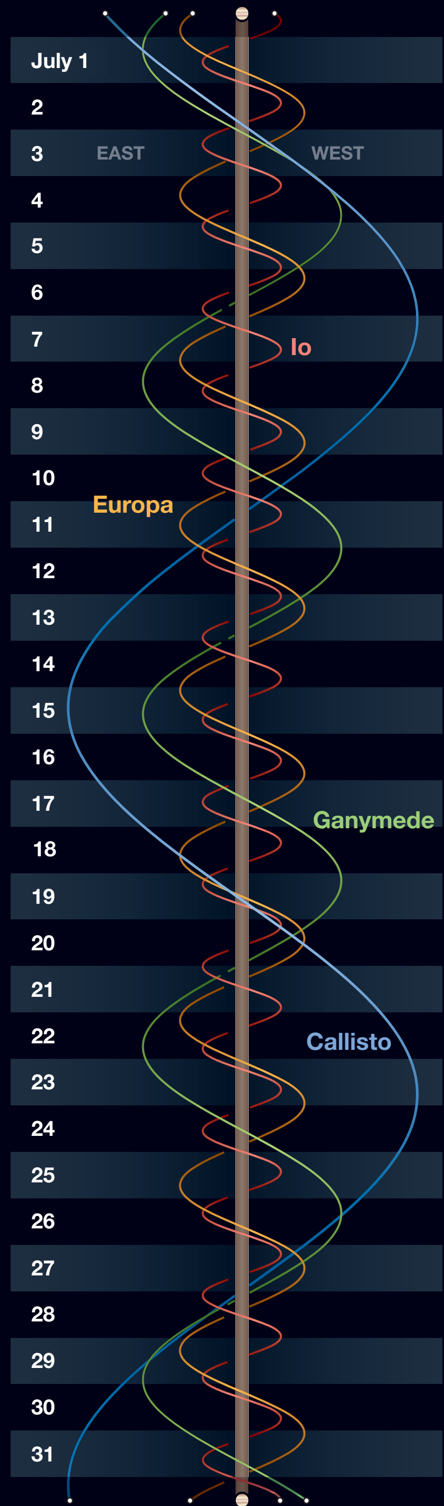
These times assume that the spot will be centered at System II longitude 290°. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 290° and 1⅔ minutes later for each degree more than 290°.

Phenomena of Jupiter's Moons, July 2018

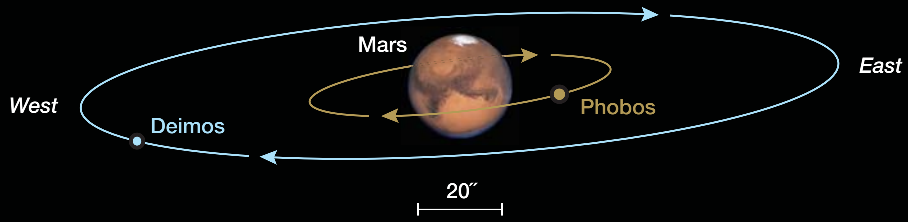
July 1	1:20	I.Oc.D
	4:34	I.Ec.R
	16:44	II.Tr.I
	18:54	II.Sh.I
	18:59	II.Tr.E
	21:09	II.Sh.E
	22:39	I.Tr.I
	23:42	I.Sh.I
July 2	0:48	I.Tr.E
	1:51	I.Sh.E
	19:47	I.Oc.D
	23:03	I.Ec.R
July 3	0:35	III.Tr.I
	2:21	III.Tr.E
	4:58	III.Sh.I
	6:42	III.Sh.E
	11:43	II.Oc.D
	16:08	II.Ec.R
	17:07	I.Tr.I
	18:11	I.Sh.I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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 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.



Hunting Phobos and Deimos

Spotting these diminutive moons is a daunting challenge for dedicated observers.

◀ The tiny moons of Mars do not stray far from the Red Planet. Phobos at its farthest extends less than one Mars diameter from the planet's limb, while Deimos reaches about three. See **https://is.gd/marsmoonstable** for a list of elongation times of both moons in the months closest to opposition.

This year, a three-month-long window from mid-June to mid-September will present an opportunity to glimpse the tiny moons of Mars, which rank among the most difficult targets for amateur telescopes. Your chances of success will increase the closer you observe to July 31, the date of the closest approach of Mars to Earth this apparition. Deimos will then be a 12.0-magnitude object, while Phobos will shine at magnitude 10.9.

Both satellites would be easy prey for a 6-inch telescope if they weren't so close to their parent planet, which is hundreds of thousands of times brighter. They were only detected in 1877 by American astronomer Asaph Hall using the recently commissioned 26-inch Clark refractor at the U.S. Naval Observatory, decades after considerably fainter satellites of Saturn, Uranus, and Neptune were discovered. In 1971, NASA's Mariner 9 spacecraft revealed both Phobos and Deimos as irregularly shaped, heavily cratered shards of cosmic debris that are among the least reflective objects in the entire solar system.

In 1939, astronomers Harry Edward Burton and Bevan Sharpless of the U.S. Naval Observatory began to systematically study the orbital behavior of the Martian satellites. Drawing on observations made between 1879 and 1941, Sharpless published a paper in 1945 in the *Astronomical Journal* entitled "Secular Accelerations in the Longitudes of the Satellites of Mars" that presented the first evidence that the orbit of Phobos was decaying and would ultimately result in the satellite's destruction.

Sharpless's work attracted little interest until the late 1950s, when Soviet astrophysicist Iosif Shklovsky alleged that tidal forces and the frictional drag imparted by the tenuous Martian atmosphere were causing Phobos to spiral toward the surface of the Red Planet at a much faster rate than was possible for a solid body. Shklovsky speculated that Phobos and Deimos might be hollow artificial satellites. This suggestion was taken seriously by several luminaries, including Raymond Wilson, Chief of Applied Mathematics at NASA, and Carl Sagan, a rising star among American planetary scientists. However, President Eisenhower's national science adviser Fred Singer cautioned:

> *The big 'if' lies in the astronomical observations; they may well be in error. Since they are based on several independent sets of measurements taken decades apart by different observers with different instruments, systematic errors may have influenced them.*

Singer was prudent — Shklovsky's calculations were based on flawed data. Phobos is indeed spiraling inward but at a rate of only 1.8 meters (about 6 feet) per century. The doomed satellite will not collide with Mars or be torn to pieces and scattered as a ring around the planet for another 40 million years.

While Shklovsky regarded the moons as the relics of a long-dead race of Martians, to Felix Zigel, of the USSR Academy of Sciences, they were evidence of an existing civilization on Mars. In 1960 Zigel wrote that he was puzzled by the fact that during the favorable Mars opposition in 1862, Phobos and Deimos had eluded experienced observers equipped with much larger telescopes than the 26-inch refractor employed by Hall in 1877, namely William Lassell's 48-inch reflector on the island of Malta and Lord Rosse's 72-inch "Leviathan of Parsontown" at Birr Castle in Ireland, the largest telescope in the world at the time. Despite the mediocre reflectivity of their metal speculum mirrors, these reflectors were vastly superior in light-gathering power. Zigel reasoned that the failure to detect the presence of Phobos and Deimos was because they had been lofted into orbit around Mars sometime between 1862 and 1877.

Zigel failed to take into account that Hall succeeded where his predecessors failed because he was an unusually

NASA / ESA / HUBBLE HERITAGE TEAM

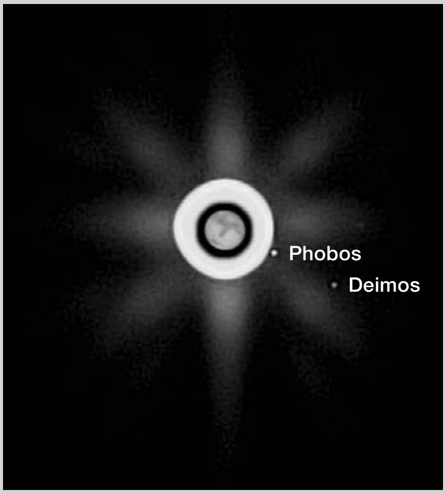
astute observer who carefully scrutinized the sky surrounding Mars using a novel technique. Hall recounted:

> *I began to examine the region close to the planet and within the glare of light surrounding it. This was done by keeping the planet just outside the field of view and turning the eyepiece so as to pass completely around the planet.*

Several weeks after its discovery, Hall and two of his colleagues glimpsed Deimos through the Naval Observatory's smaller 9.6-inch refractor using this "right way of looking."

In 2001, renowned planetary observer Stephen James O'Meara devised an elegant method of heeding Hall's advice to "get rid of the dazzling light of the planet." Instead of positioning Mars just outside the field of view, he cut a semicircle from a Wratten gelatin filter and mounted it against the field stop at the focal plane of his eyepiece, where it bisected the field of view.

Rather than affixing the filter to the field stop with a dollop of glue or a sliver of tape, a rubber O-ring from the local hardware store makes an ideal temporary retainer on some oculars that is easy to install and remove. Short-focal-length eyepieces that provide high powers generally have small lenses that



◀ Because the moonlets are vastly fainter than Mars, amateur John Boudreau overexposed the planet to capture both Phobos and Deimos as they were best positioned on the night of December 26, 2007 using a 5½-inch Astro-Physics refractor and Imaging Source video camera. He then composited a properly exposed image of the planet into the final image.

make the installation of a filter mask more challenging. The combination of a low- or medium-power eyepiece and a Barlow lens to boost the magnification is recommended.

Although a neutral-density filter will give excellent results, O'Meara prefers to use a blue (Wratten #47) filter that selectively attenuates the planet's ruddy glow. "Since Mars will shine dimly through this mask," he advises, "you can more easily judge the distance and direction from the planet where you should look for each moon." It's always best to attempt to detect these tiny wisps of light near the time of their eastern or western elongations, when their apparent distance from Mars is greatest; rotate the eyepiece so that the edge of the filter mask is aligned on the planet's north-south line.

Deimos, the fainter and more distant satellite, circles Mars once every 30 hours 18 minutes, appearing about two-and-a half Mars diameters from the planet's brilliant limb at greatest elongation. Roger Venable of ALPO notes that for 2½ hours before and after each time of maximum apparent elongation, its separation is still greater than 85% of maximum. Outside that interval it is quite hard to see.

Although Phobos is considerably larger and brighter, its closer proximity to Mars makes it a far more challenging quarry. Orbiting a scant 6,000 kilometers (3,700 miles) above the Martian surface and circling Mars in only 7 hours 39 minutes, Phobos never appears more than 16 arcseconds from the planet's limb (only ⅔ the apparent diameter of the Martian disk at the end of July), and it moves fast. For 30 minutes before and after the time of maximum apparent separation, it's still greater than 86% of maximum.

Using the highest magnification the seeing will bear and clean, well-collimated optics are essential ingredients for success. Diffraction from the vanes of a Newtonian reflector's secondary mirror support can be a troublesome source of scattered light, so refractors and catadioptrics are the preferred weapons of choice. Experienced observers with superior visual acuity have bagged Phobos using 8-inch telescopes, while Deimos has been glimpsed with only 6 inches of aperture. Good luck and good hunting!

▲ Instead of making an occulting bar to help him see the moons of Mars, long-time observer Stephen James O'Meara fashioned a semi-circular filter using a Wratten #47 gelatin filter affixed in front of the field stop on a medium-power eyepiece using a 1⅛-inch outer-diameter O-ring.

FILTER: SEAN WALKER / S&T

■ Contributing Editor **THOMAS A. DOBBINS** has been observing Mars since 1965, the year that NASA's Mariner 4 spacecraft flew by the enigmatic world.

The Season's Top 10 Globulars

Even small scopes can track down these striking summer star balls.

▲ M62 is one of the closest globular clusters to the center of our galaxy. Galactic tidal forces affect the distribution of M62's stars, displacing them to the southeast. This gives the northwestern side of the cluster a flattened appearance in the eyepiece.

M62: NASA / ESA / STSCI / S. ANDERSON / J. CHANAME

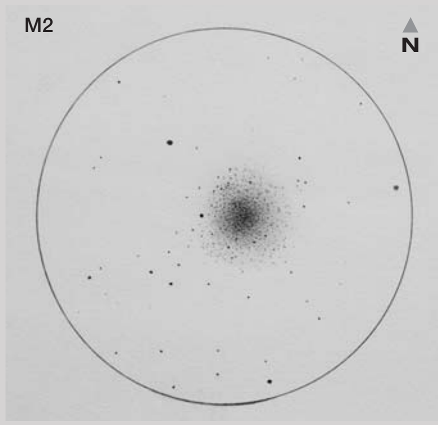
Globular clusters are ancient systems with tens to hundreds of thousands of stars packed into a globe. While open clusters are generally confined to our galaxy's disk, globular clusters inhabit an enormous sphere around the galactic center. Let's take a look at this season's top ten globulars, cherry-picked by the following rules. They must be within the domain of the all-sky chart at the center of this magazine, with their ranking determined by visual magnitude according to the *Catalog of Parameters for Milky Way Globular Clusters*, 2010 edition, compiled by globular-cluster maven William E. Harris.

