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# SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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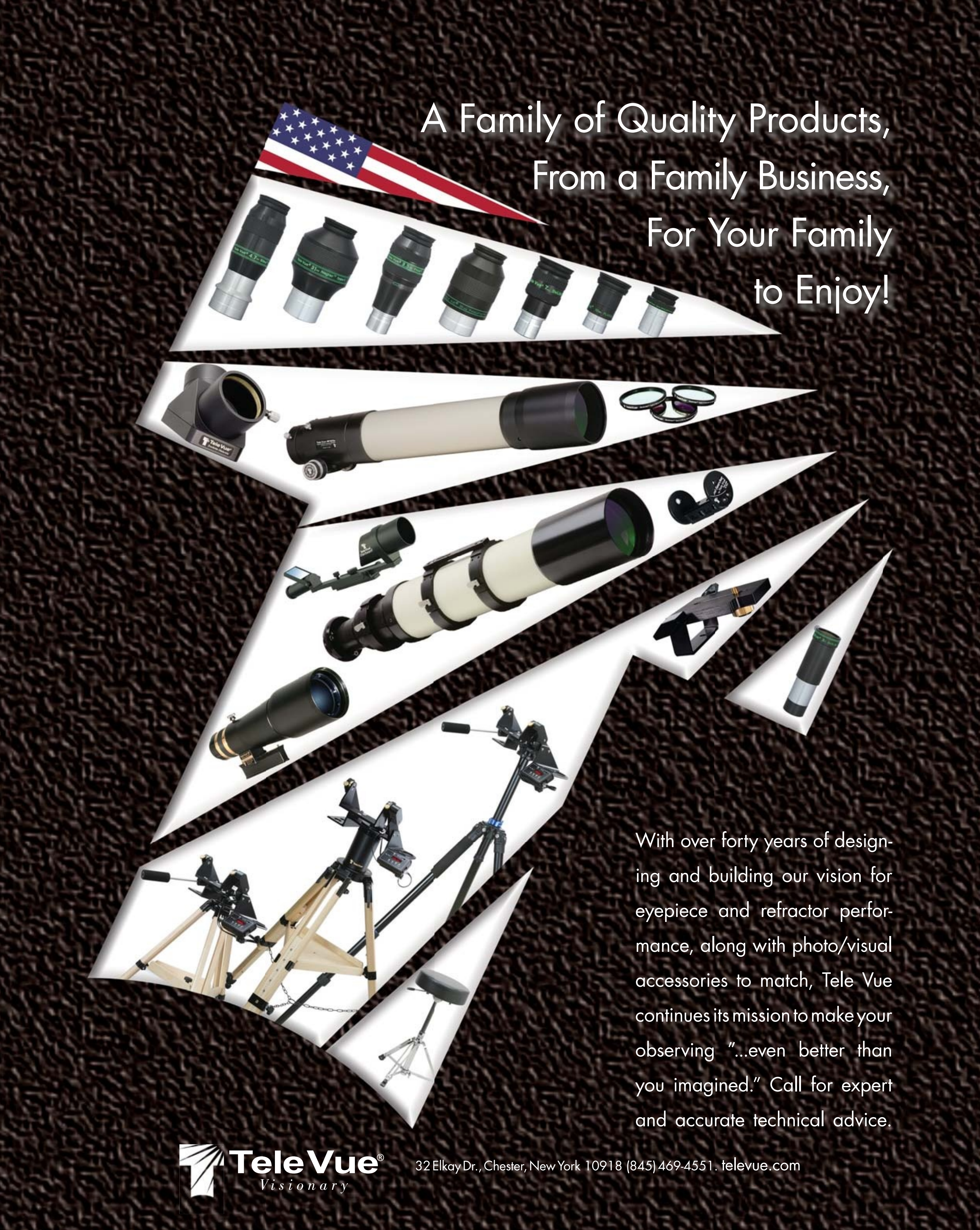

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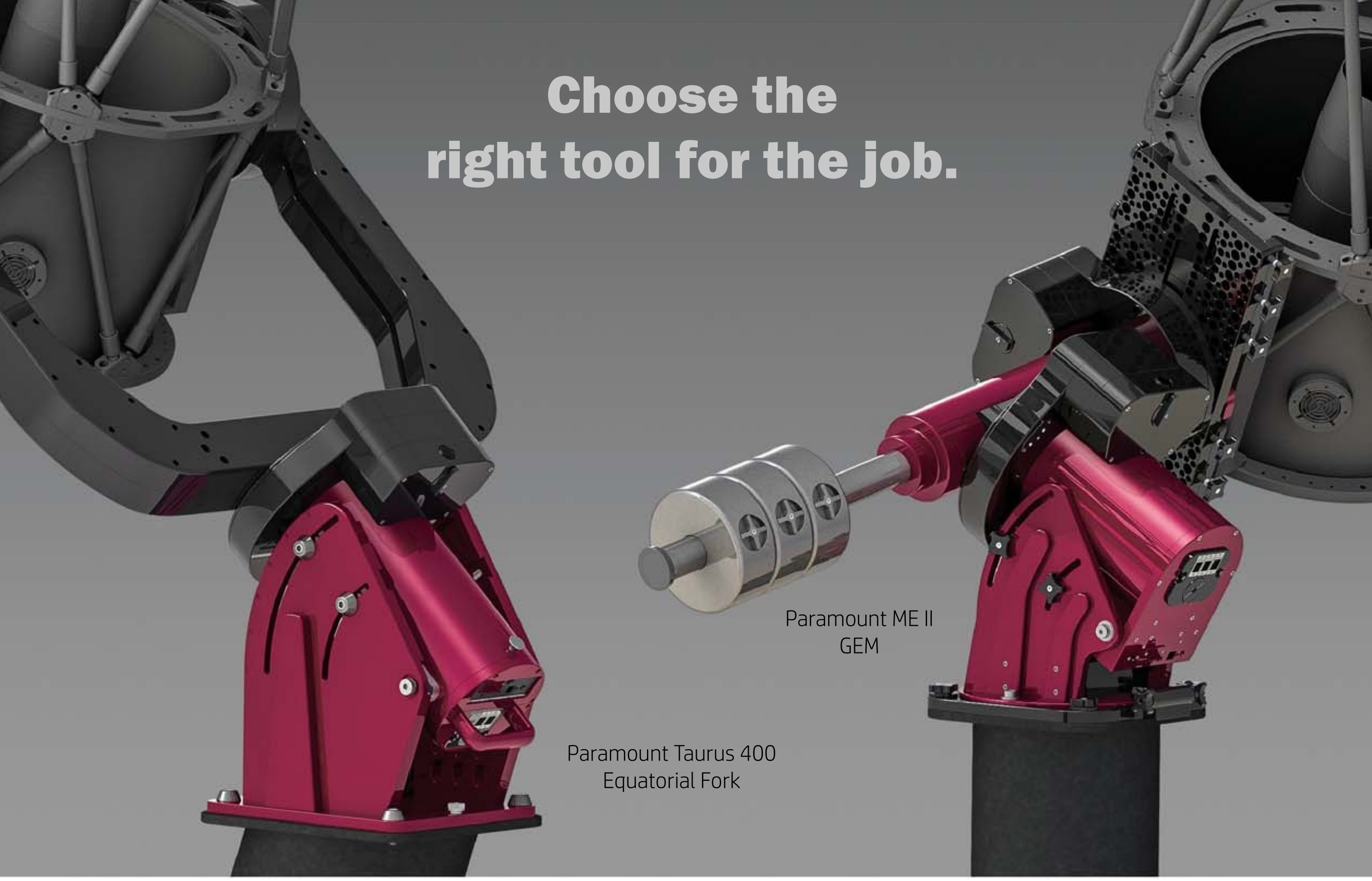
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No spacecraft has visited Uranus or Neptune since the 1980s.

URANUS AND NEPTUNE: NASA / JPL-CALTECH (2)

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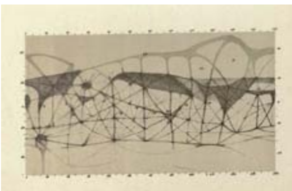
# Time Travel

**TO AN ASTRONOMER INTENT ON** measuring change, 100 years might as well be no time at all. Professionals and amateurs alike are used to evaluating variations that occur over millions or even billions of years. What's a century in the lifetime of a star or the parallax shift of a distant galaxy?

Yet when it comes to the *field* of astronomy, a century has brought truly radical change, as Klaus Brasch chronicles in his article on page 58. You might liken the transformation to a blue supergiant before and after going supernova.

To get my own sense of this — Brasch considers other examples — I looked at two books, one published in 1904 and the other in 2004. (I chose those years because my paternal grandfather was born in the first and died in the second, and his lifetime serves as a handy yardstick for me when contemplating a century.) The first book is Sir Robert Ball's *A Popular Guide to the Heavens*, images from which handsomely adorn the opening spread of Brasch's piece. The second is *Astronomy: A Visual Guide*, by Mark Garlick. Both offer a glimpse at the then-current state of astronomy for the interested layman.



Mars map made in 1896-97. Do you see canals?

ROBERT BALL, *A POPULAR GUIDE TO THE HEAVENS* (1904) / PUBLIC DOMAIN

Skimming through Ball's book, certain lines jumped out at me: "Observers of Mars are divided into two camps — those who see the canals and those who do not." "The whole [of Messier 13] contains at least 5,000 stars . . ." "The light of the [Great Nebula in Andromeda] is such as would be given by vast numbers of stars crowded together [but] it is altogether premature to argue . . . that the nebula is really an enormous system of stars far away."

Today, no one except perhaps a conspiracy theorist would posit artificial canals on Mars. We know that the globular cluster M13 has several *hundred thousand* stars. And the Great Nebula of Andromeda? That's indeed "an enormous system of stars far away" — the Andromeda Galaxy. Ball and his contemporaries knew of only a single galaxy, the Milky Way; today we count them in the billions.

Flipping through Garlick's book elicits even more arresting realizations. The index alone lists terms that would have left Ball scratching his head. Active galactic nucleus. Big Bang. Black holes. Cosmic background radiation. Dark energy. Neutron stars. Pulsars. Radio astronomy. Supernovae. White dwarf.

All of those subjects, studies of which drive much of modern astronomy, were entirely unknown in Ball's day.

Before we begin feeling smug about how much more we know than Ball did, we need to ask ourselves the obvious question: What will astronomers know at the turn of the 22nd century that we haven't the slightest clue of today?

Peter

Editor in Chief



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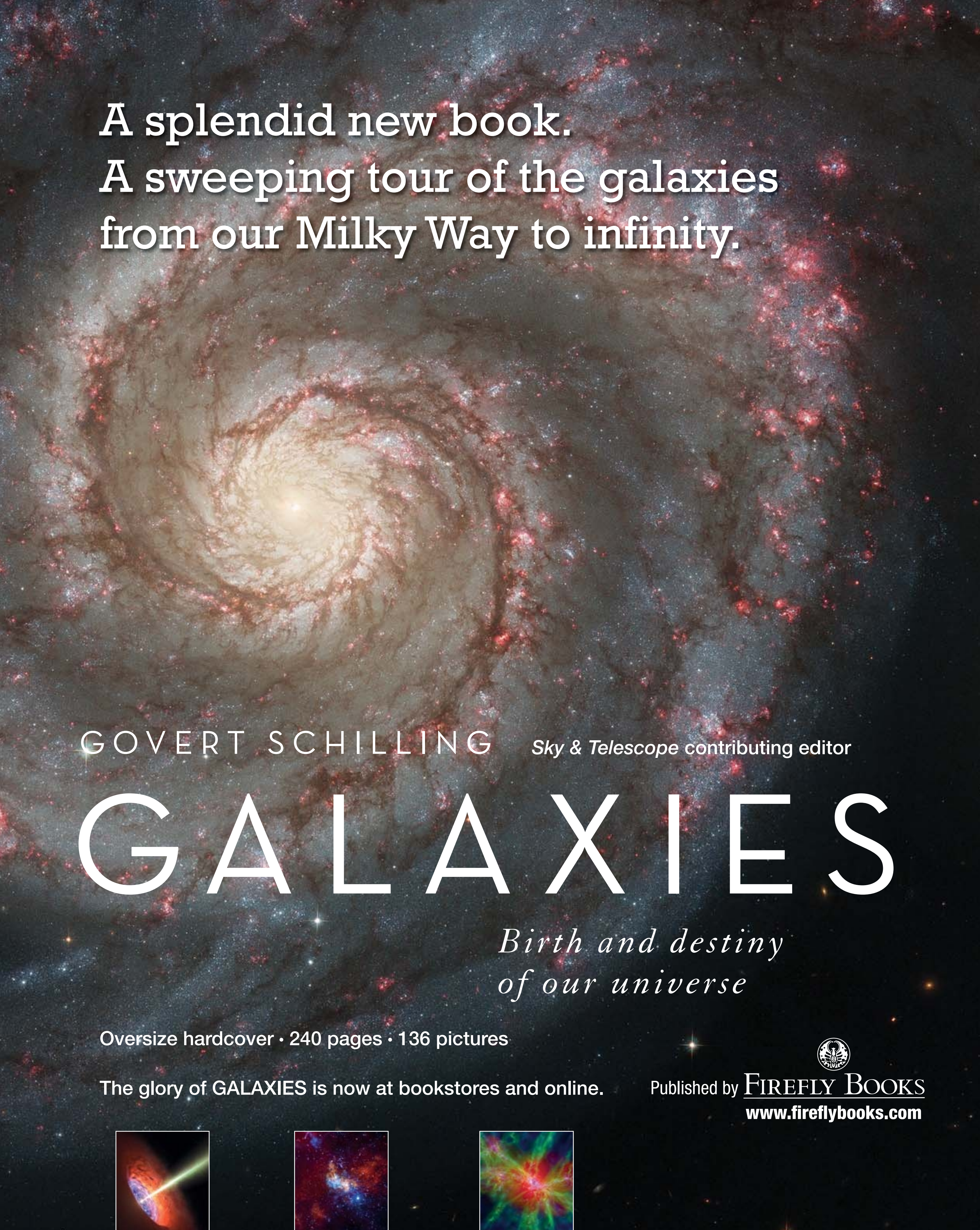
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## Membership Has Its Privileges

Early this year a fellow member of the Smoky Mountain Astronomy Society (SMAS) and I rode to the top of Chilhowee Mountain in eastern Tennessee to take pictures of the elusive Omega Centauri. The summit overlooks Great Smoky Mountains National Park and has a very good view of the southern sky.

Unfortunately, clouds lingered there for the whole night, and we had to pick another target. The Hercules cluster, M13, was rising in the east and in perfect position for photography. Three hours and 20 minutes later, I had accumulated a hundred 2-minute exposures, and Jammey Church processed them. We created a beautiful picture with brilliant colors, but the story doesn't end there.