Holding 10th place in our countdown, **Messier 2** resides in Aquarius. Through my 130-mm refractor at 37×, M2 is a bright little guy with a faint halo reaching 4.4′ northeast to a 9.9-magnitude star. At 102× the halo becomes grainy with one standout star near the core's eastern side. The view at 164× shows quite a few stars in the halo and the outer part of the core, but the inner core is just a mottled glow. In my 10-inch reflector at 187×, many stars adorn the cluster. Its oval core is very bright and enfolds an intense nucleus. Dark lanes dwell beyond the core, one northeast and a less obvious one south-southeast, and there's a shadowy incursion in the cluster's southwestern side. M2 is quite lovely at 299×, bright and richly resolved.

Number nine on our list is **Messier 62** in Ophiuchus. The refractor at 37× exposes a fairly small, moderately bright, hazy ball wearing a faint fringe. It's about 4′ across and somewhat grainy at 102×. Even at 164× only a few stars are visible within the confines of the cluster. At 166× the reflector uncovers many faint to very faint stars in the 5′ halo and 1½′ outer core, which grows denser and brighter toward the center. The core appears rather flattened on its northwestern side.

Our eighth-place cluster is **Messier 92** in Hercules. In the refractor at 37×, its large halo is decorated with pinpoint stars, and the relatively small core holds an intensely bright center. M92 is generously flecked with stars at 102×. The halo covers about 7′, and the 2′ core harbors a small, very bright center. At 164× at least 25 stars freckle M92's face, the fainter ones winking in and out of view. Turning to the reflector at 187×, this attractive cluster boasts nice swirls of stars that bring to mind the arms of a spiral galaxy. The cluster is well resolved into stars down to its brilliant core, whose center appears vaguely triangular.

NGC 6541 in Corona Australis should be seventh, but cresting only



▶ Michael Vlasov sketched his impression of M2 as viewed through a 10-inch f/5 Newtonian reflector at 240×. M2 is a symmetrical globular with a bright core. Look for the attendant star at the cluster's eastern side.

▶▶ At low power, M3 appears as a soft gray spot on a gray background. Increasing the magnification pops up several pinpoints of light. Jeremy Perez sketched M3 on a night of average seeing as viewed through an 8-inch f/6 Newtonian at 120×.

3° above my horizon, it's too low to profitably observe. Arbitrarily disqualifying NGC 6541 gives seventh place to **Messier 55** in Sagittarius. Through the refractor at 48×, M55 is a large, ghostly glow with a dash of very faint stars overlaying its outer reaches. This 11′ cluster is delicately pretty at 102×, with a score of stars scattered across its hazy, ashen surface. A more conspicuous star tacks the halo's south-southeastern edge. With the reflector at 68×, M55's irregular form is nicely speckled with stars. It's well resolved at 187× and shows almost no concentration toward the center. Prominent star chains crisscross the cluster and darkling veins decorate its face. A relative paucity of stars creates a murky bay that dents into M55's southeastern side.

For sixth place we turn to **Messier 15** in Pegasus. This pretty cluster grows ever more brilliant toward the center in the refractor at 37×. M15 takes magnification well, and at 234× it shows some resolution right down to a very small, intense core that hosts a tiny, dazzling center. Wide spikes of stars stick out from the cluster, and the sparsely populated outer halo spreads to a diameter of roughly 8′. M15 is gorgeous in the reflector at 187×. Many of the halo stars gather into starfishy arms, which yields an irregular diameter of as much as 10′. Even the brilliant core surrenders some resolution into stars. At 299× they show a large range in brightness, and apparent outliers stretch the group to 11′.

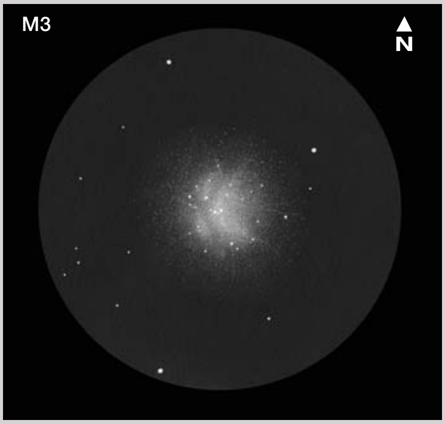
Messier 3 in Canes Venatici holds fifth place, sporting a bright core and fairly bright, 9½′ halo when viewed through the refractor at 37×. At 164× the halo and core are rich in pinpoint stars, the core brightly backdropped with mist. A scattering of brighter stars stands out from the rest, most notably an 11.7-magnitude star on the western side. At 234× this beautiful group shows stars right across the core's 2½′ glow. Some dusky areas shadow the northeastern part of the outer core, and the cluster's brightest region extends northeast-southwest. In the reflector at 187×, the 7′ outer core is irregular and vaguely boxy with a flat eastern side. M3's thinly populated halo swells the cluster to about 14½′.

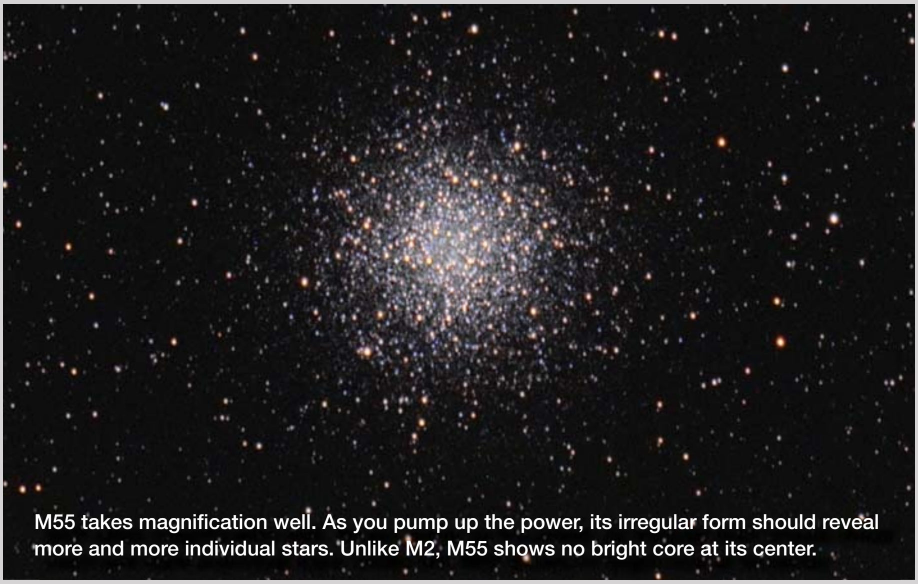
Fourth place goes to magnificent **Messier 13** in Hercules. At 37× the refractor bares a large, bright core with a very bright center and a 10′ halo dosed with stars. The cluster is beautifully resolved at 102×, with its signature, drooping arcs of stars giving it a tarantula-like mien. There's even some resolution across the core. At 164× M13 is well resolved and at least a dozen stars fleck the center. Outliers stretch the group to about 11′. In the reflector at 187×, M13 presents a wonderful fireworks display frozen in time for our prolonged enjoyment. A dusky three-bladed propeller garnishes the

Summer Globular Clusters

Object	Mag(v)	Size	V_{tip}	V_{hb}	Dist (l-y)	RA	Dec.
M2	6.47	16′	13.1	16.05	38,000	$21^h\ 33.5^m$	–00° 49′
M62	6.45	15′	13.5	16.25	22,000	$17^h\ 01.2^m$	–30° 07′
M92	6.44	14′	12.1	15.10	27,000	$17^h\ 17.1^m$	+43° 08′
M55	6.32	19′	11.2	14.40	18,000	$19^h\ 40.0^m$	–30° 58′
M15	6.20	18′	12.6	15.83	34,000	$21^h\ 30.0^m$	+12° 10′
M3	6.19	18′	12.7	15.64	33,000	$13^h\ 42.2^m$	+28° 23′
M13	5.78	20′	11.9	14.90	23,000	$16^h\ 41.7^m$	+36° 28′
M5	5.65	23′	12.2	15.07	24,000	$15^h\ 18.6^m$	+02° 05′
M4	5.63	36′	10.8	13.45	7,200	$16^h\ 23.6^m$	–26° 32′
M22	5.10	32′	10.7	14.15	10,000	$18^h\ 36.4^m$	–23° 54′

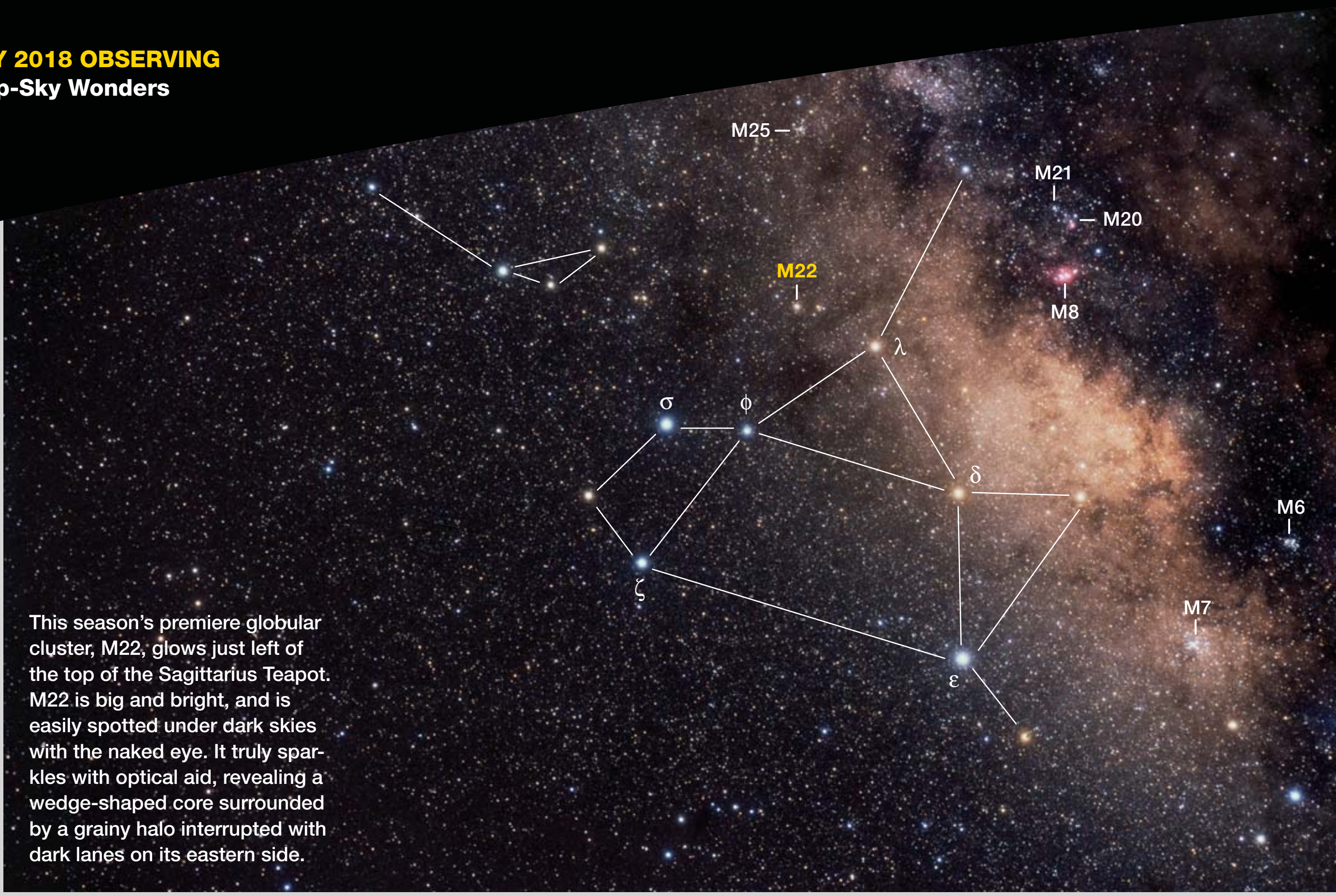
Angular sizes and separations are from recent catalogs. Visually, an object's size is often smaller than the cataloged value and varies according to the aperture and magnification of the viewing instrument. Right ascension and declination are for equinox 2000.0.





M55 takes magnification well. As you pump up the power, its irregular form should reveal more and more individual stars. Unlike M2, M55 shows no bright core at its center.

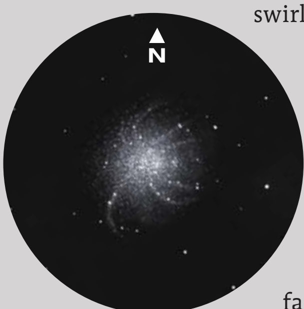
M55: HUNTER WILSON



This season's premiere globular cluster, M22, glows just left of the top of the Sagittarius Teapot. M22 is big and bright, and is easily spotted under dark skies with the naked eye. It truly sparkles with optical aid, revealing a wedge-shaped core surrounded by a grainy halo interrupted with dark lanes on its eastern side.

southeastern reaches of the cluster. Two blades cradle the core, while the third strikes outward until lost from view in the sparseness of the halo, whose draggled edges span 17′.

Messier 5 in Serpens Caput takes the bronze, parading a small, blazing core and granular halo in the refractor at 37×. An 11.9-magnitude star ornaments the halo's western side. At 102× M5 is nearly 15′ across, exposing many stars and brightening toward the center. The cluster is richly resolved at 164×, except in its luminous heart. Halo stars are strewn considerably farther in some directions than others. In the reflector at 187×, a curious distribution of halo stars evokes a spiral galaxy or perhaps a Catherine wheel firework, its curving arms springing mostly from the cluster's western half. At 299× several stars emerge in the core's compact center.



▶ M13, the Great Globular Cluster in Hercules, is a summer favorite for a reason. Under magnification, it resolves into a miniature firework, with stars appearing to spring and arc from its bright core.

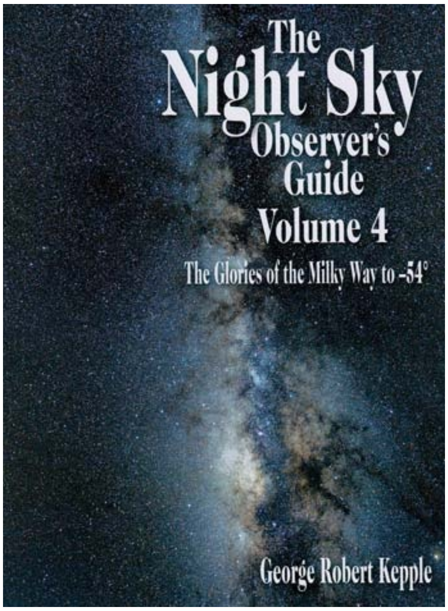
Messier 4 in Scorpius is awarded the silver. With the refractor at 37×, M4 is liberally spattered with pinpoint stars. At 102× a prominent band of stars crosses the brightest part of the core, running north-south through its center. As the outer core reaches about 9′, it thins into the nearly 14′ halo. At 164× this striking cluster is well resolved into many stars over patchy haze, looking much like a populous open cluster. The stars show a large range of brightness in the reflector at 166×, the brighter ones forming beautiful chains and long, swirling arcs.

Winning the gold, spectacular **Messier 22** in Sagittarius shows a wealth of stars in the refractor at 37×, including one standout on the eastern edge of the core. There's a pretty mix of bright and faint stars at 68×, with dim halo stars spread to a diameter of 14′ and partial resolution across the irregular core. The brightest part of the core is wedge-shaped and crowned to the north with a broad wrap of stars that's more prominent than its counterpart in the south. The overall size of the core is roughly 4½′ × 2½′, and it's enfolded by a somewhat dimmer and less dense region 8′ × 7′. In the reflector at 187×, M22 flaunts dimmer patches and bright star chains crisscrossing its face. Some particularly dark lanes occupy the eastern side of the cluster, including one that's quite long. Stragglers expand M22 to 19′, and the core is heavily stippled with stars.

I hope you'll enjoy exploring these clusters as much as I did. To help foretell how many stars you're likely to see, the table on the previous page includes V_{tip} and V_{hb} columns. V_{tip} tells you the magnitude of the cluster's brightest stars, and V_{hb} gives the magnitude of its horizontal-branch stars. If your scope can show you stars to V_{hb}, the cluster is considered well resolved and may show you dozens to hundreds of stars.

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

M22: AKIRA FUJII; M13: JEREMY PEREZ



◀ OBSERVING GUIDE

Willmann-Bell releases *The Night Sky Observer's Guide Volume 4: The Glories of the Milky Way to -54°* by George Robert Kepple ($34.95). This fourth volume of the series describes the appearance of more than 1,800 deep-sky objects in the Milky Way as seen through 6- to 18-inch telescopes, including more than 1,000 targets not included in previous volumes. The book begins with a primer on the types of objects to be observed, as well as equipment and observing strategies. The following 23 chapters focus on each individual constellation of interest within the plane of the Milky Way. Nearly 1,000 black-and-white photographs and sketches complement the author's detailed descriptions. Hardbound, 8½ by 11 inches with 500 pages, ISBN 978-1-942675-06-8.

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▶ ULTIMATE ASTROGRAPH

Celestron announces its flagship astrograph, the 36 cm Rowe-Ackermann Schmidt Astrograph ($12,995). This 14-inch, f/2.2 optical system is designed to record pinpoint stars across a 60-mm image circle. The telescope incorporates a new moving mirror focuser design that minimizes focus shift and includes ventilation fans to allow the scope to rapidly reach ambient temperature. Its 42½-inch-long, 16-inch-diameter optical tube assembly includes two Losmandy-style mounting bars and weighs 75 pounds. Additional accessories include a 48-mm camera adapter and a battery pack for the cooling fans.

Celestron
2835 Columbia St.
Torrance, CA 90503
celestron.com

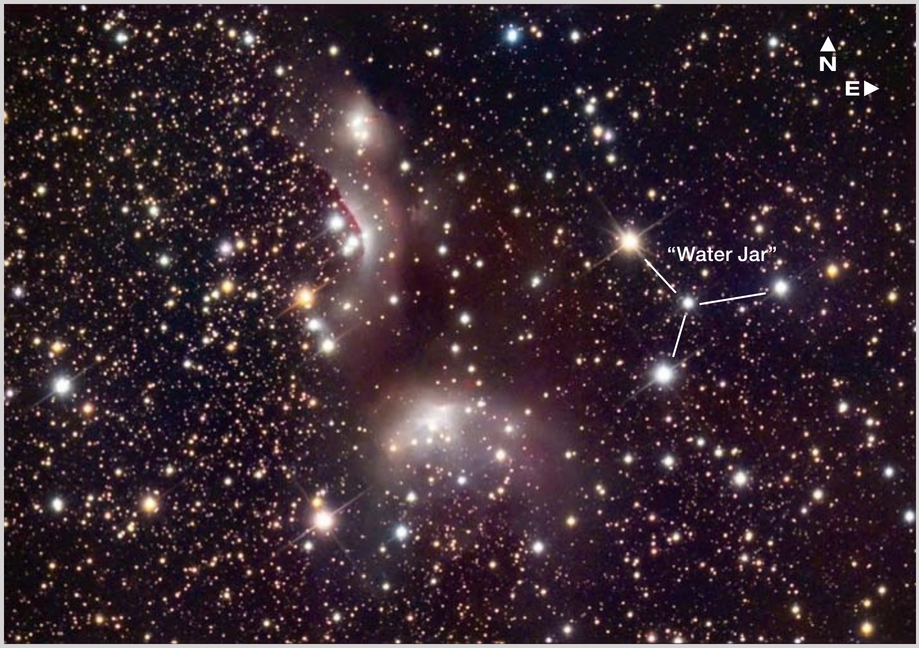
▶ SATELLITE SPOTTER

Southern Stars now offers an updated app for satellite observers using Apple devices. Formerly known as *Satellite Safari*, *Orbitrack* ($4.99) includes a host of new features to track the orbital path of more than 3,500 satellites, permitting users to quickly identify these moving spacecraft in real time, including many military satellites. Its voice-controlled Virtual Reality (VR) mode provides an immersive 3D spaceflight experience that works with any iPhone-compatible VR headset. The app displays a chosen satellite's path across the sky as well as a simulated view from the Earth below the satellite itself. Its orbital elements are updated daily to ensure accurate predictions. *Orbitrack* is compatible with iPhone models 5s and up, or iPads running iOS 10 or higher. An Android version is expected by mid-2018. See the manufacturer's website for a complete listing of features.

Southern Stars
(Available on the App Store)
404 Bryant St.
San Francisco, CA 94107
southernstars.com

Slightly off the Beaten Track

A “backroad” route from Vulpecula to Lyra features worthy treasures.



▲ **CLUMPS OF STARS, CLOUDS OF NEBULOSITY** Despite its ragged appearance, Roslund 4 is a single, sparse cluster enveloped in a convoluted reflection nebula. Two bright concentrations of nebulosity explain the double designation of IC 4954 and IC 4955, often denoted IC 4954/5. East is to the right in this image, while standard configuration (east to the left) applies to the other images.

ADAM BLOCK / NOAO / AURA / NSF

Hey, it’s no contest! In Vulpecula and Lyra, the Dumbbell Nebula (M27) and the Ring Nebula (M57) are the unrivalled favorites of deep-sky observers. Everyone wants a peek at the prizewinning planetaries.

I’m no different. While attending the Mount Kobau Star Party last July, I spent several moments on both M27 and M57 with my 18-inch f/4.5 Dobsonian. But I yearned for deeper challenges. Soon, I was exploring a narrow section of the Milky Way roughly in between the famous planetaries. In the end, I tallied eight inconspicuous yet interesting objects scattered across three constellations.

To Upper Vulpecula

Starting from the Dumbbell, I swept 5° northward to 5th-magnitude 15 Vulpeculae, then veered northeastward for another 1¾° to a rich Milky Way field containing **IC 4954** and **IC 4955**, reflection nebulae enveloping an obscure open cluster called **Roslund 4**.

The cluster is essentially two coarse clumps of stars, together a mere 5′ in length, oriented northwest-southeast. Immediately east of the clumpy stuff is an eye-catching, 2′-wide asterism of 11th- to 13th-magnitude stars reminiscent of the Water Jar in Aquarius. Examining the southeast clump at 228×, I saw only a few faint specks dominated by one 11th-magnitude star; however, 411× showed them wrapped in a mist half a “Water Jar” in size.

The northwest clump comes in three parts. Its bottom end comprises three 12th- and 13th-magnitude stars making a short row slanted northwest. Northward, parallel to the row, are two slightly brighter stars, the southerly one a tight triple. The clump’s top end at 411× was just an 11th-magnitude blur, the fuzzy product of unresolved suns swathed in nebulosity. When I stared directly at the central gleam, the surrounding gauze disappeared. With averted vision, the gauziness grew.

I reduced to 84× and shifted westward 2° to **NGC 6842**, a 13.6-magnitude planetary nebula 1′ in diameter. My search for this pale puff was aided by a 20′-long star chain, aligned north-south and bulging westward toward the target. NGC 6842 was a grey ghost at low magnification, unfiltered, but 228× produced a diffuse patch whose dusky middle turned darker when viewed through an Ultra High Contrast filter. Upping to 294× and switching to an O III filter enhanced the annulus considerably.

The unfiltered scene was rewarding in a different way. At 147×, I noticed that NGC 6842 is accompanied eastward by a pair of stars, magnitudes 13.7 and 14.6, the latter almost touching the disk (closer still is a third star, magnitude 15.9, visible in images). Applying averted

SUMMERTIME SMOKE

These observations were conducted over several nights at high-elevation sites many miles apart in an attempt to escape persistent high-altitude smoke from forest fires across central British Columbia and northern Washington State. The insidious menace has become increasingly frequent in recent years. For westerners like me, summertime smoke is sadly becoming the new normal.

▶ **PALE PLANETARY** A chain of 8th- to 10th-magnitude stars lies just east of the ghostly planetary nebula NGC 6842. The chain's westernmost star, 8.7-magnitude HD 332981, shines helpfully 7′ northeast of the faint target. The image is approximately 30′ × 30′ in size.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

vision at 228×, I glimpsed two or three exceedingly faint flecks on the disk itself. At 411×, the number increased to four or five. One of them might have been the 15.9-magnitude central star.

Across Lower Cygnus

Next, I pushed less than ²/₃° west-northwestward into Cygnus to find **NGC 6834**. This 7.8-magnitude open cluster is similar to Roslund 4 in size; however, unlike the Roslund example, NGC 6834 is a compact, alluringly triangular grouping.