We proudly showed the results to other SMAS members, with one taking an acute interest. Michael McCullough was more interested in the objects captured in the background. After studying the uncropped original (**https://is.gd/Dunlap_M13**), he discovered more than 20 galaxies surrounding the cluster. Researching the subject further, we came across Bob King's "M13 with a Side of Galaxies, Please" on the *S&T* website (**https://is.gd/M13_galaxies**), which helped greatly, but the story doesn't end there either.

McCullough turned to the SIMBAD database to identify additional galaxies. Then he used redshift values to determine their corresponding distances in light-years and an online estimator to get the light-travel time, assuming a flat universe. One of the galaxies captured in our image is more than 2 billion light-years away!

This experience shows the value of being in an astronomy club and reading *Sky & Telescope.*

**Duane Dunlap • Knoxville, Tennessee**

▲ Messier 13, the majestic globular cluster in Hercules, shares the field with many fainter deep-sky companions — such as the 12th-magnitude galaxy NGC 6207 at upper left. North is up.

DUANE DUNLAP & JAMMEY CHURCH

## Tidal Triggers

In the News Note "Apollo-era Data Reveal the Moon's Tectonic Activity" (*S&T:* Aug. 2019, p. 8), Javier Barbuzano notes that six of the 28 detected moonquakes occurred during lunar apogee, when the Moon is farthest from Earth. He explains, "The connection with apogee is important, because that's when Earth's tidal pull per lunar surface area is largest."

I thought that the farther the Moon is from us, the weaker Earth's tidal pull (gravitational stress) should be — or am I mistaken?

**Michel Bonnement**
**Courseulles sur Mer, France**

**Kelly Beatty replies:** *Researcher Thomas Watters and his coauthors point out that the quakes result from a combination of global contraction, Earth-induced diurnal tides, and the Moon's orbital recession. The fault scarps they found are due to compression of the lunar crust, and (counterintuitively) the diurnal and recession stresses are most compressive near the tidal axis when the Moon is near apogee.*

## Over the Limit

Don Ferguson states that both his 3.5-inch and 7-inch Questar telescopes exceed the resolving power predicted by Dawes' equation (*S&T:* June 2019, p. 36). For example, while the Dawes limit is 1.3″ for a 3.5-inch scope, Ferguson's achieves 1″. He gets similar results with the 7-inch. Part of this is likely due to the high quality of modern optical components, compared to what Dawes was working with in the 1860s, but I've always suspected that Dawes was being a bit conservative, too. (Interestingly, Questar claims a 1″ resolution for the 3.5-inch in its spec sheet.)

This leads me to wonder whether a 3.5-inch refractor would get even better results. The 89-mm Questar scope is a Maksutov with a central obstruction of 27.9 mm, giving it an effective aperture of just 84.5 mm. Would a good apochromatic refractor of this aperture achieve the same results as Ferguson's Questar? Either way, I'm jealous of him for owning *two* of these marvelous telescopes!

**Tom Sales**
**Somerset, New Jersey**

I have owned five 3½-inch Questars since 1966, and on the night of August 7, 1966, I elongated Gamma$^2$ ($\gamma^2$) Andromedae at 160× and 200× with one of those scopes when the seeing was virtually perfect. According to the 13th edition of *Norton's Star Atlas*, $\gamma^2$ Andromedae's 5.4- and 6.6-magnitude components have an orbital period of 55 years and were at their widest separation in 1971.

Based on this and my visual observations of other doubles, I concluded the telescope's resolution was around 3.5″/*a* (with *a* the aperture in inches) — the same as Ferguson found many years later, rather than the Dawes value of 4.56″/*a*.

The ability of the Questar's optics to resolve below the Dawes limit is readily explained. As pointed out by Henry E. Paul in his 1965 classic *Telescopes for Skygazing*, the presence of a central obstruction decreases the size of the Airy disk of a diffracted point source. Current Questar literature states this obstruction is 32.5% of the aperture's diameter. This results in a decrease in size of the Airy disk by about 9%, so you get a 9% improvement in resolution.

Also, it's well known that blue stars can be resolved at closer separations than red or yellow stars can, and $\gamma^2$ Andromedae's stars are intensely blue in color.

J. B. Sidgwick also wrote that some visual observers put central obstructions on their refractors to get better resolving power on some doubles. For example, S. W. Burnham detected some equal or nearly equal doubles separated by just 0.2″ with his 6-inch Alvan Clark refractor — a feat that was difficult to equal even with the 36-inch Lick refractor!

Scattered throughout the astronomical literature are many examples of resolution below the Dawes limit. Sometimes resolution and detection are confused, but Ferguson has done an excellent job of getting rid of any confusion between them.

**Rodger W. Gordon**
**Nazareth, Pennsylvania**

## A Big Event (Horizon)

Your article on imaging M87's supermassive black hole (*S&T:* Sept. 2019, p. 18) states that it would take light 1½ days to cross this black hole. That means the distance from its center to its event horizon is more than four times the distance from the Sun to Neptune. Is that right?!

**James Folsom**
**Portola Valley, California**

**Camille Carlisle replies:** *That's correct! Using the calculated mass of 6.5 billion Suns, M87* would have a Schwarzschild radius of 128 astronomical units — compared to Neptune's semimajor axis of 30 a.u. But this calculation assumes it's a non-spinning black hole. If M87* spins, it will drag spacetime closer around it and effectively shrink the event horizon's size.*

*Since all the supermassive black holes that we've measured spins for generally have rapid rotations, it's likely that the event horizon for M87* is somewhat smaller than 128 a.u.*

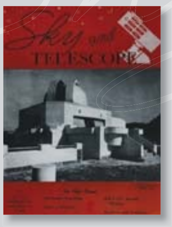
### FOR THE RECORD

- Two labels in the graph of potentially resolvable supermassive black hole silhouettes (*S&T:* Sept. 2019, p. 23) were duplicated. The labels on the leftmost dotted vertical lines should read, "0.8 mm (ground+GEO)" and "1.3 mm (ground+MEO)".
- In "The Great Attractor" (*S&T:* Oct. 2019, p. 17), Sandra Faber (not Donald Lynden-Bell) led "The Seven Samurai" research team.
- In "A Full Deck of Kings" (*S&T:* Nov. 2019, p. 60), the correct Trumpler classification for King 10 is II1m.

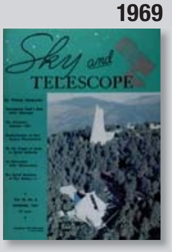
**SUBMISSIONS:** We welcome your comments and questions! Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, USA, or by email to: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1944



1969



1994


**December 1944**

**Galaxy Centers Resolved** "One of the observational problems that most astronomers expected could be solved only with the new 200-inch telescope has been successfully tackled with the Mount Wilson 100-inch by Dr. [Walter] Baade. Making long exposures on red-sensitive photographic plates, he has [resolved] into stars the nebulous nucleus of the Andromeda galaxy and its two companions, Messier 32 and NGC 205. The *Griffith Observer* attributes this success to the Los Angeles–Pasadena dimout, which allowed longer exposure times than were previously possible."

*The term "dimout" refers to the nighttime use of blackout curtains in homes and restrictions on outdoor lighting during World War II.*

**December 1969**

**Messier's Mistake** "It can be simply demonstrated that the lost Messier object M91 is very probably the galaxy NGC 4548 . . . M91 was the last of a group of eight nebulae observed by Charles Messier on the night of March 18, 1781. The French astronomer described it as a 'nebula without stars' and fainter than M90. . . .

"My solution of the puzzle assumes that Messier determined the position of NGC 4548 by measuring its right ascension and declination relative to those of the nearby galaxy M89 (since there is no suitable reference star in the vicinity) . . . It is further assumed that, in calculating the coordinates of the new object, by mistake he applied the observed differences to the coordinates of M58, a 9th-magnitude galaxy Messier had recorded two years earlier. . . . [This switch] reproduces the [erroneous] Messier position to $0^m.1$ in right ascension and 1′ in declination. . . .

"Since NGC 4548 is probably the long-lost M91, as a Messier Club member I would be pleased to see this fine spiral galaxy returned to the Messier catalogue."

*This reasoning by amateur William C. Williams is now generally accepted; M91 is missing no more.*

**December 1994**

**Bigger, Biggest** "What kind of large-scale structure exists in the universe? Are galaxies really arrayed in great sheets wrapped around giant voids? . . . In an attempt to answer these challenging questions, a team of French astronomers led by Georges Paturel (Lyon Observatory) has mapped more than 24,000 galaxies . . .

"When . . . each galaxy is plotted in three dimensions, a striking pattern emerges. A giant shell of galaxies stretches more than 650 million light-years [in extent], roughly centered on the Local Supercluster of which the Milky Way is a part. . . . It is currently the largest known structure in the universe, incorporating the 'Great Wall' of galaxies discovered in 1989 . . ."

*We now know about arrangements of remote quasars stretching across several billion light-years.*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STARS

# A Century of Amateur Observations Sheds Light on Stellar Evolution

**THE AMERICAN ASSOCIATION OF VARIABLE STAR OBSERVERS** (AAVSO) has been monitoring the star T Ursae Minoris (T UMi) since its brightness variations were discovered in 1912. Now, astronomers are using this century of observations to understand the star's recent change in behavior.

For the first few decades, the star's brightness went up and down by about 4½ to 5 magnitudes over the course of some 300 days. But over the past 20 years, this pattern changed to a more rapid cycle: The star now brightens and fades by only 1½ to 2 magnitudes over a period of roughly 200 days. Astronomers noting this change have proposed that the star is undergoing a rare and (from a stellar perspective) short-lived change in structure.

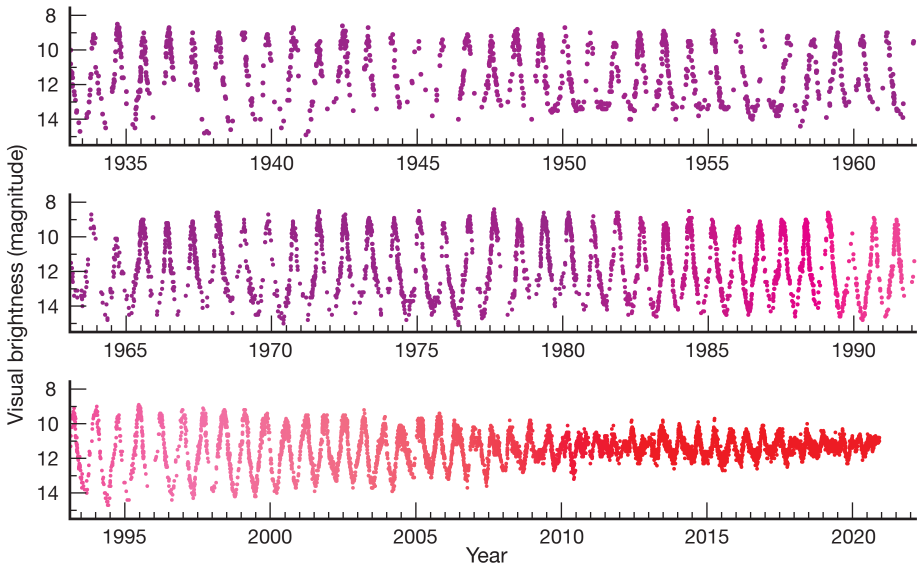
Now, László Molnár (Konkoly Observatory, Hungary) and colleagues have used the amateur observations as input to state-of-the-art computer simulations to understand the star's inner structure as it goes through this change. The results appear in the July 1st *Astrophysical Journal*.

T UMi is a red giant whose inert carbon-oxygen core is not under enough pressure to ignite fusion. Instead, the star fuses hydrogen in a shell around the core, eventually stockpiling enough helium for it to ignite. In the picture that has emerged, such a flash briefly expanded the inner regions of the star so much that it temporarily extinguished the hydrogen-burning shell and shrank the outer layers. The star as a whole dimmed and contracted. The smaller radius meant that the pulsations shrank, too. This *helium flash* is the reason behind the star's sudden change in behavior two decades ago.

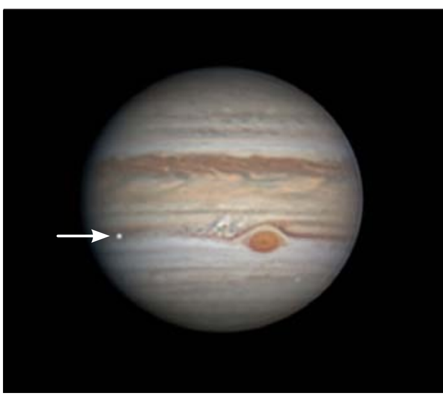
As the star contracted, a second pulsation mode appeared in the star. While the fundamental period of the star's brightness changes is now 198 days, there's an "overtone" of variations that occur on a 111-day timescale. AAVSO observations were crucial to seeing this overtone, and the overtone is in turn crucial to understanding the star's interior.

Using their model of the star's internal structure, Molnár and colleagues deduce that T UMi is twice the Sun's mass, about 300 times its diameter, and 1.2 billion years old. The model also predicts that the star's recent contraction, and the subsequent decrease of its pulsation period, will last another 50 years. Then the star should begin to expand and brighten again. The star's ultimate fate — collapsing to a white dwarf several hundred thousand years from now — is beyond human lifetimes. But amateur observers, or perhaps their children, will be able to watch the end of this brief phase of stellar evolution.

■ MONICA YOUNG




▲ Light variations of T UMi show that the star's pulsation period (purple to red) has been decreasing since the 1980s. In 2000, the shape of the brightness variations began changing as well.



◀ A processed color image shows the flash in the South Equatorial Belt, which appeared at 4:07.5 UT on August 7, 2019.

SOLAR SYSTEM

# Impact Flash on Jupiter

**WHEN TEXAS AMATEUR** Ethan Chappel looked up at the sky for Perseid meteors on the night of Tuesday, August 6th, he didn't know that his Celestron 8-inch EdgeHD telescope was capturing the possible impact of a much larger "meteor" at Jupiter.

After running his camera data through software called *DeTeCt*, which alerts the user to transient events, Chappel spotted a flash of light just inside the southern edge of the planet's South Equatorial Belt (SEB), west of the Great Red Spot. The pinpoint of light expanded slightly before fading away — telltale signs of a possible impact based

LIGHT CURVES: LÁSZLÓ MOLNÁR AND MERIDITH JOYCE; JUPITER: ETHAN CHAPPEL

EXOPLANETS

## Hot Jupiter on the Verge of Falling into Its Star

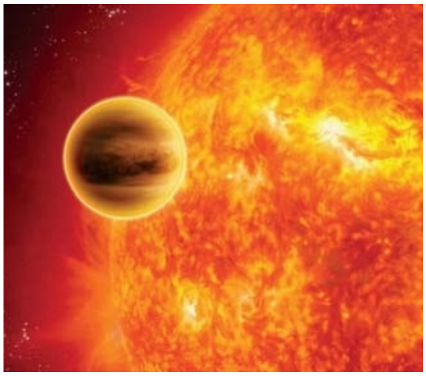
**ASTRONOMERS MAY BE WITNESSING** the slow and steady inspiral of the planet WASP-12b into its star, Joshua Winn (Princeton University) reported at the Extreme Solar Systems IV conference in Reykjavik, Iceland.

The planet is a puffed-up gas giant that transits its star every 1.1 days from a distance of just 0.02 astronomical unit (a.u.). Astronomers had previously noticed that the time intervals between its successive transits had decreased by 29 milliseconds a year, adding up to an overall decrease of 0.3 second since the planet's discovery in 2008.

Fred Rasio (Northwestern University) and colleagues predicted back in 1996 that hot Jupiter orbits might decay due to tidal interactions with their parent stars. But that decay ought to happen very slowly, at least initially. The rapid change in WASP-12b's orbital period implies that we happen to be observing the planet close to the end of its inspiral.

An alternative is that the planet's orbit might be slightly elliptical. Its orientation would then change over time (an effect known as *apsidal precession*), producing a gradual shift in transit times. But this explanation faces challenges, too, as tidal forces ought to have circularized WASP-12b's orbit by now.

Astronomers used the Spitzer Space Telescope to observe WASP-12b's transits as well as its occultations.



▲ An artist's concept shows a hot Jupiter similar to WASP-12b.

In the case of apsidal precession, the true orbital period doesn't change — if transits occur earlier than expected, occultations would occur later. But in the case of orbital decay, the exact times of transits and occultations would shift in the same direction. The Spitzer observations support the latter case, Winn says.

According to David Latham (Center for Astrophysics, Harvard & Smithsonian), the evidence that WASP-12b is going into a death spiral is "quite convincing." But, he adds, "I think it is too early to conclude that apsidal precession is excluded."

The new results fit with earlier observations showing that WASP-12b is losing its atmosphere at some ten-millionths of a Jupiter mass per year. Apparently, the planet's demise has already begun.

■ GOVERT SCHILLING

on previous events observed at Jupiter. The flash captured on Chappel's video lasts around 1.5 seconds.

Unlike with some previous Jupiter strikes, amateurs haven't spotted any dark impact scars in the wake of this one. Heidi Hammel (Space Science Institute) noted that this event was consistent with an impactor on the order of 10 meters wide and was therefore unlikely to leave dark debris.

If confirmed, this would be the 7th recorded impact at the solar system's biggest planet since July 1994, when 21 fragments of Comet Shoemaker-Levy 9 slammed into the planet and created a rosary of dark impact boils visible in amateur telescopes. Additional crashes by either asteroids or comets were observed in 2009, 2010 (two events), 2012, 2016, and 2017.

■ BOB KING

NASA / JPL-CALTECH

## IN BRIEF

### India's Lander Crashes on the Moon

India's attempt to land on the Moon ended when mission control lost contact with the Vikram lander, part of the Chandrayaan 2 mission, moments before touchdown. It was a disappointing finish to a six-week journey. After launch, a series of orbital boosts gradually raised the mission's elliptical orbit around Earth, until it was captured by the Moon's gravity on August 20th. Vikram separated from the orbiter on September 2nd for a four-day descent that took it 100 kilometers (62 miles) down to the lunar surface. Contact was lost at just 2 km above the surface; the lander appears to have landed in one piece but efforts to restore communication have failed. Vikram landed near its target, on a plain near the lunar south pole. It would have deployed a small rover, named Pragyan, to search for water ice trapped near the poles. Nevertheless, the Chandrayaan 2 mission overall has achieved 90% of its objectives. The orbiter remains fully functional and will continue to map the Moon's surface and monitor the lunar environment over the coming year.

■ DAVID DICKINSON

### Final Four Asteroid Sites Selected

NASA has narrowed down Osiris-REX's potential landing sites on asteroid 101955 Bennu to four possible locations. The spacecraft will touch down on the surface next year to collect some 60 grams of regolith. The site selection comes after Osiris-REX surveyed the jumbled surface of the ½-kilometer (0.3-mile) wide rock. NASA had hoped to have the sites narrowed down to two by now, but fortunately, the mission timeline allows an extra 300 days for site assessment. The four sites are named after birds native to Egypt:

- Nightingale is located the farthest north. The area shows characteristics of dark, fine-grain material suitable for collection.
- Kingfisher is located near the asteroid's equatorial region. A spectrum of the site shows the strongest signature of hydrated material of the four sites.
- Osprey is also located in the equatorial region and appears to have a diverse array of rock types. It also shows the strongest signs of carbon-rich material.
- Sandpiper is the farthest south of the four sites and also contains hydrated minerals.

The team will announce the two final sites — a primary and a backup — in December.

■ DAVID DICKINSON

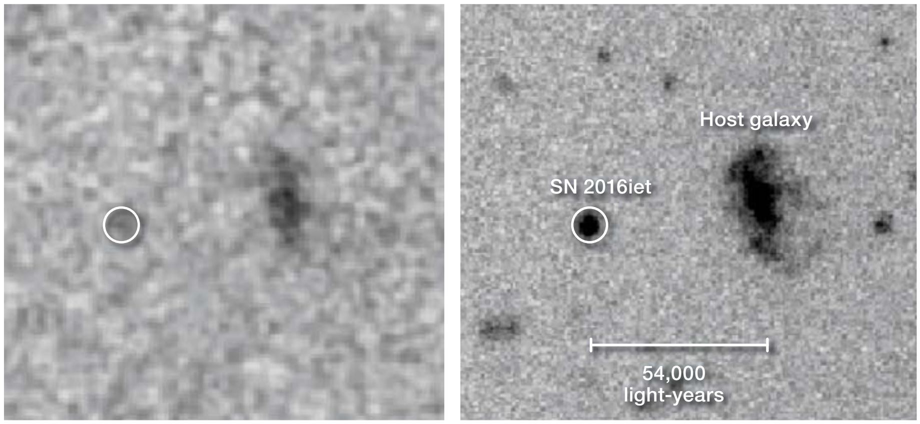
STARS

## The Supernova That Destroyed Its Star

**THE FIRST STARS** in the early universe may have ended their lives in total annihilation. Sebastian Gomez (Center for Astrophysics, Harvard & Smithsonian) and colleagues think they've caught a bona fide example of such a stellar detonation, designated SN 2016iet. They report the results in the August 20th *Astrophysical Journal*.

When a typical massive star runs out of fuel, its core collapses into something that's stable against gravity's pull — either a neutron star or a black hole. But when a star has an initial mass of at least 100 Suns, the core heats up to such a degree that it begins to form electrons and their antimatter partners, *positrons*. Electron-positron pairs don't push against gravity, so the star keeps collapsing, igniting runaway fusion. The entire star detonates before it has the chance to transform into a black hole.

Astronomers call this event a *pair-instability supernova*. But while a few candidates have been observed, none have provided enough information to confirm the scenario.




▲ A 2018 image shows the supernova 54,000 light-years from its dwarf galaxy host.

GOMEZ ET AL. 2019 / *ASTROPHYSICAL JOURNAL*, AUGUST 20, 2019

SN 2016iet is different. Automated systems and observatories, including a data-processing pipeline that looks for transients in data from the European Space Agency's Gaia mission, provided initial images of the supernova. Astronomers have also followed it for years using ground-based telescopes.

Initial observations showed that the supernova was isolated, occurring an incredible 54,000 light-years from its dwarf galaxy host. A spectrum showed no hydrogen, leading researchers to classify the blast as a Type I supernova. But the object's properties don't resemble any other known supernovae.

The astronomers tested various scenarios against the light curve of the supernova's fading brightness. Based on the results, the team concluded that before it exploded, the star had between 55 and 120 Suns' worth of mass. It existed in a relatively pristine environment that hadn't changed much since the Big Bang. In other words, in both its mass and environment, the star was similar to the universe's first stars — and had the right properties to be a pair-instability supernova.

■ MONICA YOUNG

EXOPLANETS

## Have Astronomers Detected Exomoons At Last?

**NO MOON HAS BEEN CONFIRMED** around any of the thousands of exoplanets discovered to date. But Cecilia Lazzoni (University of Padova, Italy) reported at the Extreme Solar Systems IV conference in Reykjavik, Iceland, that her team might have found two giant exomoons orbiting two low-mass brown dwarfs.

The astronomers analyzed a three-year span of data from the Spectro-Polarimetric High-Contrast Exoplanet Research (SPHERE) instrument on the European Southern Observatory's Very Large Telescope in Chile of substellar companions around two parent stars. Both companions appear to be low-mass brown dwarfs. Around each of these objects, further analysis of the images by Lazzoni's team turned up a faint candidate moon.

But it's unclear whether these candidates should really be classified as "moons." Lazzoni said that the candidates are so large that the planet-moon pairs could alternatively be described as binary planets.

The first brown dwarf orbits its red dwarf parent star at a distance of at least 300 astronomical units (a.u.) — some 10 times the distance between the Sun and Neptune. The brown dwarf's "moon" appears to be just less massive than Jupiter, based on its infrared brightness, and orbits its host at a distance of 10 a.u.

The second brown dwarf orbits more than 270 a.u. from its Sun-like star, and it has a moon 4.6 times Jupiter's mass that orbits at a distance of 8 a.u. The team is still collecting additional observations on these objects in preparation for publication and so hasn't yet revealed the host stars' identities.

The potential discoveries could shed light on the formation of brown dwarfs around stars. If the planet-size moons are indeed on such wide orbits, then the brown dwarfs might have come together more like stars than like planets — born via gravitational instabilities in the same cloud of gas and dust from which the central star formed.

Eric Nielsen (Stanford University), who wasn't involved in the study, says he's "intrigued" by the result. But, he adds, "these are extremely difficult techniques, so we really need independent confirmation."

■ GOVERT SCHILLING

MILKY WAY

## Untangling Stellar Strings

**ASTRONOMERS HAVE IDENTIFIED** thousands of new groupings of stars within 3,000 light-years of the Sun, and hundreds of them appear to be surprisingly string-like in shape. These stellar threads may trace the evolution of the Milky Ways' spiral arms, Marina Kounkel (Western Washington University) and colleagues explain in the September issue of the *Astronomical Journal*.

Kounkel and colleagues started with almost 20 million stars for which the European Space Agency's Gaia satellite had measured distances, positions on the sky, and velocities toward or away from Earth. Using a type of machine learning (*S&T:* Dec. 2017, p. 20), the researchers sorted through the immense amount of data to determine whether and how stars are clustered.

While less than 1.5% of the 20 million stars belong to a group, of those stars that do move through space together, roughly half belong to long, string-shaped groups. The other half divide themselves among more than 1,300 smaller, more spherical groups.

The stellar strings are on average 30 light-years across and 650 light-years long, which falls into the typical size and shape range of star-forming clouds. Kounkel says it's likely that a single cloud would make a single string.

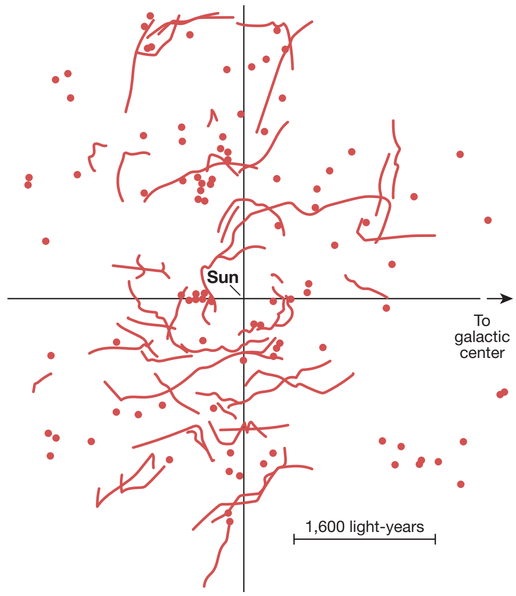
The astronomers determined the strings' ages to explore their evolution, finding that the structures are surprisingly long-lived. "We generally thought young stars would leave their birth sites just a few million years after they form," Kounkel explains. "But it seems that stars can stay close to their siblings for as long as a few billion years."

At the same time, the strings appear to trace something ephemeral: The Milky Way's spiral arms. The youngest strings — those younger than 100 million years old — together form a narrow structure that follows along the Local Arm, the spiral arm that houses the Sun (*S&T:* Nov. 2019, p. 16). The strings themselves lie perpendicular to the arm.

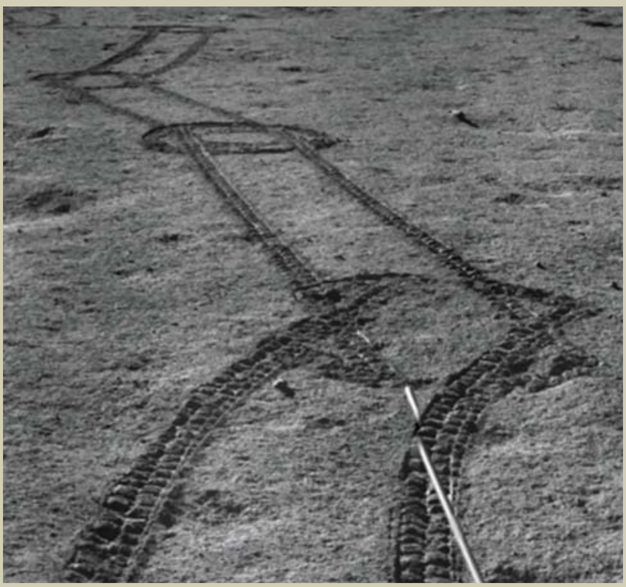
Older strings appear to align in ways that don't relate to the Local Arm, but the team argues they might mark other spiral arms that have since dissipated. Coauthor Kevin Covey (also at Western Washington University) notes, "Older strings are an important 'fossil record' of our galaxy's spiral structure."

■ MONICA YOUNG

● Explore an interactive 3D version of the map at https://is.gd/stellarstrings.




▲ As a group the youngest strings (less than 100 million years old, shown here) follow the Local Arm of the Milky Way, which runs along the vertical line that crosses this plot. However, individual strings line up perpendicular to this arm. The Sun is located at the center.



▲ This image comes from the Yutu 2 rover as it looked back over its tracks across the lunar surface. As it drives, instruments aboard Yutu 2 investigate the regolith for clues to the Moon's past.