The cluster's 9.7-magnitude lucida centers a 6′-long row of five stars (none dimmer than magnitude 11.6) stretching east-northeast by west-southwest along NGC 6834's northern region. At 69×, I observed the glittering row as one prominent side of an equilateral triangle. The other sides raggedly defined the east and west edges of the cluster. The stars inside the triangle thinned toward the indistinct apex establishing NGC 6834's south end. Near the apex on the cluster's west edge was a blurry, 13th-magnitude "knot" begging scrutiny.

An eyepiece generating 147× resolved the knot into five tightly packed points. That magnification picked up more dim dots interspersed among the row-of-five, plus maybe a half-dozen 13th- and 14th-magnitude stars north of the row, outside the triangle. The bulk of the cluster lay southward, where the dense central population numbered possibly two dozen stars, all of them beyond 12th magnitude. In total, I tallied 50 to 60 suns — hardly epic; still, the glittery package was attractive.

After NGC 6834, I hopped 3¾° westward to 5th-magnitude 9 Cygni, then reversed ⅓° east-northeastward to snag **Minkowski 92** (M1-92), an exotic object nicknamed Minkowski's Footprint. The 11.7-magnitude nebula lies 28″ east of a 9.7-magnitude star (the southern of

▲ **THE ROAD LESS TRAVELED** A route northward from M27, then westward toward M57, passes by several disparate deep-sky objects.

two, 2.3′ apart). This is a rare preplanetary nebula: an ejected gaseous shell not yet fully heated to emission. M1-92's "footprint" results from two shells, or lobes, one of which is expanding toward us, therefore looking bigger and brighter than the opposite lobe.

Officially, M1-92 sports dimensions of 20″ × 4″, though to my eye it was a terribly tiny blob. Its binary nature eluded me until I applied 228× and perceived something star-like on its southeastern side. At 411×, the lesser component remained virtually stellar (the 9.7-magnitude star mentioned above was handy for comparison), but, happily, the increased magnification did create a narrow lane to separate the "sole" and "heel" of Dr. Minkowski's intriguing celestial foot.

Finishing In Lyra

Continuing 4° west-northwestward took me into southeastern Lyra. There, in a pretty field ½° southeast of a 6th-magnitude orange variable star, is the globular cluster **Messier 56**. Although M56 possesses a total visual magnitude of 8.3, its leading members are barely 13th magnitude, and those in its populous horizontal branch are about three magnitudes lower. The modest starball is loosely concentrated and under 9′ in diameter. Fortunately, big aperture can bring a little globular to life.

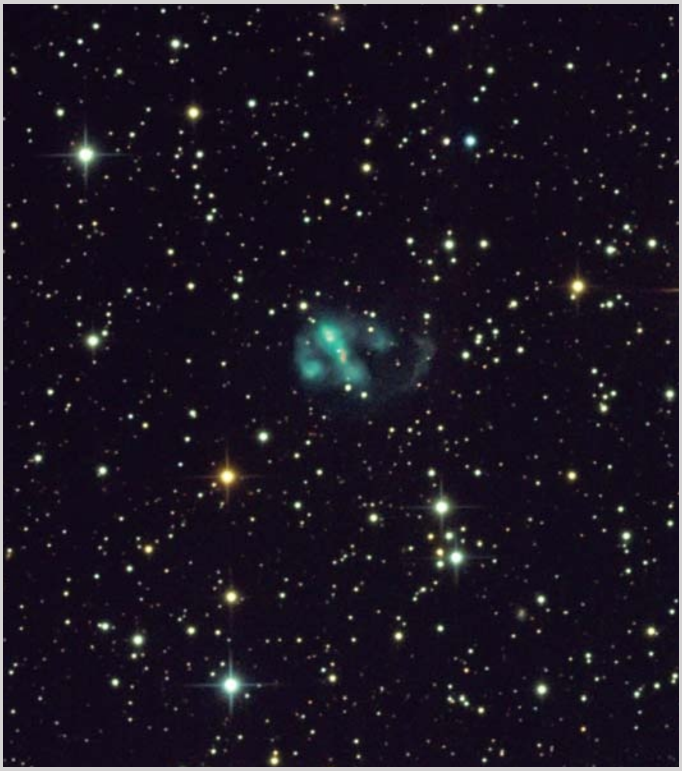
The view at 84× featured a broad, mottled mass, its periphery lightly salted with pinprick stars. A 10.2-magnitude "guardian" star glared 2′ westward. At 228×, I counted perhaps a dozen 13th-magnitude members on the cluster's face. Teensy pinpoints glimmered in between the leaders, and a couple of lumpy "arms" radiated northwestward. At 411×, the arms crystalized into chains of stars; indeed, much of M56 was resolved. The high power also yielded a dim companion aside the 10.2-magnitude guardian star.

To finish off, I visited Lyra's "other" planetary nebula, **NGC 6765**. I got there from M56 by shifting ½° northwest to the earlier-mentioned 6th-magnitude orange variable, then heading 1° westward. My path took me just north of a superb, 10″ binary. **Struve 2483** displays 8.1- and 9.2-magnitude stars together with an unrelated 9.6-magnitude attendant 70″ southwest. Shortly after that attractive set, I spotted two 10th-magnitude reddish-orange stars 8′ apart. They framed a 30″-wide pair of 11th- and 12th-magnitude stars aiming north-northeastward roughly toward the 12.9-magnitude planetary, 2′ away.

▲ **SMALL BUT ATTRACTIVE** A striking characteristic of the cluster NGC 6834 is the straight row of five prominent stars stretched along its northern portion. The dimensions of the image are approximately 30′ × 20′.

◀ **TINY CELESTIAL FOOTPRINT** The preplanetary nebula M1-92, dubbed Minkowski's Footprint, is a challenging, high-magnification target. Can you detect its two lobes as separate components?

NGC 6834: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY; M1-92: ESA / HUBBLE / NASA



▲ **FUZZY STARBALL AND WEE WISP** The second-tier globular cluster M56 *(left)* is an easy catch in any telescope, but resolving it into individual stars is more difficult. Look for at least two "arms" extending roughly northwestward from the cluster. This image combines visible and near-infrared exposures taken with Hubble's Advanced Camera for Surveys, and the field of view is approximately 3.3′ × 3.3′. There's more to the planetary nebula NGC 6765 than meets the eye *(right)*. In a high-power ocular, it's a tiny, elongated, asymmetrical patch. Images, though, reveal multiple components that greatly enlarge the object's physical size.

M56: NASA / ESA; NGC 6765: STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY

Working at 84×, unfiltered, I noted an elongated, weirdly uneven wisp — its irregular form due to NGC 6765, like M1-92, being a twin-lobed specimen. At 147×, the diffuse lozenge measured approximately 25″ × 10″ and was clearly asymmetric, the southwest part smaller and fainter than the northeast part. A 15.8-magnitude star hugged the end of the luminous northeast portion.

The gap between star and nebula was obvious at 228×. An O III filter erased the star but revealed a tenuous halo around the northeastern half of NGC 6765. Additional magnification, unfiltered, accentuated the longish, oddly misshapen outline of this intriguing planetary. My lone disappointment concerned the 16th-magnitude central star, which stayed beyond my reach.

Targets off the Beaten Track

Object	Type	Mag(v)	Size/Sep	RA	Dec.
IC 4954/5	Reflection nebula	—	25.0′	20^h 04.8^m	29° 15′
Roslund 4	Open cluster	10.0	—	20^h 04.9^m	29° 13′
NGC 6842	Planetary nebula	13.6	0.8′	19^h 55.0^m	29° 17′
NGC 6834	Open cluster	7.8	5.0′	19^h 52.2^m	29° 25′
Minkowski 92	Preplanetary nebula	11.7	0.2′ × 0.1′	19^h 36.3^m	29° 33′
M56	Globular cluster	8.3	7.1′	19^h 16.6^m	30° 11′
NGC 6765	Planetary nebula	—	0.6′	19^h 11.1^m	30° 33′
Struve 2483	Binary star	8.1, 9.2	9.9″	19^h 12.4^m	30° 21′

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.

Purely for the Fun of It

Admittedly, my "off the beaten track" tour was a one-off, arbitrary exercise. I saw it as a mini-treasure hunt, and my pursuit of the loot embodied the kind of observing project I enjoy most: a variety of often-overlooked objects in a relatively small area of sky that can be explored in an hour or two from a dark site. Hit the celestial backroads and sight these eight for yourself.

■ Contributing Editor **KEN HEWITT-WHITE** has been observing deep-sky objects from alpine sites in southern British Columbia for the past 45 years.

◀ The QHYCCD PoleMaster is a compact camera no bigger than an eyepiece dedicated to one purpose: performing an accurate polar alignment. It clamps to either the telescope tube (as shown here) or directly onto a mount so the camera aims at the celestial pole.

High-Tech Polar Alignment: The PoleMaster

This dedicated camera and software from QHYCCD promises to make accurate polar alignment easy and painless.

QHYCCD PoleMaster

U.S. Price: $268
qhyccd.com

What We Like

Provides easy, accurate alignment

Software with good instructions

What We Don't Like

Windows software sometimes failed

Mac software needs improvement

FOR ANYONE GETTING into deep-sky imaging, one of the most daunting tasks is often polar alignment. I personally have never found it to be an issue, but I've always used portable German equatorial mounts with built-in polar-alignment telescopes. Adjusting the mount to place Polaris at the right spot on the alignment-scope's reticle (made all the easier now with mobile apps that show you where that spot precisely is) takes only moments.

However, for anyone using a fork-mounted telescope (or any equatorial mount that lacks a polar scope), polar alignment is not so straightforward. Yet, the long focal-length telescopes that are usually paired with such mounts are the very ones requiring accurate polar alignment, particularly if your plan is to record long-exposure astrophotography.

Some Go To mounts have polar alignment routines as part of their firmware. If not, there's always the tried-and-true but tedious drift-alignment method, which can take the better part of a precious clear night to complete.

The PoleMaster from QHYCCD promises to sidestep the tedium. When I first heard of the device I was skeptical. Was this yet another gadget to hook up and learn to use? Surely, it was technical overkill — a high-tech alternative to simply learning the skill of using a polar-alignment scope.

But after using the PoleMaster on a number of nights, I am impressed. It really does work. The device provides a great solution for many photographers for whom using a polar scope is not feasible, not accurate enough, or simply inconvenient to use.

Alignment Process

The PoleMaster is a CCD camera with a stated 11×8° field of view. It connects to any computer with a supplied Mini-USB-to-USB-A cable and continuously streams its live images into QHY's *PoleMaster* software, available for both Windows and MacOS. The camera is powered through its USB cable; no other power source is required.

The *PoleMaster* alignment process has several steps, requiring you to first match the actual star field to the software's built-in template of known stars around Polaris. Rotating the mount around its polar axis tells the software where the mount's rotational axis is versus where the actual celestial pole is. You then use the mount's altitude and azimuth adjustments to align the former with the latter by aligning on-screen markers.

The multi-step process initially took me 15 to 20 minutes, but once I performed it a few times, it typically took only 5 minutes. However, on occasion,

ALL PHOTOS BY THE AUTHOR

the Windows software failed to present the required overlays, requiring me to restart the steps, prolonging the process.

To its credit, the software provides good on-screen prompts, so there is no need to consult the included PDF instruction manual, a good thing as it doesn't illustrate the steps very clearly.

You first need to aim the mount's polar axis to within at least a few degrees of the celestial pole to be sure Polaris is in the PoleMaster's field. If it isn't, or, as I found, if you click on the wrong star not realizing it isn't Polaris, the next step of matching the star field to the overlay pattern will never work. In addition, my little Windows 7 netbook's 1,024 × 600-pixel-resolution screen required me to zoom out to see the whole field to find Polaris. A laptop with a larger screen would be helpful, so you don't miss — or misidentify — Polaris.

To that end, I tried the MacOS version of the software on my 15-inch retina-screen MacBook Pro. As QHY's website warns, this will not work — the stars and overlay never line up. The solution, while it is mentioned, is not obvious. Select the *PoleMaster* app, open its Get Info window (Command-I) and check the box "Open in Low Resolution." Once I did that, the PoleMaster worked just fine on the MacBook.

The process is also promised to work in the Southern Hemisphere, using Sigma Octantis as the main alignment star. However, having aligned many times using a polar scope Down Under, I can attest that just aiming a mount's polar axis at the right area of sky, then identifying Sigma, can be a real challenge, particularly for those visiting from the north. I did not test the PoleMaster under southern skies to know how well it works south of the equator.

Alignment Accuracy

I tested the PoleMaster on a Sky-Watcher HEQ5 mount. The test unit was supplied on loan from a local telescope dealer, All-Star Telescope (**allstartelescope.com**), which also stocks the required adapter for my HEQ5. In addition to the PoleMaster, users also need to purchase an adapter to attach it to their particular mount's polar-axis aperture. Adapters for many popular mounts are offered by QHYCCD, each about $30 to $40.