## On the Farside: Chang'e 4 Update

China's Chang'e 4 mission has completed its ninth lunar day on the farside of the Moon, during which the Yutu 2 rover has driven 284.7 meters (933.9 feet). The mission is due to enter its 10th lunar day exploring Von Kármán Crater in the South Pole-Aitken impact basin on September 22nd. First results came in the May 16th *Nature*, in which mission scientists reported in situ observations of materials that might have originated from below the Moon's crust. Additional results are forthcoming from radar measurements of the lunar subsurface. Meanwhile, the Queqiao relay satellite, which facilitates communications between Chang'e 4 and Earth, will soon be starting a science experiment of its own. It carries the Netherlands-China Low Frequency Explorer (NCLE), a pathfinder experiment for low-frequency radio astronomy. In the coming months, NCLE will begin observations between 80 kHz and 80 MHz. (Frequencies below 30 MHz are only accessible from space.) Finally, a tiny, 47-kilogram (100-lb) satellite that launched with Queqiao ended its mission on July 31st by crashing into the Moon. Longjiang 2 lasted more than a year as a technology verification and amateur radio and imaging satellite.

■ ANDREW JONES

● See more images at https://is.gd/change4.

STELLAR STRINGS: M. KOUNKEL / *ASTRONOMICAL JOURNAL* 2019; MOON VIEW: CLEP / CNSA

Half a century ago, Uranus, Neptune, and Pluto marked the ultimate in planetary mystery. Even as men set foot on the Moon and spacecraft sped past Venus and Mars, the outermost worlds seemed to yield their secrets as slowly as they revolve around the Sun: Uranus, twice as remote as the Ringed Planet, completing an orbit once every 84 years; Neptune, a billion miles beyond, taking a leisurely 165 years to do the same; and Pluto, nearly a billion miles beyond that, its year 248 times longer than our own.

Today, planetary scientists marvel at exquisite images from our recent trip to Pluto, but its two giant neighbors still languish. Uranus and Neptune have entertained only one passing spacecraft, Voyager 2, back in 1986 and 1989, respectively. Since then, we've relied on the Hubble Space Telescope and adaptive optics on large ground-based telescopes, which now let astronomers scrutinize Uranus and Neptune from afar.

"We have learned an incredible amount since Voyager," says Imke de Pater (University of California, Berkeley), who tracks storms on Uranus and Neptune by using Hubble and the Keck Observatory in Hawai'i. Other observers have spotted new rings and moons.

But David Stevenson (Caltech), who is more interested in the planets' interiors than their atmospheres, sees things differently. "We've learned remarkably little about Uranus and Neptune since the Voyager encounters," he says. We still don't know what substance constitutes the bulk of each planet, he adds, nor do we know whether the planets are layered like Earth, with a core, mantle, and envelope.

Planetary scientists do agree on one thing, though: "We're all eager to go back," says William McKinnon (Washington University).

## Twin Planets

With similar colors, diameters, masses, densities, and rotation rates, Uranus and Neptune are twin worlds. Even their discoveries were intertwined. Irregularities in the motion of Uranus around the Sun stemmed from Neptune's gravitational pull, leading to the more distant planet's discovery.

Both planets owe their distinct colors — Uranus is green or aqua, Neptune blue — to methane gas. Their atmospheres consist mostly of hydrogen and helium, but 3% or 4% of the air is methane. This molecule absorbs red light but reflects green and blue.

No one knows, however, why the planets differ slightly in hue. Perhaps Neptune's air has more methane, causing a deeper blue. Perhaps haze subdues the color on Uranus. Or perhaps Neptune has tiny particles that enhance its color via *Rayleigh scattering*, the same phenomenon that causes the blue sky on Earth.

All four giant planets — Jupiter, Saturn, Uranus, and Neptune — have about the same amount of ice, rock, and metal, roughly 10 to 20 Earth masses, at their centers. A hydrogen-

▼ **FORLORN** Voyager 2 took these parting shots of the crescents of Uranus *(left)* and Neptune during its flybys in the 1980s. No spacecraft has visited since.

URANUS & NEPTUNE: NASA / JPL

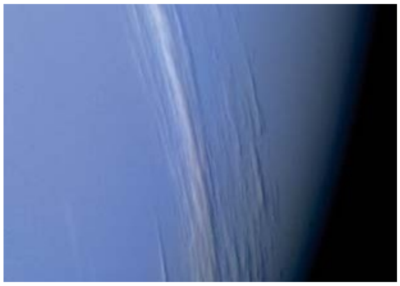
# The NEGLE

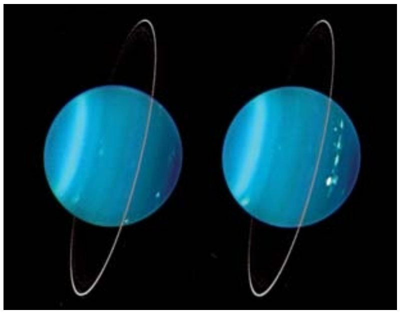
Decades after a lone spacecraft flew by, the solar system's ice giants and their many moons still guard plenty of secrets.

helium envelope surrounds these centers. Yet this similarity points to a great difference. For Uranus and Neptune, the hydrogen-helium envelope accounts for just a small fraction of each planet's mass. Jupiter and Saturn, on the other hand, are mostly hydrogen and helium.

When Jupiter and Saturn were forming, they must have grabbed lots of hydrogen and helium from the protoplanetary disk around the newborn Sun, whereas Uranus and Neptune took just a little. "You might think of Uranus and Neptune as being naked Jupiter and Saturn," Stevenson says. McKinnon adds, "They're baby giant planets that didn't get to grow up." Indeed, each of these "baby giants" is only 5% as massive as Jupiter and, at four times Earth's diameter, about a third as wide.

Because hydrogen and helium are gases on Earth, planetary scientists call Jupiter and Saturn gas giants, but their great gravity actually squeezes most of these gases into a fluid. In contrast, Uranus and Neptune are ice giants, so named because they have large quantities of three compounds that were frozen solid in the cold outer solar nebula: water ($H_2O$), methane ($CH_4$), and ammonia ($NH_3$), in unknown proportions. Because oxygen is more common in the cosmos than carbon and nitrogen, the main component





◀ *Top:* Voyager 2 caught these linear clouds on Neptune, where they stretched approximately along lines of constant latitude. *Bottom:* Several storm systems appear in these infrared composites of Uranus taken by the Keck II telescope.

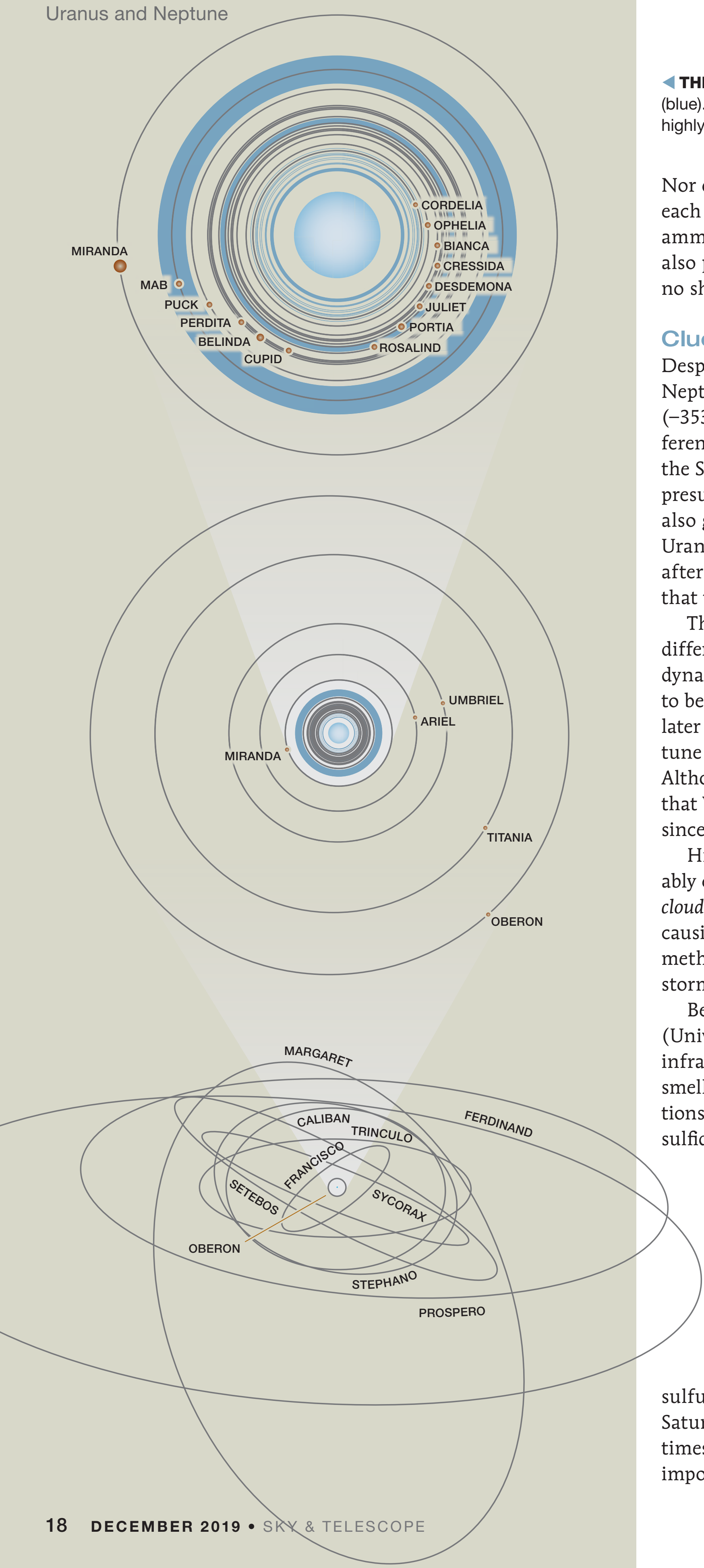
NEPTUNE CLOUDS: NASA / JPL; STORMS ON URANUS: LAWRENCE SROMOVSKY / UNIVERSITY OF WISCONSIN, MADISON / W. W. KECK OBSERVATORY

in both planets may be water. And despite the term "ice giant," this water is mostly liquid, because the interiors are so hot.

At the greatest depths, however, intense pressure may squeeze the water into *superionic ice*, which Burkhard Militzer (University of California, Berkeley) compares to a soft solid, like chalk. "It's neither completely solid nor completely liquid," he says. In superionic water, the oxygen atoms are locked into place but the smaller hydrogen nuclei move like people walking through a parking lot full of stationary cars, he explains.

Hydrogen nuclei are protons, and a current of protons through each planet's mantle may explain one of Voyager's strangest findings: Both planets have tilted magnetic fields that arise far from the planets' centers. In contrast, Earth's magnetic field comes from the flow of electrons through molten iron in our planet's outer core.

Uranus and Neptune probably have more "ice" — that is, water, methane, and ammonia — than rock and metal combined, but Stevenson says this is not known with certainty.




◀ **THE URANUS SYSTEM** Uranus has 27 known moons and 13 rings (blue). The inner 18 moons orbit the planet's equator; the others follow highly inclined paths, suggesting they're captured objects.

GREGG DINDERMAN / S&T

Nor do we know whether the planets are layered. If they are, each planet may have a rock-iron core, a water-methane-ammonia mantle, and a hydrogen-helium envelope. But it's also possible that the various substances mix together so that no sharp boundaries exist.

## Clues from Clouds

Despite their different distances from the Sun, Uranus and Neptune have the same effective temperature of 59 Kelvin (−353° Fahrenheit). This similarity actually betrays a key difference: Uranus radiates no more heat than it receives from the Sun, whereas Neptune emits more than twice as much, presumably leftover heat from its birth. Jupiter and Saturn also give off more heat than they receive. No one knows why Uranus is unique. Perhaps it lost its heat of formation soon after birth, or, conversely, perhaps its interior is so stratified that the heat can't escape.

The unexplained contrast in heat flow does explain another difference between the two ice giants: "Neptune is a lot more dynamic than Uranus," de Pater says. Voyager showed Uranus to be so bland that the planet made news when astronomers later detected clouds and storms there. In contrast, Neptune has plenty of both, thanks to its vigorous internal heat. Although the planet's best-known storm, the Great Dark Spot that Voyager 2 saw, has vanished, similar storms have erupted since. Fast winds race across both planets.

High white clouds often fringe the dark storms and probably consist of methane ice. These clouds resemble *orographic clouds* on Earth, where air rises over mountains and cools, causing water vapor to condense and form clouds. Likewise, methane-laden air on Uranus and Neptune rises over the storms and condenses, creating the high white clouds.

Below lies the main cloud deck. In 2018 Patrick Irwin (University of Oxford, UK) and his colleagues reported the infrared signature of hydrogen sulfide, a poisonous gas that smells like rotten eggs. This work confirmed earlier suggestions indicating that the main cloud deck consists of hydrogen sulfide ice.

Why hydrogen sulfide? Beneath the hydrogen sulfide clouds, ammonia ($NH_3$) and hydrogen sulfide ($H_2S$) join to form yet another compound, ammonium hydrosulfide ($NH_4SH$). Because each molecule has one atom of nitrogen and one of sulfur, whichever element is less abundant gets used up, leaving the other to form a gas. An overabundance of sulfur explains the hydrogen sulfide in the air above.

The discovery means Uranus and Neptune have more sulfur than nitrogen. That makes them unlike Jupiter and Saturn and unlike the overall galaxy, which has nearly five times as much nitrogen as sulfur. "This observation is quite important," de Pater says. "It really does show that the forma-

## URANUS STATS

**AVERAGE DISTANCE FROM THE SUN**
2.87 billion km (19.2 a.u.)

**YEAR**
84 Earth years

**ESTIMATED DAY**
17 hours 14 minutes

**AXIAL TILT**
97.8°

**MASS**
14.54 Earths

**RADIUS**
4.0 Earth radii

**MEAN DENSITY (WATER = 1.00)**
1.27

**KNOWN MOONS**
27

**RINGS**
13

**DISCOVERED**
March 13, 1781

tion of the planets isn't as simple as people initially had thought."

If instead nitrogen were more common in the atmosphere, ammonia clouds would form, as they do on Jupiter and Saturn. Perhaps, at the greater distance and colder temperatures of Uranus and Neptune, water ice in the planetesimals that built the two worlds trapped more sulfur-bearing gases than nitrogen-bearing ones.

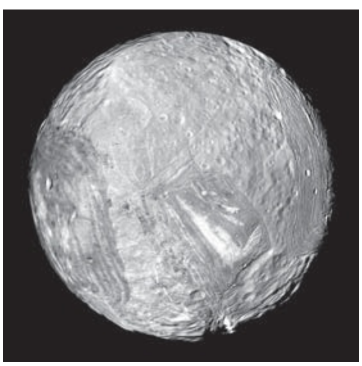
Far below all these clouds, temperatures become warmer, and scientists expect good old-fashioned water clouds to exist. But no one has yet seen them.

### Rings and Things

Both Uranus and Neptune spin fast but have very different axial tilts. Voyager found that Uranus spins every 17 hours or so and Neptune about every 16 hours — faster than Earth but more slowly than Jupiter and Saturn. These figures constrain models of planetary interiors; however, with only one spacecraft measurement, some scientists have questioned the numbers.

Although Uranus and Neptune have similar spin periods, their rotation axes are another story. Early in Uranus's life, an object roughly twice as massive as Earth might have slammed into the planet, knocking it over. Or that object may have whizzed by the planet, twirling it around via gravity. Either way, Uranus now lies on its side as it spins, with an axial tilt of 98°. In contrast, Neptune's axis tilts only 28°, similar to Earth's.

Both Uranus and Neptune have rings, though they're much darker than those around Saturn. Astronomers first detected Uranus's rings in 1977, when the planet passed in front of a star and 5 narrow rings blocked the star's light before and after the planet did. Subsequent discoveries have boosted the total number of known rings to 13. Because of its drastic axial tilt, Uranus points one pole almost directly sunward during summer and winter solstices, giving observers on Earth a face-on view of the rings, first from the top, then decades later from the bottom.



◀ **MIRANDA** This 1986 image from Voyager 2 shows the varied terrain on Uranus's icy moon Miranda. Features that look like compressional folded ridges mix with faults, and some of the scarps are up to 5 km high — higher than the walls of the Grand Canyon. The moon itself is less than 500 km wide.

URANUS PLAYING CARD: TERRI DUBÉ / *S&T*, BACKGROUND IMAGE: ALLIES INTERACTIVE / SHUTTERSTOCK.COM, URANUS IMAGE: NASA / JPL-CALTECH; MIRANDA: NASA / JPL

Neptune has six rings. Ground-based astronomers saw hints of one in the 1980s (*S&T:* June 1989, p. 606), but Voyager definitively discovered five. A sixth ring, which may not fully wrap around the planet, also appears among the others in the Voyager data. In addition, the spacecraft saw enhancements of material in four sections of the outermost ring. How these *ring arcs* arose is unknown, but they may owe their existence to gravitational resonances with various satellites or to collisions in the ring. Since Voyager's visit, two of the four ring arcs have disappeared; perhaps new ring arcs will form in the future.

Whereas Saturn's stunning rings glisten with water ice, those of Uranus and Neptune are dark, probably due to carbon compounds. Small moons tug on the rings and actually spawn others. For example, the moons Cordelia and Ophelia orbit Uranus on either side of its brightest ring, named Epsilon, their gravity keeping that ring narrow, while Neptune's moon Galatea probably sprinkles material along its orbit and creates the diffuse ring it inhabits.

### It's a Mab Mab World

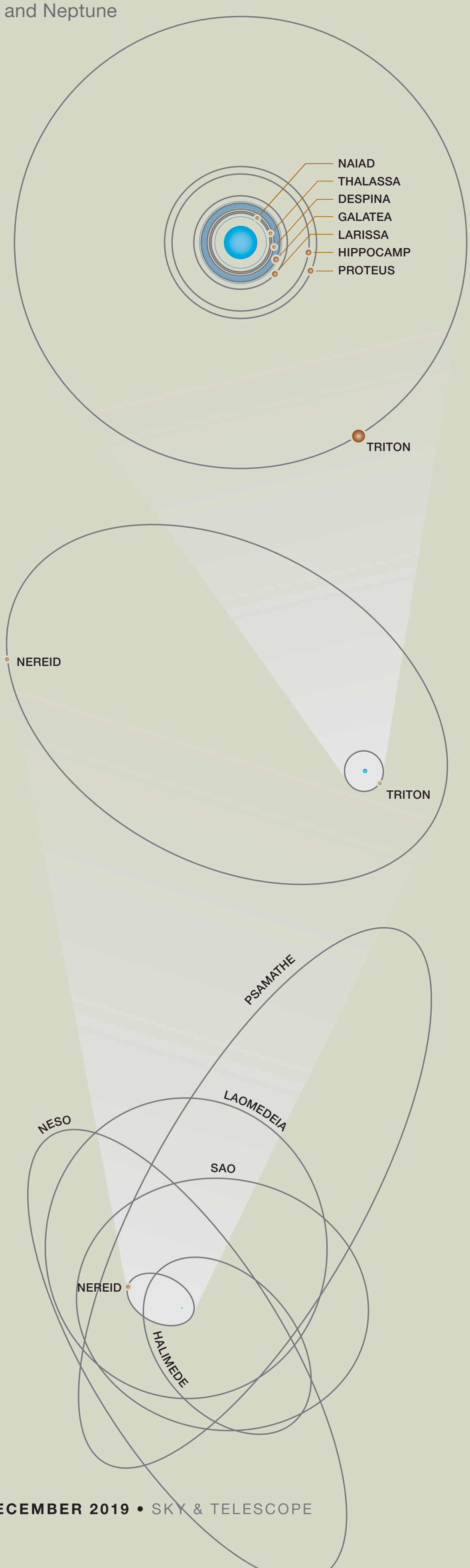
Indeed, both planets have lots of moons. When Voyager flew past, it tripled the number known at Uranus from 5 to 15 and quadrupled the number known at Neptune from 2 to 8. This created the pleasing coincidence that the eighth planet from the Sun had eight known moons.

But Hubble and ground-based telescopes have nearly doubled the numbers again. Today, Uranus has 27 known moons and Neptune 14.

On its visit to Uranus, Voyager passed closest to Miranda, the smallest and innermost of the five classical Uranian moons, and astonished scientists with pictures of radically different terrain types, some ancient, others young. "It's a kind of schizophrenic world," McKinnon says.

Thirteen additional moons, most found by Voyager, lie inside Miranda's orbit. All are smaller than Miranda. One of the most intriguing is Mab, which Mark Showalter (SETI Institute) and Jack Lissauer (NASA Ames) found in 2003. Mab lies in the outermost ring, named Mu. In like fashion, the moon Enceladus, which orbits Saturn and is about the size of Miranda, lies in that planet's E ring. The E ring comes from geysers on Enceladus that spew water along its orbit. Both rings are blue, so Mab might be doing something similar around Uranus.

But there's a problem. "Mab is tiny," Showalter says. It's much smaller than Enceladus. How can a moon that's roughly a dozen miles across be geologically active? No one




◀ **THE NEPTUNE SYSTEM** Neptune has 14 known moons and six rings (blue, four combined here due to scale). The planet likely captured Triton from the Kuiper Belt, as well as five far-out satellites that travel on wildly tilted orbits.

knows — so perhaps the ring comes instead from meteoroids that strike the moon and kick up dust. But dusty rings are reddish, not blue. The puzzle therefore remains.

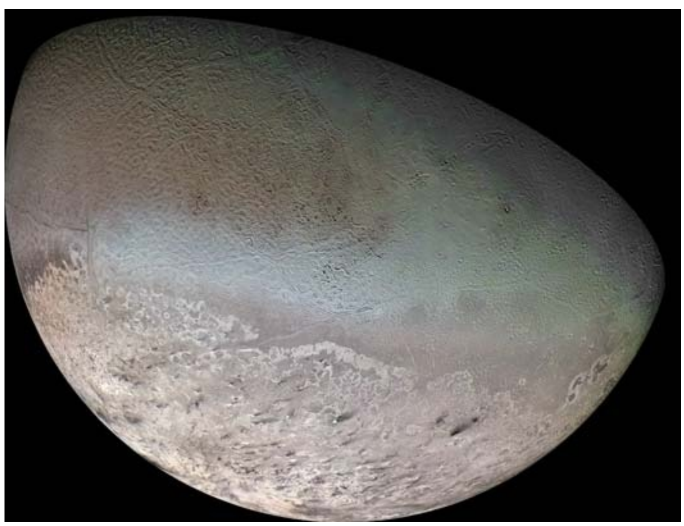
Nine of Uranus's inner moons constitute the most tightly packed satellite system ever seen. Planetary scientists have long recognized that the moons are in danger, as gravitational tugs among the moons may make them swerve into the wrong lane. In 2017, Robert Chancia (University of Idaho) and his colleagues measured the mass of a small inner moon named Cressida based on how its gravity distorts Uranus's Eta Ring. Knowing the mass, the scientists then predicted that the moon might crash into its neighbor, Desdemona, in just a million years. The debris from that collision should encircle the planet in a new ring.

All the moons near Uranus — the 13 innermost moons plus the 5 satellites known prior to Voyager — are so-called regular satellites, because they follow fairly circular orbits close to the planet's equatorial plane. In contrast, at much greater distances lie 9 additional moons, all found since Voyager, on elliptical and inclined orbits. These "irregular" satellites did not form with Uranus but instead were captured by it. All but one of the irregular satellites orbit the planet backward, opposite the direction it spins. Retrograde irregular moons outnumber prograde ones because the Sun's gravity can't as easily yank a retrograde moon away from its planet.

## Far-Out Moons

At Neptune, the standout moon is Triton. It is nearly twice as large as Uranus's largest moon and slightly larger than Pluto. Yet Triton revolves backward, a sign that it, too, is a captured world, one that once roamed through space on its own as

▼ **TRITON** This color mosaic of Voyager 2 images shows the nitrogen-ice surface of Neptune's largest moon. The dark streaks overlying the south polar cap's pinkish ice may be from geyser plumes.



NEPTUNE MOONS: GREGG DINDERMAN / S&T; TRITON: NASA / JPL / USGS

Pluto still does. Triton is the largest retrograde moon in the solar system.

Its arrival doomed most of Neptune's other moons. Triton probably smacked into some, tossed others into the planet, and ejected still others altogether. One moon that managed to hang on was Nereid, but its orbit became stretched out due to the newcomer's gravity. Nereid now has the most elliptical orbit of any moon in the solar system, with an orbital eccentricity of a whopping 75%.

Triton suffered, too. Its initial orbit around Neptune was elongated, but Neptune's tides forced its path to become circular, internally scorching the moon and melting all its ice and maybe even its rock. Volcanic eruptions must have spewed out lots of gas, wrapping the moon in a thick atmosphere. Today, Triton's atmosphere resembles Pluto's, tenuous and full of nitrogen. Geysers send additional gas into the air.

Triton is about as close to Neptune as the Moon is to Earth. Inside Triton's orbit lie seven other satellites, all on circular paths, all but one found by Voyager. The largest, and the second largest orbiting Neptune, is Proteus. Voyager images revealed a battered world with a huge crater named Pharos. The crater might be a scar from an impact that created the small moon Hippocamp, which Showalter spotted in 2013 in an orbit that lies near Proteus.

Beyond the orbits of Triton and Nereid, five other irregular satellites pursue elliptical and inclined orbits around Neptune. The most distant, Neso, ventures farther from its planet than does any other moon in the solar system. At its extreme, Neso skirts 72 million kilometers from its master — nearly half the distance between the Sun and Earth. So distant is Neso that it takes 26 years to orbit Neptune once, nearly as long as Saturn takes to circle the Sun. Yet Neptune can retain this remote retrograde moon because the planet itself is so far from the Sun's gravity.

In 2003 Scott Sheppard (Carnegie Institution for Science) and his team discovered Psamathe, a retrograde moon whose orbit overlaps Neso's. He speculates that the two moons might once have been a single object that split apart when a large comet hit it.

"Almost all these moons are just points of light" through a telescope, he adds. "So we really don't know much about them."

## NEPTUNE STATS

**AVERAGE DISTANCE FROM THE SUN**
4.5 billion km (30.1 a.u.)

**YEAR**
165 Earth years

**ESTIMATED DAY**
16 hours 7 minutes

**AXIAL TILT**
28.3°

**MASS**
17.15 Earths

**RADIUS**
3.9 Earth radii

**MEAN DENSITY (WATER = 1.00)**
1.64

**KNOWN MOONS**
14

**RINGS**
6

**DISCOVERED**
September 23, 1846

## Return to the Ice Giants?

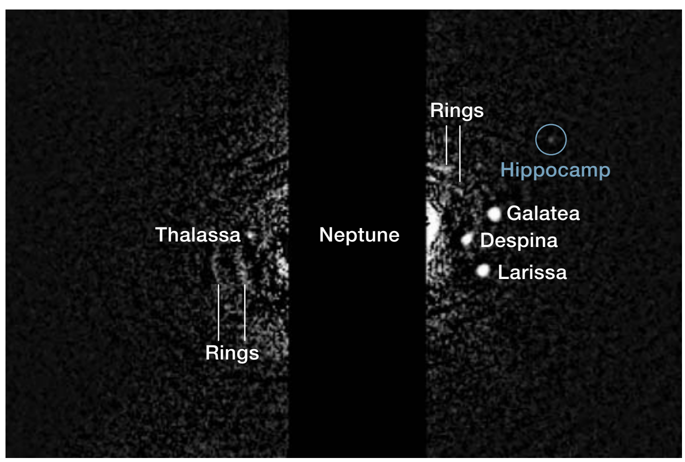
All these moons and the planets they orbit provide rich targets for future spacecraft. An orbiter like the ones Jupiter and Saturn have received would scrutinize these systems for years. To reach the planets quickly, a spacecraft must swing by Jupiter, whose gravity would fling the craft outward. The next launch opportunities to Uranus and Neptune occur around 2030, leading to encounters around 2040.

No such missions are yet funded, but planetary scientists in both the United States and Europe are drawing up plans. After all, every planet from Mercury to Saturn has received at least one orbiting spacecraft, and we now know that planets the size of Uranus and Neptune abound throughout the galaxy (*S&T:* Sept. 2019, p. 16). Orbiters to the two nearest examples would divine clues to their interiors, compositions, and atmospheres. Moreover, such spacecraft would fly past moon after fascinating moon and could discover additional satellites as well.

Uranus in particular presents a timely opportunity. By bad luck, Voyager flew past when one of the planet's poles pointed nearly sunward, which meant that, even as Uranus and its regular satellites turned, one side of each world stayed hidden in darkness. In contrast, sunlight will illuminate them in full at the next equinox, in 2050, so a spacecraft still in orbit then could see all of Uranus and its regular moons.

The challenges of reaching these distant worlds are great, but the scientific rewards are likely to be far greater.

Ever since childhood **KEN CROSWELL** has been especially intrigued by distant and mysterious Uranus, Neptune, and Pluto. He is the author of eight books, including *Planet Quest* and *Ten Worlds.*




**MOON SHARD** Little Hippocamp (about 18 km across) appears around Neptune in this Hubble Space Telescope composite. Also visible are four other moons and a couple of rings. The black bar prevents the planet's light from swamping the image.