For mounts without a polar-axis aperture, such as a fork mount, one solution is to purchase a third-party adapter made by ADM Accessories (**admaccessories.com**). It allows the PoleMaster to instead clamp to the telescope tube, onto either a Vixen dovetail bar or to a Losmandy D-system plate. I call this arrangement the off-axis method.

For my testing, I photographed through a TMB 92-mm refractor with a focal length of 500 mm, which is usually very forgiving of polar-alignment

▲ For telescopes that do not have a polar-axis aperture, adapters are available to attach a PoleMaster either to another location on the mount or, as here, to the dovetail mounting bar on the telescope tube. This is the Vixen V-Series bracket from ADM.

errors. I shot a series of 30-second unguided exposures over a 30-minute interval, then overlaid the first and last frames in *Adobe Photoshop* to see how far the star field had shifted in each of several runs over several nights.

On the first run, I eyeballed polar alignment using the polar scope, without taking too much effort to be very precise, as might be the case for many astro-imagers in the field.

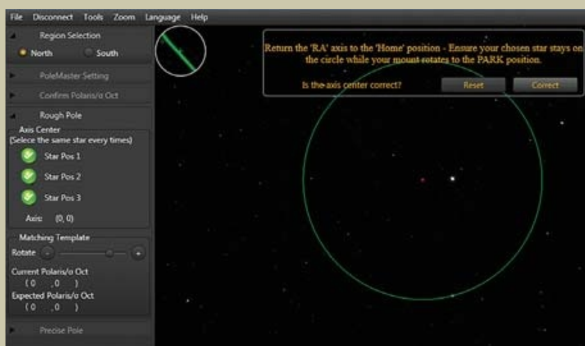
I then ran exposures after aligning using the PoleMaster on the mount's polar-axis aperture (what I call the on-axis method). The next night, after

▼ *Left:* Using one of the well-machined adapters offered for popular mounts, the PoleMaster clamps over the polar-scope aperture of a German equatorial mount. *Middle:* When the PoleMaster is not in place, the aperture remains open to allow using the polar-alignment scope as usual, which is often necessary for the initial rough alignment. *Right:* When not in use at all, a supplied metal cover clamps over the adapter, to prevent dust from entering the polar axis. The camera also includes a screw-on metal cover.

STEP 1
The exposure time and Gain can be adjusted to increase the brightness of stars around the celestial pole, making them more obvious.

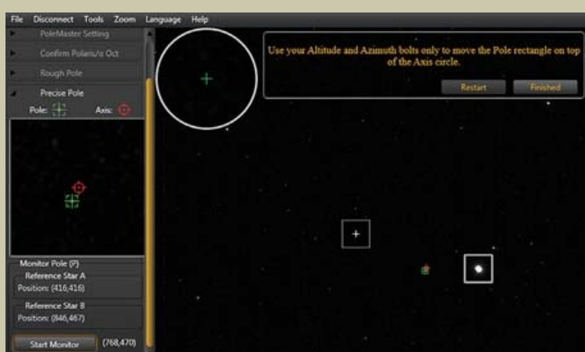
STEP 2
Clicking on Polaris brings up an overlay which you rotate using the slider at left to match the template's circles to the pattern of actual stars.

STEP 3
You then click on one of the surrounding stars several times as you turn the mount around its polar axis, for the software to determine the axis of rotation.

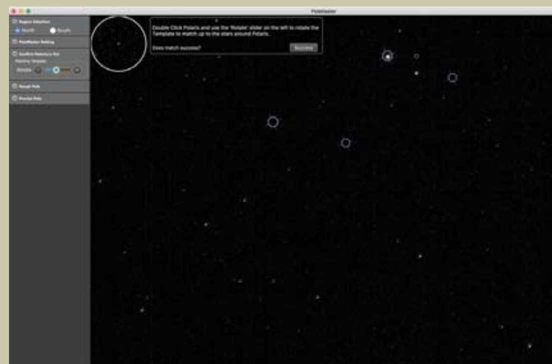


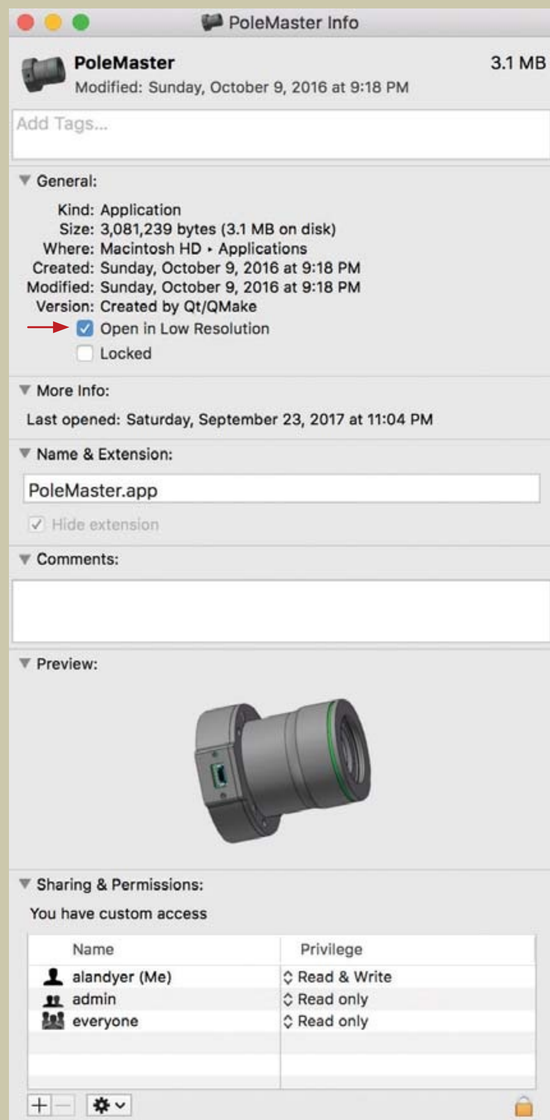
STEP 4
Next you physically adjust the mount's polar axis in altitude and azimuth to place Polaris in the open circle.

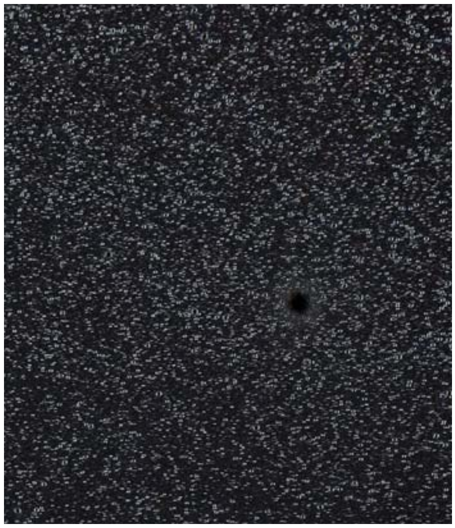
STEP 5
The software switches from Rough Pole to Precise Pole mode, for a final physical move of the mount to align the green Pole box over the red Axis box.

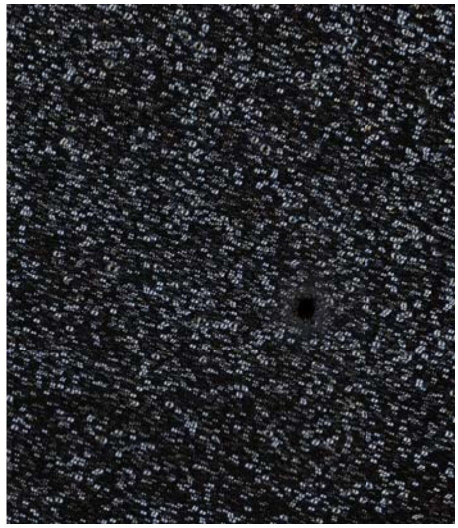


▼ As installed, the MacOS version of the *PoleMaster* application fails on retina-screen Macs, as the template overlay will never align with the actual stars, as is happening here. The solution is in the Get Info box for the app (Command-I), where the option "Open in Low Resolution" should be selected. Once this is completed, the overlay then aligns with the star field properly.









▲ *Left:* In these examples two unguided images taken 30 minutes apart are layered with a "Difference" blending mode applied in *Photoshop* to better show the image movement from misalignment. After performing a conventional polar alignment with the HEQ5's polar scope, stars exhibited a north-south drift in declination (the vertical shift here) as well as an east-west drift in RA during the half hour. *Middle:* After using the PoleMaster mounted on-axis to perform an alignment, the images show markedly less shift after 30 minutes. The small amount of shift in this example is left-right in right ascension, likely from the mount's tracking error, not from poor polar alignment. There was no declination drift, a testament to the accurate polar alignment. *Right:* A test on another night shows the effectiveness of the PoleMaster even when mounted off-axis on the telescope tube. The software still correctly located the mount's axis of rotation and provided an accurate final alignment with only a slight declination drift.

moving the mount to start afresh, I tried an alignment with the PoleMaster mounted off-axis on the telescope tube. I performed alignments with the Windows software, and then ran a sequence of exposures on another night after re-aligning using the MacOS software.

Using the PoleMaster in either mode — on-axis or off-axis, or with the Windows or MacOS app — worked equally well. Each method produced a much greater accuracy with minimal image shift in declination or right ascension over 30 minutes compared to the visual alignment method with the mount's built-in polar scope. The difference was noticeable even when imaging with short focal-length instruments.

In a nutshell, the PoleMaster worked as advertised, providing an accurate polar alignment. One caveat is that achieving the final "Precise Pole" step depends on the mechanical smoothness of your mount's altitude and azimuth adjustments. As I turned, then tightened, the HEQ5's adjustments, the image would shift. After several attempts to get the two markers to exactly match, I'd say, "Good enough!" and call it done.

That final step in particular also requires that your computer screen be close to the mount, so you can inspect the readout carefully while making the final adjustments.

Recommendations

If you shoot primarily with short-focal length telescopes (say, under 600 mm) on small equatorial mounts, as I often do, I feel the PoleMaster is a luxury you could probably live without. Certainly I have. For many years I've eyeballed polar alignment using my various mounts' built-in polar scopes and have never encountered issues with trailing or the inability to align and stack short exposures as long as I was auto-guiding.

I also prefer to avoid having to use a computer at the telescope if I can help it, to keep my field set-up simple and avoid dreaded "Application Not Responding" errors. As such, I use a stand alone autoguider that doesn't require a computer. Still, even wide-angle photographs of entire constellations with exposures of, say, 10 minutes or more will display field rotation in the corners of the frame if my polar alignment isn't accurate.

But for those shooting with CCD cameras (and for many photographers who shoot with DSLRs) a computer has to be present anyway, to run the main camera and the auto-guider. In addition, as the number and length of exposures goes up, accurate polar alignment becomes far more critical.

The PoleMaster provides a quick yet precise method of achieving the required accuracy, avoiding any need to perform tedious drift alignments. The PoleMaster is ideal for those shooting with long-focal-length Cassegrain systems, especially on mounts that lack an on-axis polar scope such as fork mounts.

Even on a mount that includes a polar scope, using a PoleMaster avoids having to bend down and crane your neck to sight through the scope. For aging astrophotographers, saving wear and tear on necks, backs, and knees may be reason enough to rely upon the PoleMaster. It provides truly painless polar alignment!

■ Contributing Editor and TWAN (**twanight.org**) member **ALAN DYER** often photographs the night sky from his dark location in Alberta, Canada. Visit his website at **amazingsky.com.**

Messier 27: The First Planetary Nebula

Explore this complex object through your telescope with the help of an experienced observer's ever-so-elaborate sketches.

M27 has everything going for it. It's a large, bright planetary nebula with a striking and subtly detailed shape. It's well placed in the Northern Hemisphere sky during the peak observing season — late spring through early fall. It has a famous nickname that captures the essence of its shape. It's even easy to find, especially if you triangulate its position using Gamma (γ) and Delta (δ) Sagittae.

Almost universally referred to as the Dumbbell Nebula, the brightest parts of M27 really do look like a handheld workout weight. But it often looks even more like an apple core or an hourglass. John Herschel coined the dumbbell name and suggested the hourglass comparison in 1827. The resemblance to an apple core, which is a more modern nickname, is just as strong.

However, I think Herschel's best description of M27 is "A most extraordinary object," and anyone who's seen it through a telescope will probably agree that that describes its impact in the eyepiece better than any of its nicknames.