NEPTUNE PLAYING CARD: TERRI DUBÉ / *S&T*, BACKGROUND IMAGE: ALLIES INTERACTIVE / SHUTTERSTOCK.COM, NEPTUNE IMAGE: NASA / JPL; HIPPOCAMP: NASA / ESA / M. SHOWALTER (SETI INSTITUTE)

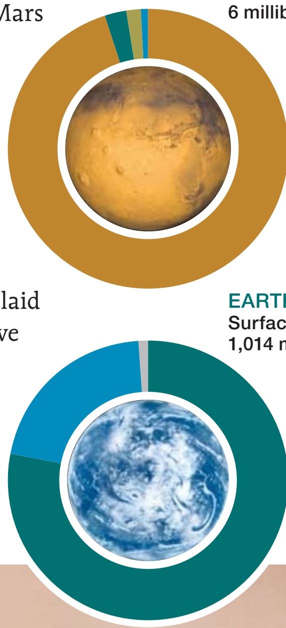
# MARTIAN Weather Report

Storms, radiation, and dust combine to create a deadly environment on the Red Planet.

Over the past few decades, spectacular photos taken by landers and rovers from the surface of Mars have joined the ranks of the Space Age's most iconic images. One reason the photos have such appeal is because they paint a picture of an Earthlike environment. Rolling hills, layered mesas, fields of boulders, distant horizons, wispy clouds streaked across an endless, clear sky . . . the scenery could be out of a Western set somewhere in the desert of the U.S. Southwest. There is a familiarity to it, a timelessness evoked by geology laid bare, a sense of déjà vu — one feels like one may have driven through here before . . .

In reality, of course, nothing could be further from the truth. The "Earthiness" of Mars is a cruel illusion. While Mars is the most Earthlike planet in the solar system besides Earth itself,

LANDSCAPE: NASA / JPL; GRAPHS: TERRI DUBÉ / S&T; EARTH: S&T ILLUSTRATION; MARS: NASA / GODDARD SPACE FLIGHT CENTER SCIENTIFIC VISUALIZATION STUDIO




Unprotected on the surface, you would not only suffocate and get the mother of all sunburns, but you'd also freeze to death.

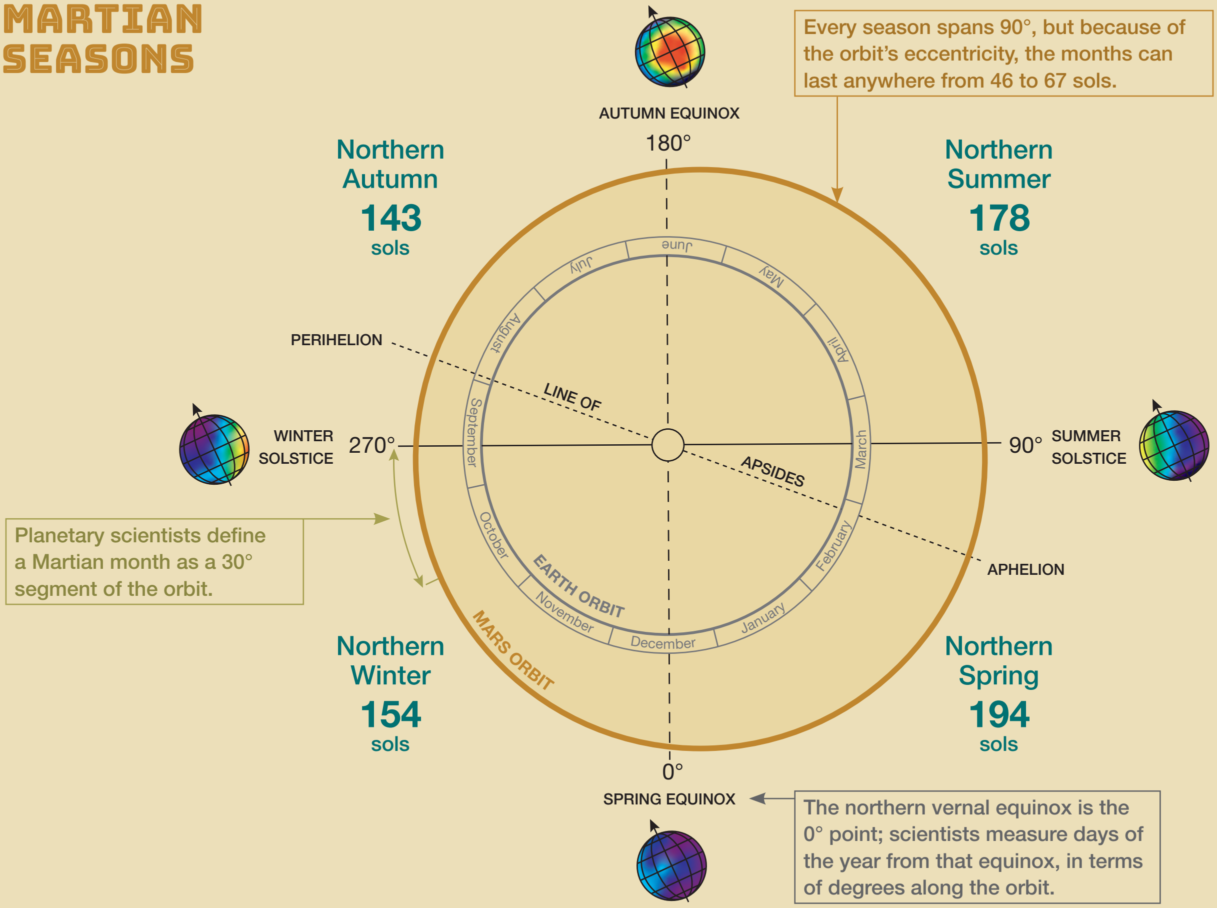
**MAIN ATMOSPHERIC COMPONENTS**

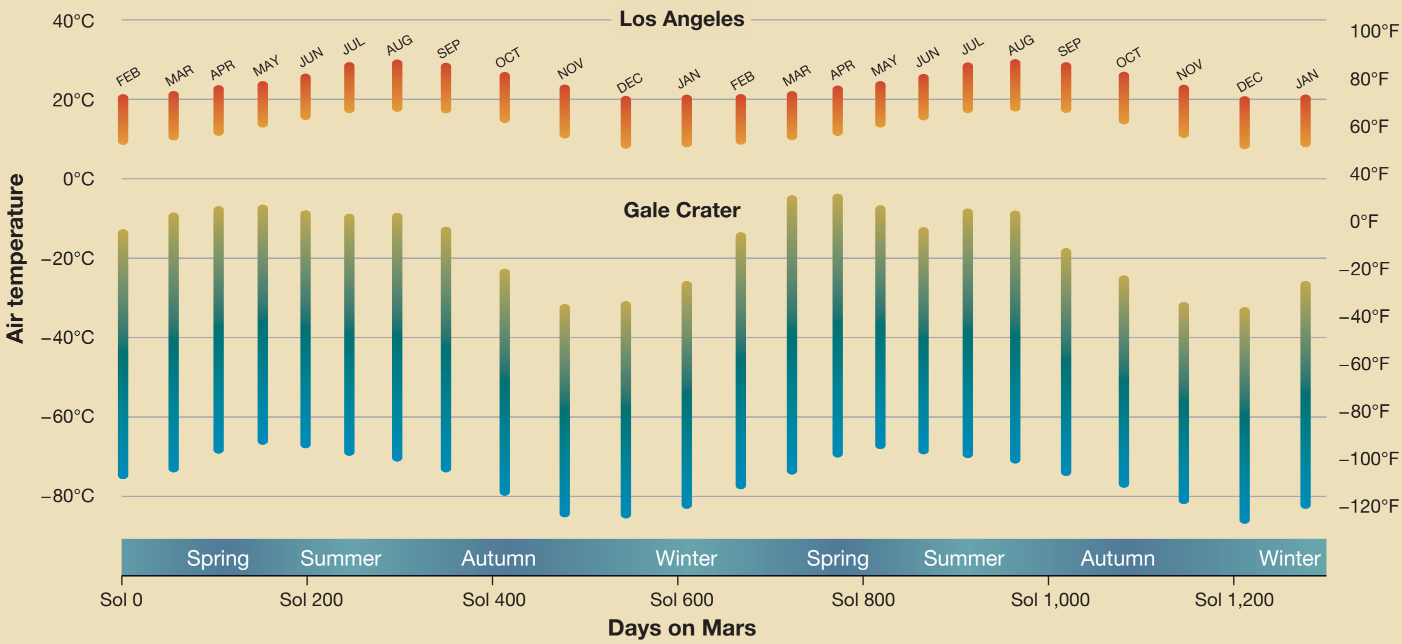
- Carbon dioxide
- Nitrogen
- Argon
- Oxygen
- Other

*Planets not to scale*

**TWIN PEAKS** Two modest-size hills sit about a kilometer away in this Mars Pathfinder composite. The colors are adjusted to approximate true color on Mars.

# MARTIAN SEASONS




▲ **BALMY OR BRRR** About two Martian years' worth of temperature data from the Curiosity rover's weather station show a clear seasonal pattern inside Gale Crater, which lies just south of the equator. Although the annual average temperature doesn't change much, daily conditions oscillate by about 60°C.

ORBIT AND SEASONS: GREGG DINDERMAN AND TERRI DUBÉ / *S&T*, SOURCES: J. D. BEISH / ALPO, MARS CLIMATE DATABASE; TEMPERATURE PATTERN: GREGG DINDERMAN / *S&T*, SOURCE: NASA / JPL-CALTECH / CAB (CSIC-INTA) the weather conditions on the surface are far from hospitable. From blistering cold to sky-darkening dust storms, Mars could kill you in so many ways.

## Typical Martian Conditions

The Martian atmosphere is clear and dry, but it's thin, bearing down on the surface with only about 1% of Earth's surface pressure. In composition, it's 95% carbon dioxide ($CO_2$), which we can't breathe, with traces of nitrogen and argon and only minuscule amounts of water vapor and oxygen. Most of that oxygen comes from the breakdown of $CO_2$ by harsh levels of ultraviolet solar radiation, which barrages the surface because the planet doesn't have a protective ozone layer like Earth does.

Mars is on average about 50% farther from the Sun than Earth is, so it shouldn't be surprising that the environment is colder. However, the nature and magnitude of the coldness would be stunning to even the heartiest Arctic dwellers on our planet. Near the peak of summer, near the equator, the surface temperature during the "heat of the day" can briefly go above freezing, perhaps to 5°C to 10°C (41°F to 50°F) or more in certain places. But during most other times of the year, conditions are much more frigid, averaging more like −25°C to −10°C in the daytime and dipping down below −100°C on many nights. And that's the temperature at your feet — as you raise your thermometer up off the surface only a meter or two, the midday temperature can drop by 20°C to 30°C. Cozy toes but frozen nose.

Just like on Earth, it's colder the closer you get to the poles, and if you go far enough north or south in the winter, it gets so cold that the $CO_2$ starts to snow out onto the surface, forming dry ice. There is no similar analogy on Earth, because the water vapor that turns to snow and falls to the ground here is just a tiny fraction of the gas in our atmosphere. For it to snow on Earth like it does on Mars, the temperatures would have to drop to around −200°C so that our primary atmospheric gas, nitrogen, started to snow out onto the surface. Brrrrr . . .

Unprotected on the surface, you would not only suffocate and get the mother of all sunburns, but you'd also freeze to death.

## Funky Seasons

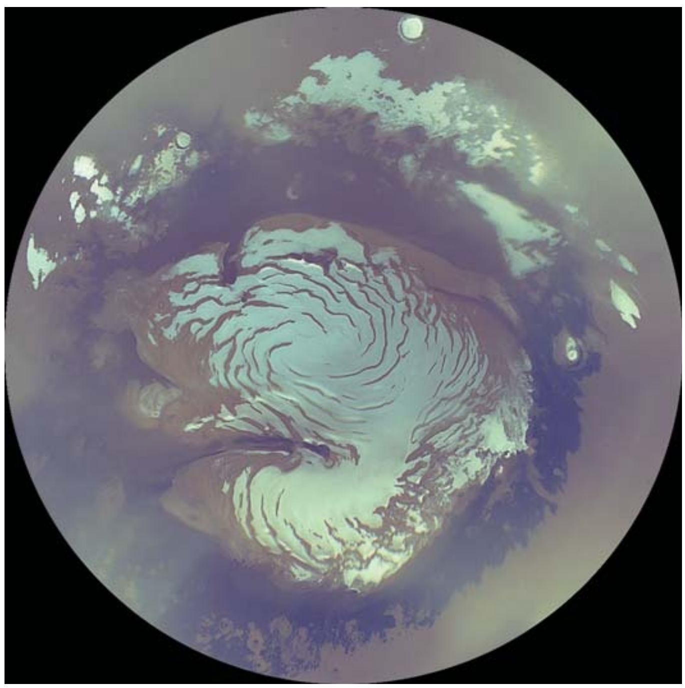
Planets have seasons because of the tilt of their rotational axes — their *obliquity* — relative to the plane of their orbit around the Sun. The tilt determines how directly sunlight hits a hemisphere — or, in the extreme case of Uranus, whether sunlight reaches the hemisphere at all (see page 16). Earth's obliquity of 23.5° results in the winter, spring, summer, and fall seasons familiar to people living in mid-latitudes, as well as the long summer days and long winter nights familiar to people living closer to the poles. Jupiter and Mercury have almost no obliquity, so those planets do not have appreciable seasons.

The obliquity of Mars (25.2°) is currently similar to that of Earth. Thus the planet has Earth-like seasons, though they're approximately twice as long as our planet's because of Mars's greater distance from the Sun. The more direct sunlight in the summertime means warmer temperatures, which in turn provide more energy to fuel storms — both Earthlike systems dominated by thin, water-ice clouds and distinctly Martian dust devils and dust storms.

Warmer temperatures provide more energy to fuel storms — both Earthlike systems dominated by thin water-ice clouds and distinctly Martian dust devils and dust storms.

Complicating obliquity's effect, however, is Mars's *orbital eccentricity*. Its orbit is far more elongated than Earth's, which has a significant influence on the weather. Specifically, Mars's orbital eccentricity of 0.09 means that the planet's distance from the Sun changes from 1.38 astronomical units at perihelion (around southern summer/northern winter) to 1.67 a.u. at aphelion. That change in distance results in a whopping 45% increase in the amount of sunlight that the planet receives around perihelion compared to aphelion. In comparison, Earth's orbital eccentricity of just 0.017 results in only about a 7% change in the intensity of sunlight between January, when we're closest to the Sun, and July, when we're farthest. The Red Planet's more elongated orbit also means that the duration of southern summer is

▼ **POLAR CAP** This four-image mosaic from the Mars Reconnaissance Orbiter's MARCI camera shows the perennial north polar cap (white) atop layered material (light tan) and circumpolar dunes (dark brown).



NASA / JPL / MSSS

significantly shorter than the duration of southern winter: 154 Martian days versus 178, where a Martian day, or *sol*, lasts 24 hours and 39 minutes.

The large increase in solar energy input during southern spring and summer increases the average surface temperature, driving stronger daily winds, fueling more frequent storms, and helping to occasionally raise surface temperatures at latitudes near the equator above the freezing point of water. Conversely, the long polar nights during each hemisphere's winter season enable the surface temperatures to drop low enough (down to around –125°C) for up to about 1 meter (3 feet) of those famous $CO_2$ snow and ice deposits to accumulate. Sadly, the physics of dry ice and even water ice at Mars polar temperatures and pressures means that traditional skiing or sledding isn't possible; fans of such winter sports will have to find other pastimes, or invent new Mars-specific equipment technologies to feed their passions.

## Uniquely Martian Storms

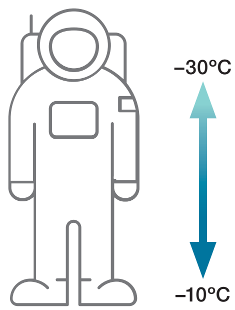
Just like on Earth, storms represent an important component of Martian weather on daily and seasonal time scales. Storms on Mars come in a range of sizes, from small house-size vortices comparable to terrestrial dust devils, to larger city-size moving walls of dust similar in some ways to terrestrial desert haboobs, to large-scale fronts that travel across major fractions of the surface, to fully planet-encircling systems that can dramatically affect the planet's surface and atmospheric temperatures. Scientists can monitor storms on all these scales using telescopes, orbiters, and surface landers and rovers. These instruments measure the way that the storms create and move clouds of both dust and water ice. They also help us study the way that movement of dust and sand can change the surface albedo over time.

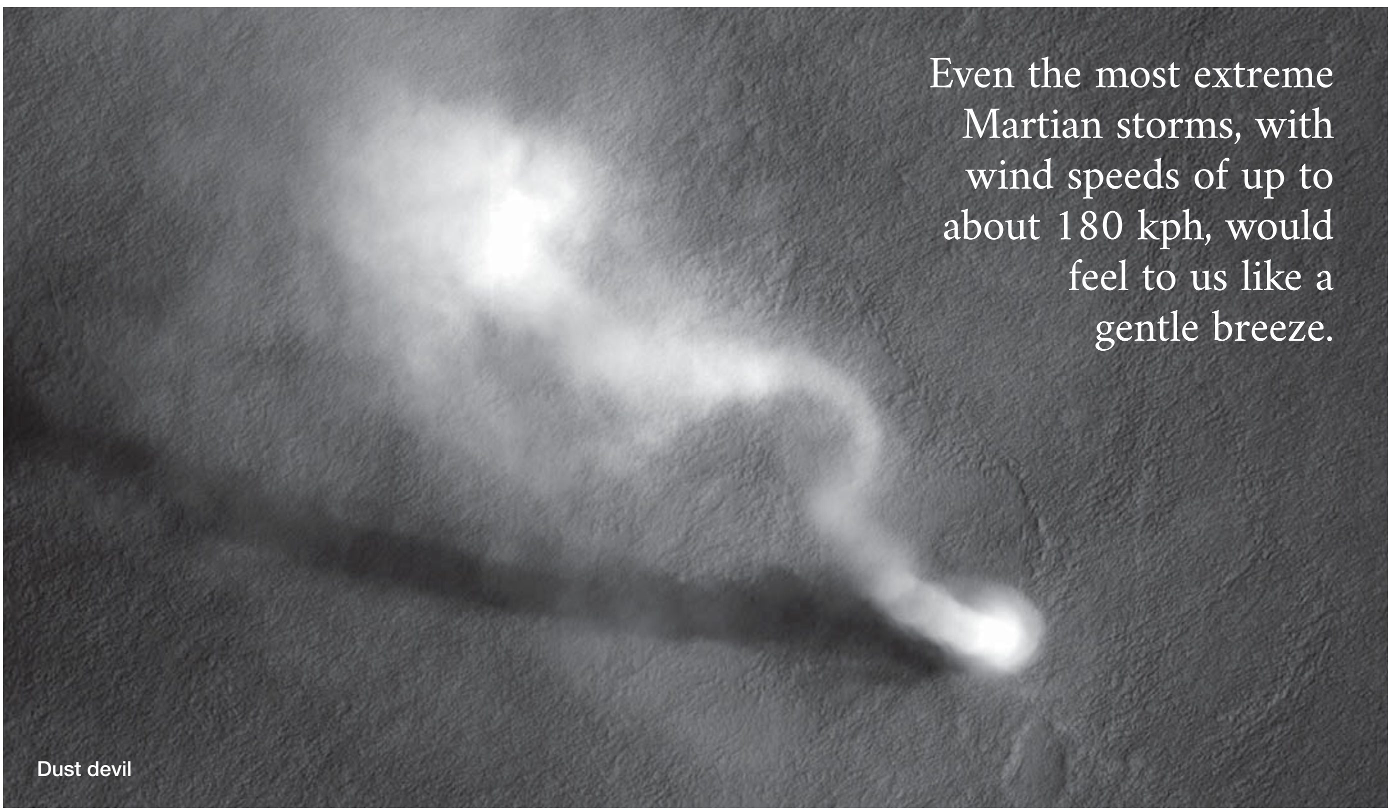
Despite some superficial similarities to terrestrial storms, however, Martian storms are significantly different from the kinds of storms that we are used to. For example, even though the planet's dust devils and dust storms can spin or move across the surface with hurricane-like wind speeds, the *force* exerted by those winds is extremely weak because the planet's atmosphere is so thin. Indeed, even the most extreme Martian storms, with wind speeds of up to about 180 kph (112 mph), would feel to us like a gentle breeze of around 21 kph (13 mph).

That might disappoint those of us who imagine our neighboring planet's tempests clobbering the surface like in the famous sandstorm scene early in the movie *The Martian*. Although the storm provided a dramatic introduction to the film's compelling "human vs. nature" theme, it's actually pure fiction. Rather than fighting intensely blowing sand and flying debris ripped off their habitats, astronauts like Matt Damon's character, Mark Watney, would instead have experienced something more like fast-moving feathers or dandelion seeds "pummeling" their

**MIDDAY TEMPERATURES ON MARS**

**Astronauts' heads would be about 20° colder than their feet.**




Dust devil

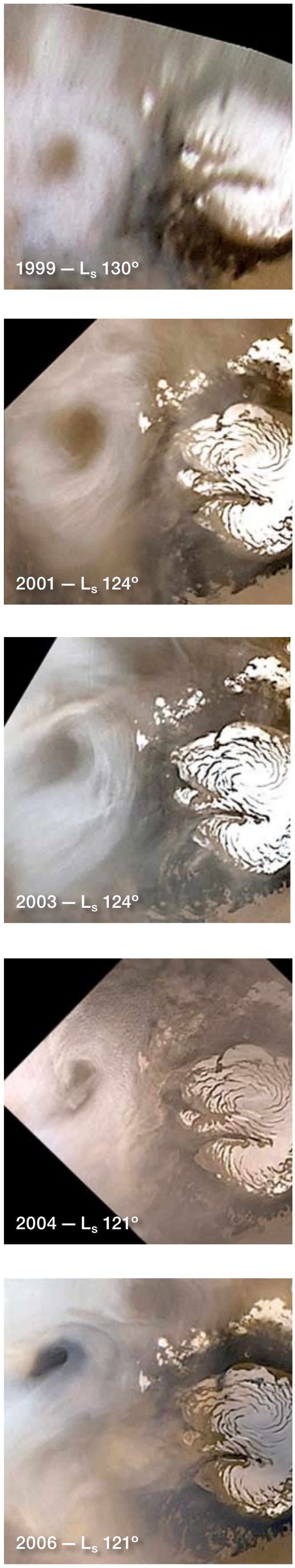
ASTRONAUT ICON: ARTEM KOVYAZIN / THE NOUN PROJECT; MID-DAY TEMPERATURES: TERRI DUBÉ / *S&T*; DUST DEVIL: NASA / JPL / MSSS spacesuits. That kind of meteorological reality would probably not have been as popular with Hollywood or moviegoers.

## Time After Time

Nonetheless, even though the forces exerted by the winds are weak, they can have dramatic effects on the planet's weather, as well as on the surface itself. Martian storms are persistent and highly repeatable from sol to sol, season to season, year to year — and probably over the hundreds of millions to few billions of years that the planet's environmental conditions have been comparable to what they are today.

Scientists have been able to monitor the weather on Mars for centuries using Earth-based telescopic observations, but only in the past few decades has it become possible to observe weather patterns form, move, and evolve on Mars at a scale comparable to what we routinely get from terrestrial weather satellites. These stunning data sets, which now span nearly a dozen Martian years, come from the wide-angle color photos taken from orbit by the NASA Mars Global Surveyor mission's Mars Orbiter Camera (MOC; from 1997 through 2006), and then the Mars Reconnaissance Orbiter spacecraft's Mars Color Imager (MARCI; still active since 2006). MOC and MARCI researchers have created daily global maps of atmospheric storms and surface albedo changes nearly continuously for almost 8,000 sols — an unprecedented record that has finally laid bare numerous secrets about the weather on Mars.

For example, time-lapse imaging over more than a Mars-decade has revealed that, as on Earth, there are specific *storm tracks* that fronts and weather systems take as they move across the planet. Among the most commonly traveled paths is a track that begins in the north polar region and extends southward along the dark region known as Acidalia Planitia, not far from the Mars Pathfinder landing site. Another storm track runs through the Utopia Planitia region, not far from the Viking 2 landing site. Several other common north-south paths have also been discovered. They all appear to be at least




▶ **DÉJÀ VU** In five successive northern summers, a water-ice cloud formed off the polar cap. The cloud appeared at about the same time of year (in solar longitude, $L_s$) and at the same location each year.

M. C. MALIN ET AL. / *MARS* 2010

**As on Earth, there are specific "storm tracks" that fronts and weather systems take as they move across the planet.**

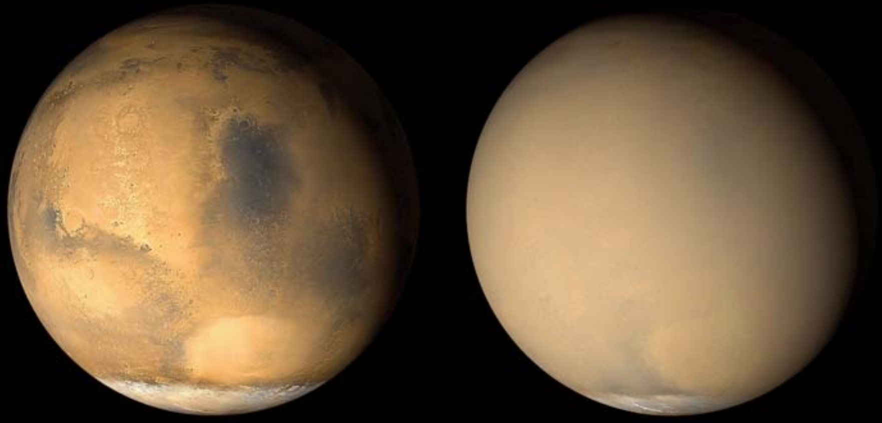
partly associated with winds intensified by two phenomena: temperature differences between bright polar ice caps and dark ice-free surface regions, and topographic differences between large low-lying basins and surrounding highland terrains. The paths taken by storms traveling south along these northern hemisphere tracks eventually cross the equator, where they begin to fan out and move in more east-west directions, partly because the terrain in the southern hemisphere is generally higher and more rugged compared to the northern one.

In general, the weather on Mars appears much more repeatable and much less chaotic than the weather on Earth. Remarkably, many of the same kinds of local storms occur in the same places and at the same times of year from Martian year to Martian year. For example, several times we've observed dust storms forming within the same part of the Valles Marineris canyon system at *almost precisely* the same time each year. Likewise, vortex-like storm systems of thin water-ice clouds peel off the north polar cap on nearly the same dates during each year's northern summer. This kind of repeatability is unprecedented on our planet — it would be like the same storm starting at exactly the same place on Earth on exactly the same day, every year.

## Dust Storm Season

Another discovery from decades of weather satellite observations is that, for the smaller-scale storms, there really is no such thing as a general "dust storm season" on Mars. The concept was proposed in the mid-20th century based on Earth-based telescopic observations, which of course could only detect and monitor the largest storms on Mars, and then only for the part of the Martian year when the planet was closest to Earth. Monitoring the Martian weather up close, however, has revealed that there are dust storms on Mars essentially *every sol*. Some of them form from winds coming off the

The trigger for global dust storms on Mars is still a mystery.



**GLOBAL STORM** These images from the Mars Global Surveyor orbiter show a 2001 regional dust storm in the basin Hellas *(left, basin is bright oval feature)* that within a few days exploded across the planet, ultimately veiling the planet in dust *(right)*.

NASA / JPL / MSSS

polar caps and traveling along storm tracks, lifting dust as they brush across the surface. Others form more locally, as winds move across hills or canyons and become turbulent, or as warmer air rises out of craters or cooler air descends down mountain flanks.

The combined MOC and MARCI observational record shows that smaller dust storms frequently merge into larger regional storms. However, we still don't fully understand what occasionally causes them to merge into even larger hemispheric or truly global dust storms that shroud the surface from telescopic and orbital view and blot out the surface's view of the Sun.

Astronomers observed many such enormous storms in the 19th and 20th centuries; among the more recent ones are those in 1971 just before NASA's Mariner 9 spacecraft went into orbit, in 1977 during the Viking Lander missions, in 2001, and in 2007. The most recent global dust storm on Mars began in June 2018 and lasted for several months, turning daytime into night in the skies above NASA's solar-powered rover Opportunity and ultimately killing that robot after more than 14 years of successful operations on the Red Planet (*S&T:* Sept. 2019, p. 24).

As with the regional storms, the trigger for global dust storms on Mars is still a mystery. What we do know is that, unlike for smaller storms, there *is* a preferred season for the largest ones: Most occur during the "heat" of southern summer. The timing indicates that the increased energy of the southern summer's more intense sunlight fuels these enormous tempests. However, just like for hurricane season on Earth, there are also relatively chaotic local to regional effects from the atmosphere and surface that frustrate global dust storm forecasting. It's not yet possible to predict exactly how many large dust storms will occur each Martian year, or even whether a global-scale storm will occur at all.