Charles Messier was able to discover the Dumbbell the night before the full Moon of July 1764 because it has the highest surface brightness of any large planetary nebula. His description reads, in part, "nebula without a star" and "it appears of oval shape." That general appearance fit many of his discoveries, so it became just the 27th object on his list of enigmatic nebulae that didn't move relative to the stars. Today we know that M27 was the first planetary nebula ever to be discovered.

Messier was using a 6-inch speculum mirror Gregorian telescope at 104× when he first found M27. His discovery not only shows that searching for comets didn't wait for the Moon to get out of the way but is also a dramatic illustration of M27's conspicuousness.

Its size and brightness — 8 × 5 arcminutes in diameter, magnitude 7.5 — make it an easy target even in binoculars and finder scopes. Its apparent shape can range from a dumbbell, to a rounded rectangle, to a slightly squashed oval depending on your observing conditions, scope, and experience. You may even see all three shapes blended together.

M27, the Planetary Nebula

Stars with 1 to 8 masses of our Sun — which make up a good proportion of stars in the universe — will probably produce a planetary nebula when they lose the ability to sustain fusion during their final red giant phase and evolve into white dwarf stars. (See the sidebar on page 68, and below, for more details of this process.)

But as common as this phenomenon is, it's also short-lived. It lasts only a few tens of thousands of years, a mere flicker compared to the billions of years that stars in this mass range live on the main sequence.

As it turns out, M27 is a young planetary nebula with an estimated age between 9,800 and 14,600 years. That's just two to three times longer than recorded human history. The nebulosity has a diameter of about 3.1 light-years (around two-thirds the distance to Alpha Centauri, the closest star system to ours) and is approximately 1,360 light-years away.

At the center of the nebula lies the largest white dwarf thus far measured, with a radius approximately 0.055 times that of the Sun's. A temperature of 108,600 K, about 18 times solar, makes it hot and bluish. At magnitude 12.9, it can be seen in a modest-size amateur telescope.

This white dwarf star has an unseen stellar companion, which is believed to have played a major role in sculpting the nebulous shape of M27.

ESO / I. APPENZELLER / W. SEIFERT / O. STAHL

▲ **A MOST EXTRAORDINARY OBJECT** Messier 27, also known as the Dumbbell Nebula, the Hourglass Nebula, and more recently, the Apple Core Nebula, was first discovered by Charles Messier in 1764 and subsequently observed by William Herschel, who bestowed upon it the "dumbbell" moniker. In this glorious composite image obtained with Antu, one of ESO's four Very Large Telescope 8.2-meter units in Chile, the structure of the nebula is clearly seen. The red color in the outer parts of the nebula traces hydrogen expelled during the first phase of mass loss from the red giant, while the green represents oxygen ejected during a second phase. North is up in all images.

And get this: The densest parts of M27's nebulosity contains up to 100,000 particles per cubic centimeter. That sounds like a lot, but astonishingly, is less dense than most laboratory-created vacuums.

Herschel's own description of M27 is "A most extraordinary object."

M27's Shape

Ionized hydrogen (H II, colored red in the image on page 67) dominates the brightest portions of M27. It's been ejected outward to form the brightest segments of the northern and southern arcs and a diagonal line of nebulosity that seems to run through its center. Doubly ionized oxygen (O III, green in the image) dominates in the interior and helps complete the familiar dumbbell. The faint extensions that close M27's oval also consist mostly of O III. Thanks to the central white dwarf star blasting out intense ultraviolet light, all this glowing molecular gas is about 10 times hotter than normal diffuse interstellar gas.

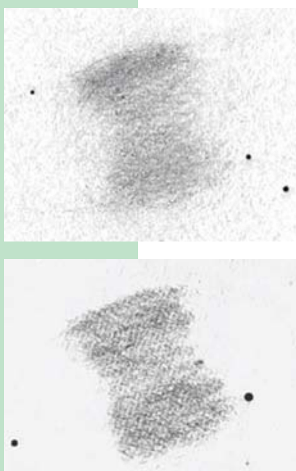
The hydrogen is from the first phase of the red giant's mass loss, while the oxygen is from a second episode. The oxygen was dredged from the inner layers of the quickly contracting star by the final bursts of nuclear fusion, along with other elements like sulphur and nitrogen.

A delightful surprise is the fundamental nature of the Dumbbell's three-dimensional shape. Studies have shown that M27 and M57, the Ring Nebula, probably have much the same intrinsic structure, and we see them as so dissimilar because our viewing angle of the two objects is different by roughly 90 degrees. The Dumbbell is presented essentially broadside from our perspective, while the Ring Nebula is oriented so we're looking straight down one end. If the viewing angles were reversed, we may well have given M57 the Dumbbell nickname and M27 would be called the Ring Nebula.

Dumbbell or Rounded Rectangle?

My earliest recorded observation of M27 is from June 1974 with my homemade 8-inch f/4 Newtonian. I'd observed it several times before with the 8-inch and my first telescope, a beautiful Tasco 3-inch f/15 achromatic refractor, but I had just begun recording my deep-sky observations that June.

My first sketch (here at left) shows the familiar dumbbell, but three nights later my second sketch shows a more rectangular shape, with an ever so slightly pinched waist and rounded ends.



◀ **EARLY SKETCHES** My first sketch of M27 is at top, and my second sketch, made three nights later, is on the bottom. In June 1974 I used my 8-inch f/4 Newtonian to make these sketches that inadvertently showed how the apparent dumbbell shape changes depending on sky conditions.

HOWARD BANICH (4)

Planetary Nebula: A Misleading and Unfortunate Name

These subtle shells have nothing to do with planets and everything to do with the death throes of Sun-like stars. The misnomer originated with Charles Messier's description of M57 and was later reinforced by both William and John Herschel. Some of these nebulae really did look like ghostly versions of Jupiter or Uranus through their telescopes — small, round, and evenly illuminated. So the term "planetary nebula" made sense from that standpoint. Even so, many of them, like M27, don't resemble planets at all.

We now know planetary nebulae are the glowing remains of a red giant star that were expelled by instabilities created inside the star as its fusion reactions sputtered to a halt. During this process, the red giant contracts into a tiny white dwarf star.

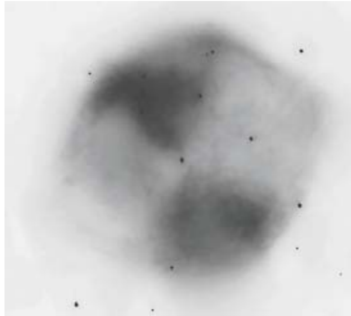
Once the white dwarf hits a temperature of 25,000 K, which is hot enough to generate copious amounts of intense ultraviolet light, the nebulous remains from the end of the red giant phase are photoionized, causing them to glow. Until this temperature is reached, the central star merely illuminates this material, and the nebula is considered a protoplanetary nebula.

Once the star shrinks down to a white dwarf, it can no longer sustain nuclear fusion and instead shines by the residual, but nevertheless considerable, heat generated by its intense contraction.

Based on this knowledge, a more accurate name for this class of nebulous object might be along the lines of "white dwarf nebula." On the other hand, "planetary nebula" isn't the only archaic and misleading name still in common use, so it seems destined to remain part of astronomy's vocabulary.

That got me wondering if sky transparency and darkness were responsible for the difference, so I next compared my deep M27 sketch made at the Oregon Star Party to a recent sketch made from my light-polluted driveway, both using my 28-inch scope. Sure enough, the pinched waist is more pronounced in the sketch from home.

Of course, the apparent shapes of all deep-sky objects are greatly influenced by the darkness and transparency of the night sky, but what's notable in M27's case is that the trademark dumbbell shape is more obvious under a moderately light-polluted sky.

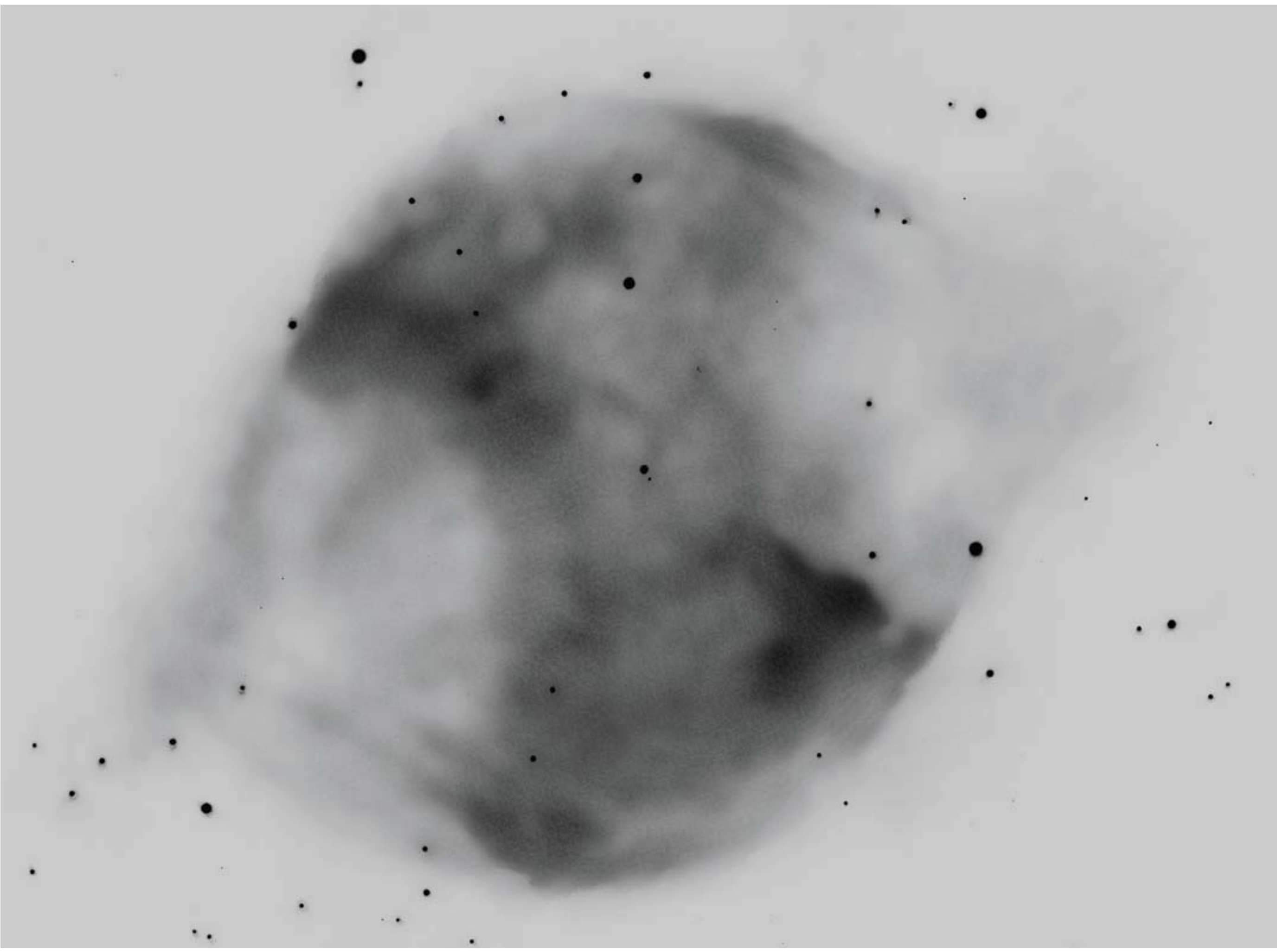


◀ **PINCHED WAIST** A 28-inch sketch of M27 as seen from my driveway — note how pinched the waist area appears compared to my larger, deeper sketch (below).

Then again, under a dark sky with my 28-inch scope I see more than just the dumbbell shape. The rounded rectangle becomes just as obvious as does the complete oval noted by Messier, and together they give M27 its robust and distinctive character. Each of these main shapes includes details of varying subtlety and is worthwhile exploring one by one.

Bright Arcs

The brightest and most sharply defined parts of the Dumbbell are the two opposing arcs that make up the north and south ends of the dumbbell shape. These H II arcs are unevenly bright and are two of the most detailed areas to study at higher magnification, particularly where they meet a lumpy line of uneven nebulosity that runs diagonally through the center of the Dumbbell. Especially interesting are the subtle striations in both arcs.



▲ **DETAILS EMERGE** My deep sketch (enhanced contrast) of the Dumbbell Nebula made with my 28-inch f/4 Newtonian shows the features described in the article. Note how the eastern and western extensions of the faint wings that complete the oval shape of M27 push out into the outer halo. The striations in the northern and southern arcs are prominent. I used magnifications from 155× to 408× under the dark, transparent skies of the Oregon Star Party over three nights. Nearly five hours of observing time went into this sketch.

Line of Lumpy Nebulosity

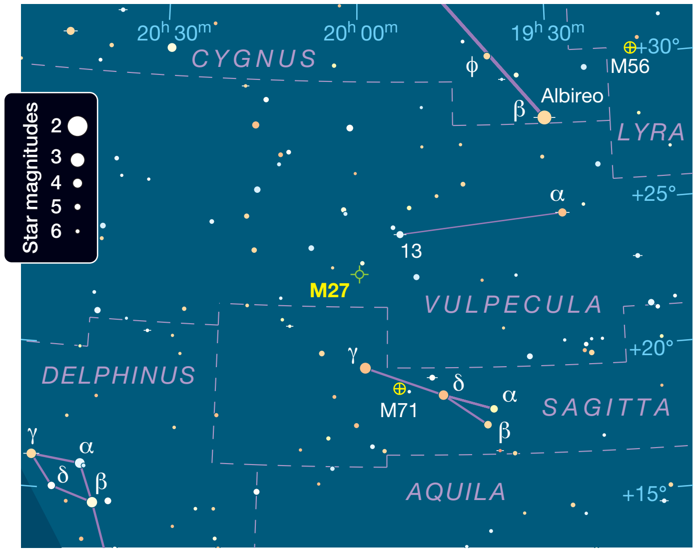
A softly glowing, uneven line of nebulous lumps runs northeast to southwest across M27, seemingly through its center. This defines one side of the internal dumbbell shape. My deep sketch (previous page) shows this feature well, and on the best nights it forms one of the more obvious and detailed internal portions of the Dumbbell. It's also composed of H II and appears red in color images. The brightest area makes up the southwest end, but the slightly less detailed northeast end is nearly as bright. Although my brain wants to make a connection right through the central star, I only see these brighter ends.

The opposing sides of the central dumbbell shape are less obvious and are made up of the brightest areas of the central O III nebulosity, which appears as green in the European Southern Observatory (ESO) image on page 67, or various shades of turquoise in other images of M27. Depending on observing conditions, this somewhat fainter and softly contoured interior nebulosity contributes to the apparent dumbbell/rectangle shape ambiguity.

Nebula filters help boost the contrast of these features. An Ultra High Contrast or O III filter brings out the fainter parts of the Dumbbell, especially in my moderately light-polluted home sky. But filters block the fainter field stars, so I find the unfiltered view more aesthetically pleasing under a dark sky. Your preference may be different, though, so try all your nebula filters and see for yourself.

The Oval

Although faint, the O III wings that complete M27's oval shape have about the same visibility as the interior nebulosity and are bright enough that they're visible on a good



night under suburban skies. That's because they have more contrast with the background sky than the interior nebulosity has with itself.

Considering that Messier saw the Dumbbell's overall oval shape in his 6-inch Gregorian telescope from a rooftop in smoky 1764 Paris, one night before a full Moon no less, your chances of seeing the entire oval are quite good. Try different magnifications and filters to see which gives the best view. And as a tribute to Monsieur Messier, have a look the next time the nearly full Moon is in the sky, too.

Outer Halo

The exceedingly faint outer halo of M27 is made of singly ionized hydrogen. It was expelled from the central star while it was ending its life as a red giant, representing the first stage of M27's planetary nebula formation. The H II halo is difficult to see not only because it's faint, but because M27 is so bright. Your best chance of detecting it is to keep the Dumbbell just outside your eyepiece field of view while looking for a nearly imperceptible glow. I've seen only the brightest, inner parts of the halo.

Central Star

The white dwarf central star was an easy catch with my old 12.5-inch, and on nights with steady seeing a faint star (which is not the physical companion) can be seen just to its southwest. The white dwarf glows at magnitude 12.9 and is much easier to see than the central star of the Ring Nebula, so it's worth the small effort to observe simply because of its current status as the largest-diameter white dwarf.

Even though it's the largest white dwarf found so far, it's still rather tiny as stars go, at only 5.5% the radius of our Sun. On the other hand, its mass is a little over half that of our Sun, which is right in the middle of the typical mass range for white dwarfs. This combination of small radius and relatively high mass explains its extreme density. Quite a contrast to the thinner-than-an-Earthly-laboratory-vacuum of M27's nebula.

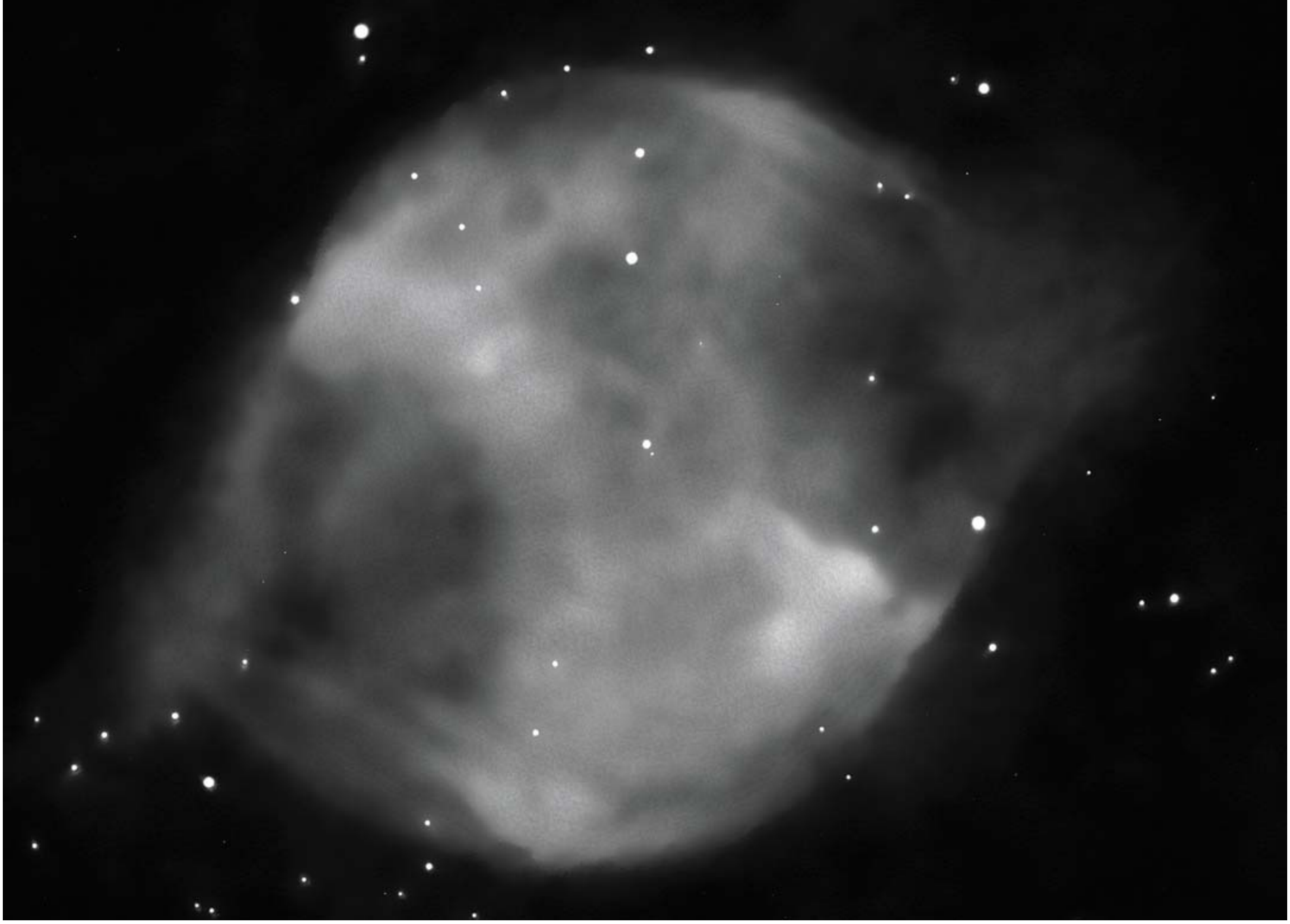
Bonus Object: NSV 24959, the Goldilocks Variable Star

Amateur astronomer Leos Ondra discovered a variable star, NSV 24959, within the nebulous borders of M27 in 1991. Because it's located farther away than M27, we view the Goldilocks Variable through the nebulosity.

NSV 24959 has a magnitude range of 15.2 to 17.1 and is apparently a Mira-type variable with a period of approximately 213 days. And much like the variable stars of Messier 5, the NSV 24959 variable is another reason to check in on the Dumbbell Nebula more often.

I haven't looked for this star yet, and it doesn't show up in any of my sketches by accident. A bit unlucky perhaps, but I'll certainly be keeping a careful eye out for it from now on.

For more information, see: messier.seds.org/xtra/leos/gl.html



▲ **DUMBBELL, HOURGLASS, APPLE CORE** And finally we get to the inverted version of my original sketch, giving a better sense of the eyepiece view through my 28-inch scope from a dark site. There are too many field stars to plot, but imagine about five times more than you see here and you'll get the idea of what a beautiful scene this is in a large telescope, and how they contribute to the 3D effect. Next time you observe this "most extraordinary object" decide for yourself what shape you see.

▶ **NESTED NEBULOSITIES** In addition to the brighter, inner nebulosity, M27 also displays a fainter, more extended nebula. Can you see it?

SKETCH: HOWARD BANICH; NEBULOSITY: MASIL IMAGING TEAM

Color?

I've only seen the Dumbbell as various shades of grey through the eyepiece. But a few people have reported a greenish hue at very low magnifications, so give it a shot with your lowest-power eyepiece. Look directly at M27 to give yourself the best chance of seeing color.

A 3D Illusion

Wonderfully, the Dumbbell Nebula can sometimes seem to float in 3-dimensional space. This is an illusion, of course, but it can be a compelling sight in the eyepiece nonetheless. I see this effect best without a nebula filter, because the more field stars are visible, the more pronounced the false 3D. Sometimes boosting the magnification helps enhance this impression. And when the illusory 3D effect is strong, it's fun to spin M27 in my imagination and visualize its head-on ring shape.

Taking all this together, on a good night at a dark site the Dumbbell is stunning in my 28-inch scope, and it barely matters what magnification is used. I like it best when it fills about half the field of view, though — a bright, subtly lumpy, and softly glowing dumbbell-rectangle-oval, with its parent white dwarf star at its center, all floating within a beautiful star field. A most extraordinary object indeed.

■ Contributing Editor **HOWARD BANICH** recently moved from Portland, Oregon, to the much darker but still light-polluted skies of Sandy, Oregon. Reach him at **hbanich@gmail.com**.

Bowling Ball Brilliance

▲ Doug Arion enjoys the freedom of ball-mounted scopes in his New Hampshire observatory.

The ultimate in alternative mounts

I CONFESS I'm a sucker for ball mounts. Isaac Newton mounted his very first telescope on a ball, and so did I. I've loved the versatility of ball mounts ever since.

New Hampshire ATM Douglas Arion (who, along with former *S&T* editor Richard Fienberg, is one of the prime forces behind the Galileoscope project at **galileoscope.org**) feels the same way. He says, "I hate axes. If you build a mount with them they're hard to set up without play, and you always end up with dead spots — the pole for equatorials, the zenith for alt-az. Equatorially mounted Newtonians really need tube rotation, too, so that has to be added to the design. Spherical mounts have none of those problems. No dead spots, no inconvenient eyepiece locations, and they are intrinsically stable."

Doug has found a convenient source of spheres for his mounts: bowling balls. The concept is simple. Drill a hole all the way through a bowling ball and put a shaft through the hole. Mount the telescope to one end of the shaft and a counterweight on the other end. Rest the ball in a Teflon-padded socket, and you're good to go. The motion is more or less alt-azimuth, but you get plenty of extra range in any direction, completely eliminating "Dob's hole" or the north-south gimbal lock in equatorial mounts.

Getting ball mounts to track, however, can be a challenge. Pierre Lemay came up with a dual-axle "equatorial sphere mount" for them back in 1995, and I independently reinvented a single-axle version which I called the "trackball" a decade later. But despite their brilliance (your humble narrator says modestly), neither Pierre's nor my design really caught on.

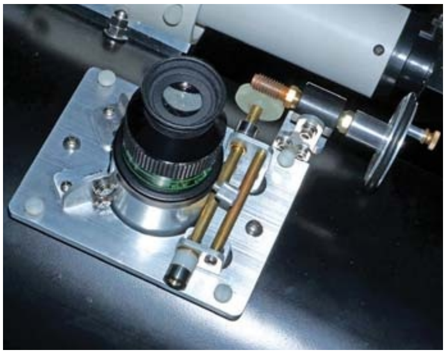
Doug took a different approach. Since bowling balls are relatively small (8½ inches in diameter), he realized that he could miniaturize the popular Poncet Platform and set the ball on one. So he did just that. Doug says, "The first one I built, in wood, required only simple shop tools (a drill press and a table saw). The second, all-aluminum mount on the 10-inch scope was fully machined."

◀ This miniature equatorial platform provides perfect tracking with the scope in any orientation. Note the tangent arm used for fine control of the declination axis.

DOUGLAS ARION (3)

Both function well. The drive systems use synchronous motors, which are inexpensive and have little or no vibration. Doug built variable frequency oscillators to power them, so slow motions are available in RA and the drive rate can be carefully adjusted for perfect tracking. The all-aluminum platform also uses a tangent arm as a pseudo-declination slow-motion control. It's a worm gear attached to the junction between telescope and mount, and it allows for fine control in a more-or-less vertical direction.

The aluminum platform will run for about 90 minutes before needing to be reset. The wooden one runs for about 50. Resetting them is simple: Just release the clutch knob and crank the drive screw back to the beginning. Doug quickly learned one important design consideration: "You have to use clockwise-turning motors on the east side of the drive system to make sure the drive gear is tightening the clutch knob. If you do it the other way with the motor on the west side,



▲ Doug's homemade focusers are equally simple and elegant.

it slowly unwinds the clutch knob and won't drive!"

Doug's telescopes have as many homemade parts as possible, from the primary mirrors to the spiders, mirror mounts, finders, and focusers. The focusers in particular show his simple, straightforward approach to telescope making. They're rock-solid Crayfords, with slow motion provided by worm gears and fast motion provided by a crank that lets you turn the worm gear more quickly.

His scopes are housed in an equally beautiful roll-off-roof observatory near the Pemigewasset Wilderness in New Hampshire's White Mountains, one of the few dark-sky sites in the East.

Doug loves observing with his bowling ball–mounted scopes. Of the experience, he says, "Not an axis to be seen in my observatory! I love the fact that pointing any of these telescopes is easy, the eyepiece is always at a convenient angle — and can easily be lowered for the less height-advantaged among us — and that the telescopes are stable and nearly vibration free. I have numerous ATM friends who, having made or acquired mirrors, have tried my telescopes and exclaimed 'Oh, can I have a mount like that?!'"

Indeed you may. Dig that old bowling ball out of the closet and get to work.

For more information, contact Doug at **darion@carthage.edu**.

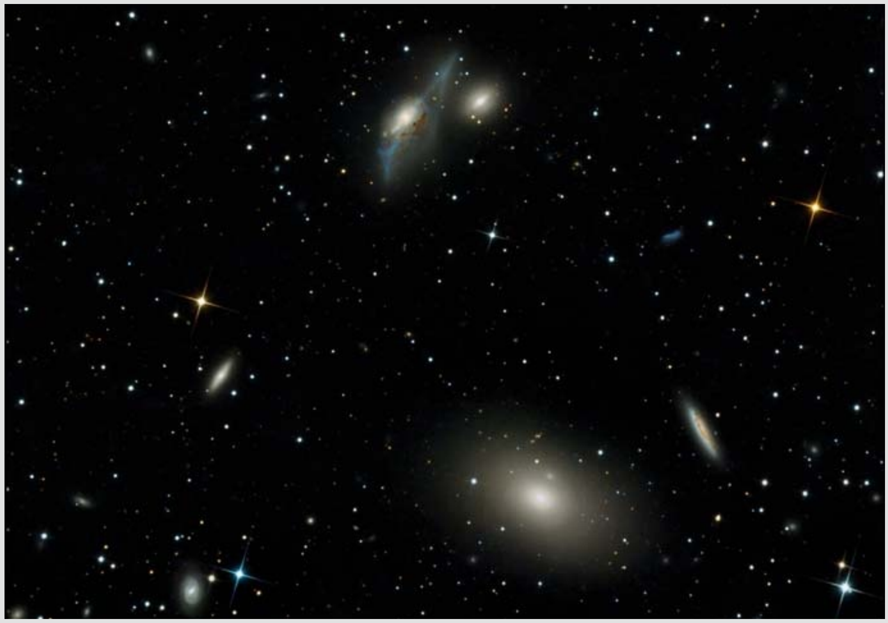
■ Contributing Editor **JERRY OLTION**, designer and builder of the trackball telescope, says "Once you track, you'll never go back."

▷ THE EYES HAVE IT

Terry Hancock

This section of the Virgo Cluster of galaxies features a handful of spirals and ellipticals. Near the top are NGC 4438 and 4435, interacting galaxies known together as "The Eyes." The large eliptical (bottom) is M86, flanked by spiral galaxies NGC 4425 and 4413 at left, and NGC 4402 to its right.

DETAILS: *AG Optical Systems 12½-inch Imaging Harmer Wynne astrograph with QHY163M CMOS camera and Optolong LRGB filters. Total exposure: 2.3 hours.*



CROWNING CASTLE

Amirreza Kamkar

The Milky Way rises above the ruins of Karshahi Castle near Kashan, Iran. At far right is Jupiter in the constellation Libra, while Mars pairs with like-colored Antares in Scorpius. To their lower left is Saturn, just left of the golden central bulge of our home galaxy.

DETAILS: *Modified Camon EOS 6D DSLR camera with Samyang 24-mm lens at f/2.8. Total exposure: 15 seconds at ISO 6400.*

◁ CRYSTAL BALL NEBULA

Brian Peterson

Located in northern Taurus near the border of Perseus, NGC 1514 is a 2-arcminute-wide planetary nebula that reveals complex loops of nebulosity shaped by the gravitational interaction between its progenitor star and a smaller companion that orbits every 10 days.

DETAILS: *Starizona 12.5-inch f/8 Hyperion Astrograph with SBIG STXL 11002M CCD camera. Total exposure: 15 hours through RGB, Hα, and O III filters.*

GEMS OF ORION

Chuck Manges

This gorgeous mosaic showcases some of the most well-known nebulae in Orion. Above center is the Flame Nebula (NGC 2024), with the Horsehead Nebula (B33) silhouetted in front of bright IC 434. At lower right is M42, the Orion Nebula, and to its north the bluish Running Man Nebula consisting of NGC 1973-1975-1977.

DETAILS: *Celestron EdgeHD 11 with Starizona Hyperstar at f/2 and a QHY163M CMOS camera. 32-panel mosaic with a total exposure of 13.75 hours through Hα and RGB filters.*

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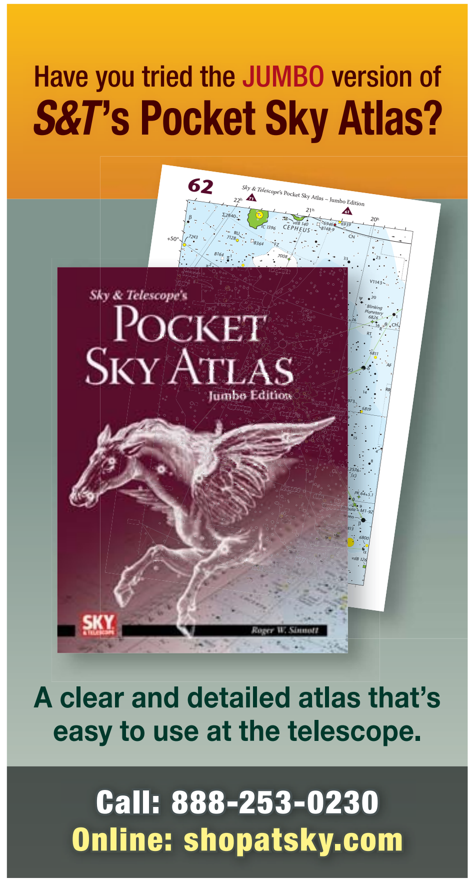
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Event Calendar

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

June 9–16
GRAND CANYON STAR PARTY
Grand Canyon, AZ
https://is.gd/GCSP2018

June 13–17
BRYCE CANYON ASTRONOMY FESTIVAL
Bryce Canyon, UT
https://is.gd/BCAAF2018

June 13–17
ROCKY MOUNTAIN STAR STARE
Gardner, CO
rmss.org

June 14–17
CHERRY SPRINGS STAR PARTY
Coudersport, PA
astrohbg.org/CSSP

June 28–July 3
RASC GENERAL ASSEMBLY
Calgary, AB
rasc.ca/ga2018

July 11–15
GOLDEN STATE STAR PARTY
Bieber, CA
goldenstatestarparty.org

July 12–15
WISCONSIN OBSERVERS WEEKEND
Hartman Creek State Park, WI
https://is.gd/WOW2018

August 4-12
MOUNT KOBAU STAR PARTY
Osoyoos, BC
www.mksp.ca

August 5–10
NEBRASKA STAR PARTY
Valentine, NE
nebraskastarparty.org

August 7–11
TABLE MOUNTAIN STAR PARTY
Oroville, WA
tmspa.com

August 7–12
OREGON STAR PARTY
Indian Trail Spring, OR
oregonstarparty.org

August 9–12
STELLAFANE CONVENTION
Springfield, VT
stellafane.org/convention

August 9–12
STARFEST
Ayton, ON
nyaa.ca/starfest.html

August 10–19
SUMMER STAR PARTY
Plainfield, MA
rocklandastronomy.com/ssp.html

August 23–26
THEBACHA & WOOD BUFFALO DARK SKY FESTIVAL
Fort Smith, NWT
tawbas.ca/dark-sky-festival.html

September 7–11
ALMOST HEAVEN STAR PARTY
Spruce Knob, WV
ahsp.org

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

Celestial Solace in Parkland

The city and local astronomy club join forces to help students begin the healing process.

The Moon as it appeared on the night of February 23rd, 2018, from the Equestrian Center in Parkland, Fla., where amateur astronomers and local officials pooled their resources for a soothing Astronomy Night for students.

ON FEBRUARY 14, 2018, the school where I've taught for the past 24 years experienced a tragedy that no school should ever have to endure. Three of my colleagues and 14 beautiful young people had their lives taken away in a senseless and unfathomable act of violence. Thankfully, my 4th-period astronomy class and I walked out to safety, not even knowing for some time the full extent of the horror that had just occurred.

For the first couple of days after the shooting, I felt like I was stuck in a nightmare, fully expecting to wake up one morning to find things back to the way they were. Like so many others, I struggled to find something, anything, I could do to be of help. After a few restless nights, it dawned on me what my own, small role should be. I realized that my colleagues and I just had to be there for our students; we simply needed to do the things we've always done to provide a positive and nurturing environment for them. And I knew exactly where to start.

For 20 years, we've held "Astronomy Nights" in the Parkland area, most recently in our garden area at the back of the school. With the entire school still a crime scene, though, we couldn't utilize "Marjory's Garden," much less get access to the telescopes in my classroom. My colleagues and I were going to need help.

I tweeted our outstanding mayor, Christine Hunschofsky, asking if there was a suitable place that we could use.

> This fellowship of students, friends, parents, and teachers proved cathartic.

Within 24 hours the city had secured the perfect location: the local Equestrian Center. It is as dark as you can get within the city limits and has ample parking and the necessary facilities to accommodate a crowd. On the night of our event, the City of Parkland provided volunteers to help with parking, arranged for Broward Sheriff's Office deputies to be on hand for security, and even donated bottled water for the evening's participants.

The next call I made was to my friend Steve Luxenberg, Director of the Fox Observatory for the South Florida Amateur Astronomers Association. He immediately offered to help and assured me that he and Monroe Pattillo, the venerable head of the SFAAA, would take care of everything. Sure enough, when I showed up that night I saw a line of at least a dozen superb telescopes already set up. As my current students and dozens of alumni arrived, I was free to spend time commiserating and reminiscing with them, while the SFAAA handled the observing.

This fellowship of students, some of their friends, and a few parents and teachers proved cathartic for all involved. It couldn't have happened without the leadership and generosity displayed by so many people from both the City of Parkland and the SFAAA. When studying the wonders of the night sky, I believe we often learn as much about ourselves as we do about the majesty and mystery of the universe. On February 23rd, my students and I learned that we share this pale blue dot of a planet with an enormous number of giving, good-hearted people. That was the most enduring observation made under the stars that night, and I'm deeply grateful to all those who made it happen.

■ **KYLE JETER** is a teacher at Marjory Stoneman Douglas High School in Parkland, Florida, where he has taught Honors Astronomy since 1997.

PHOTOS COURTESY OF KYLE JETER

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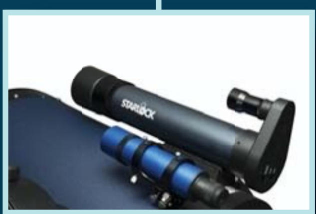

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