On a smaller scale, the important weather factor that appears to initiate many of the dust storms on Mars is the *wind stress*, a drag exerted on the surface by the passing wind. If the wind stress is above a certain threshold, the wind can lift the tiny (smoke-size) grains of dust that cover the high albedo regions of the planet, keeping that dust airborne for weeks or even months at a time. In fact, the famous reddish sky of Mars photographed by landers and rovers is evidence that there is *always* some dust suspended in the Martian atmosphere. The oxidized iron in the dust grains absorbs most of the sunlight's blueish wavelengths and scatters its reddish ones, giving the Martian sky its distinctive tan hue. Indeed, if there were no dust in the atmosphere, the sky would be dark blue or perhaps even black (comparable to being on the Moon) because the atmosphere is so thin.

The airborne dust also gives Mars its distinctive blueish sunrises and sunsets. When the Sun is low in the sky, its light has to pass through much more of the atmosphere to reach a rover's cameras than it does at other times of day, and many more of the redder hues of sunlight are scattered away. Changes in the amount of dust in the Martian atmosphere determine how blue the sunrise or sunset is — an ironic and visually stunning contrast to the varying blushes of sunrise and sunset on our own planet. Dust is not only a key part of Mars's weather, it is a key part of Mars's character.

## Long-Term Forecast

Just like on Earth, the distinction between *weather* (day-to-day environmental and meteorological phenomena) and *climate* (decades- or centuries-long weather trends) is crucial to understanding Mars. Surface, atmospheric, and satellite observations of the Red Planet are helping us to measure the sol-to-sol weather as well as to learn about long-term climate changes. Although Mars's climate is now far less volatile than Earth's, there is ample evidence in the geologic and atmospheric record that the planet's environment wasn't always the way it is today. Early Mars was much warmer and much wetter (*S&T:* July 2018, p. 14). Roughly 3½ billion years ago, this climate gave way to one influenced by widespread volcanism and episodic seas of water, then glaciers. Today's frozen desert is the result of this eons-long climatic evolution.

The evolution is currently at a standstill. The Martian climate will not change drastically in the near future — at least, not without help. Futurists have suggested that we might eventually be able to change the environment of the Red Planet by adding more heat-blanketing greenhouse gases to thicken its atmosphere, until the day-to-day weather and long-term climate match Earth-like conditions. However, such *terraforming* would take centuries to millennia, if not longer. Some researchers estimate that there is not enough $CO_2$ locked up in ice and rocks on Mars to even make it possible.

So if we want to send people to Mars in the much nearer future, we will have to find a way to live on the Red Planet the way it is, in all its stark, deadly beauty. The detailed understanding of Martian weather that is coming from recent and current robotic orbiters, landers, and rovers will become part of the common wisdom and daily reality of life for the first human settlers on the Red Planet. And perhaps they will be the ones who — spacesuited-up in layers to deal with the enormous daily swings in temperature, chipping away at the last of the long winter's dry ice, and battling (gentle) occasional dust storms — will uncover the deeper secrets still preserved on the Red Planet.

**VALLES MARINERIS** The Viking 1 orbiter took this composite image of a cloudy afternoon over Valles Marineris, the largest canyon system in the solar system.

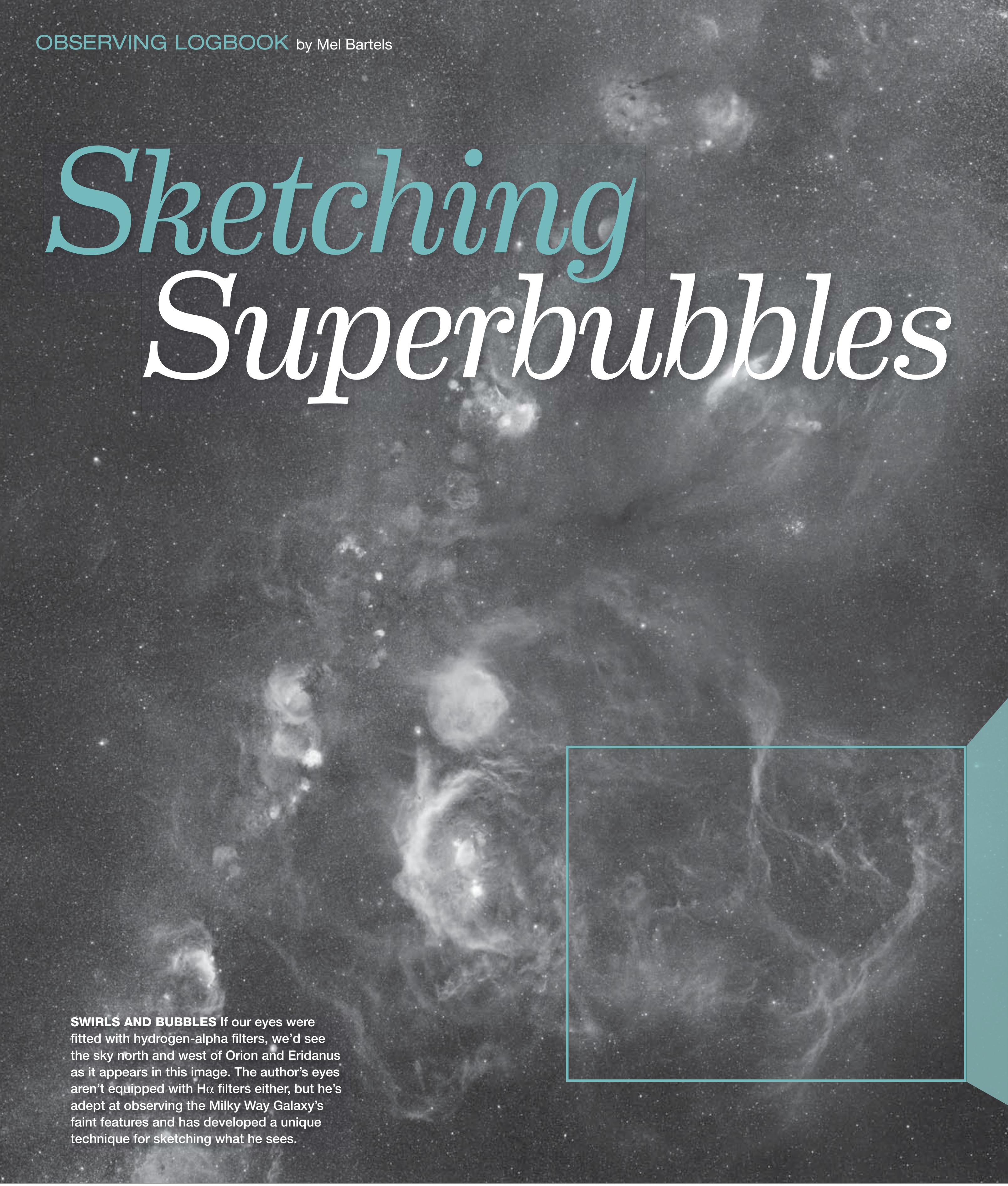
**JIM BELL** is an astronomer and planetary scientist at Arizona State University and the president of The Planetary Society. He has been a member of the Pathfinder, Spirit, Opportunity, and Curiosity Mars surface mission teams and leads the Mastcam-Z camera investigation for the upcoming Mars 2020 rover.

**Keep up with the latest scientific results about Mars with the Red Planet Report: redplanet.asu.edu.**

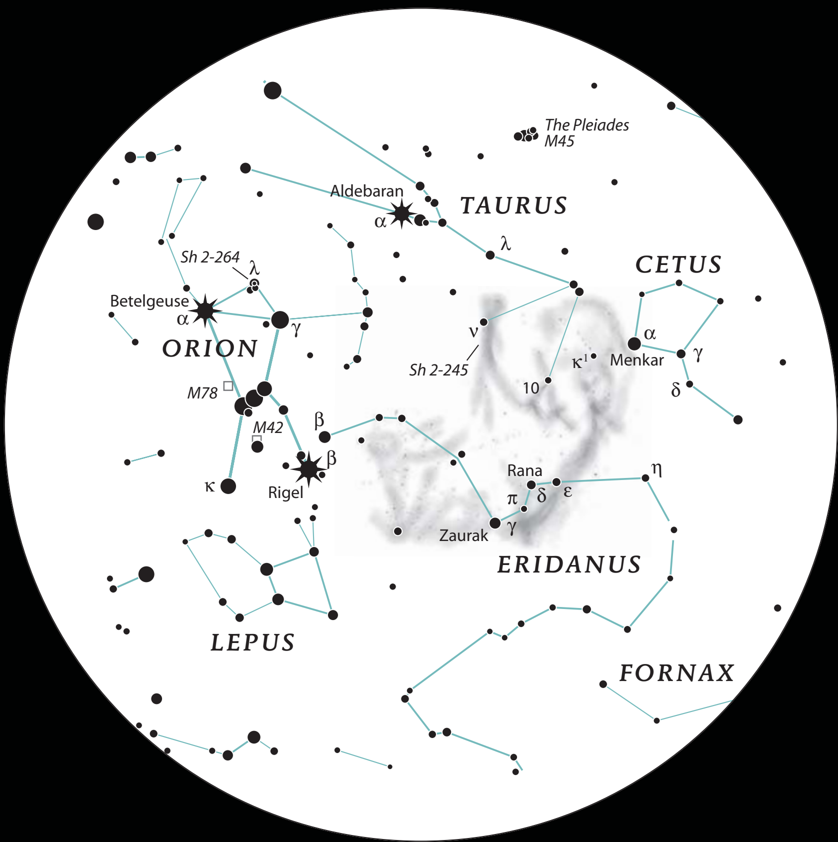
**BLUE SUNSET** The Mars Exploration Rover Spirit captured this sunset over the rim of Gusev Crater in 2005.

VALLES MARINERIS: NASA / JPL / USGS / JUSTIN COWART / CC BY 3.0; SUNSET: NASA / JPL / TEXAS A&M / CORNELL by Mel Bartels

# *Sketching Superbubbles*



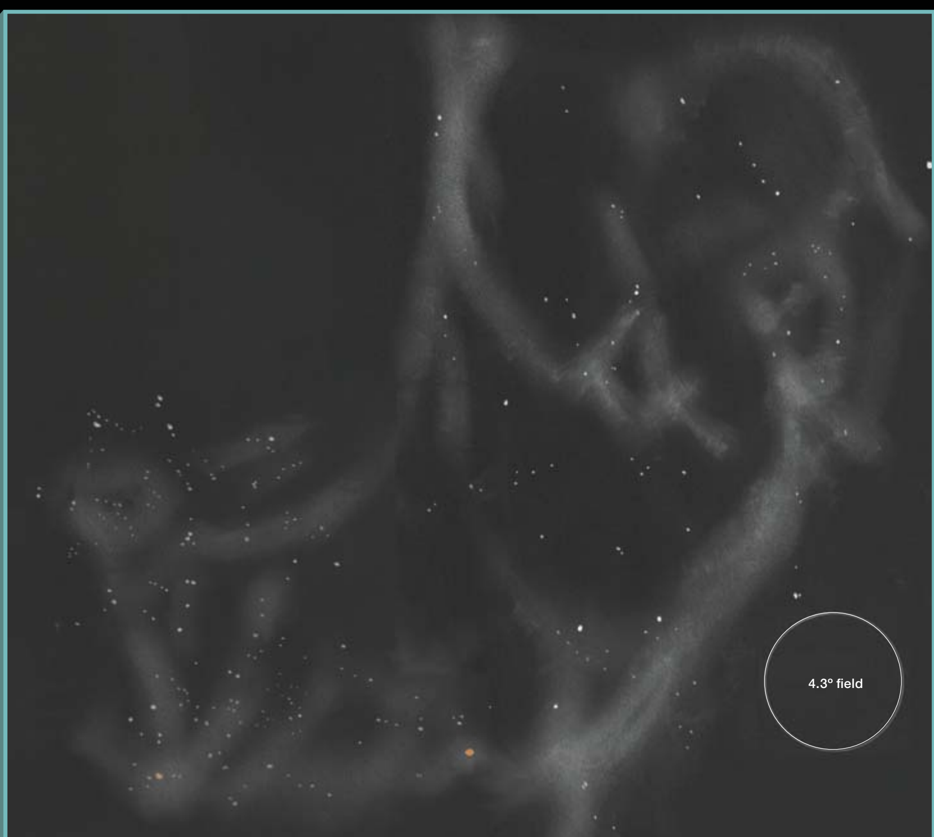
**SWIRLS AND BUBBLES** If our eyes were fitted with hydrogen-alpha filters, we'd see the sky north and west of Orion and Eridanus as it appears in this image. The author's eyes aren't equipped with H$\alpha$ filters either, but he's adept at observing the Milky Way Galaxy's faint features and has developed a unique technique for sketching what he sees.




Drawing what you see through the eyepiece adds another layer to your observing experience. Join the author as he explores the Orion–Eridanus Superbubble region, sketchpad at the ready.

A great night stays with you forever, long after ordinary good nights fade away. On the night in question, afternoon clouds earlier in the day had lowered my spirits, but a clearing twilight later raised them. I didn't need an SQM, or sky quality meter, reading to tell me that sky conditions were sterling: The winter Milky Way and zodiacal light were intense.

I grabbed my 6-inch (15-cm) f/2.8 telescope with a 4.3° field of view and pointed it at my target: the vast Eridanus Superbubble west of Orion. I warmed up on the Orion Nebula (M42) then pushed over to the Horsehead Nebula to test sky conditions. Whoa, I could see the Horsehead without need for a filter, and the Flame Nebula (NGC 2024) appeared sizeable. I scanned northward to check out the Lambda (λ) Orionis Ring, Sharpless 2-264. The edge was bright and curved in the wrong direction. Oh, I was seeing the northern reach of Barnard's Loop and it was obvious! I traced the Loop to the east and found M78 floating brightly in a sea of smoky nebulosity, then continued tracing the Loop as it arced below M42. Transparency was the best it had been in months.




◀ **THE ORION–ERIDANUS SUPERBUBBLE** The sketch at left covers an area about 30° × 25° and corresponds to the box in the image on page 30. It's also reproduced in the chart above. It took the author more than three years to produce this sketch, which he assembled as a mosaic from a series of multi-field sketches as described in the text. The circle represents his 6-inch telescope's 4.3° field of view.

HYDROGEN-ALPHA SKY IMAGE: MDW SKY SURVEY; CHART: GREGG DINDERMAN / S&T; SKETCH: MEL BARTELS

## The Project Begins

My first quarry of the night was Sh 2-245. Digital images of Sh 2-245 suggest that this nebula is a tad dimmer than Sh 2-264, the one that envelops Lambda Orionis, and Barnard's Loop. Since I'd also viewed these latter two with my 13-inch (33-cm) f/3.0 telescope with 1.8° field of view with some margin to spare, I had hopes for Sh 2-245. Of course, one never knows — sometimes the object is visible and at other times it just can't be seen.

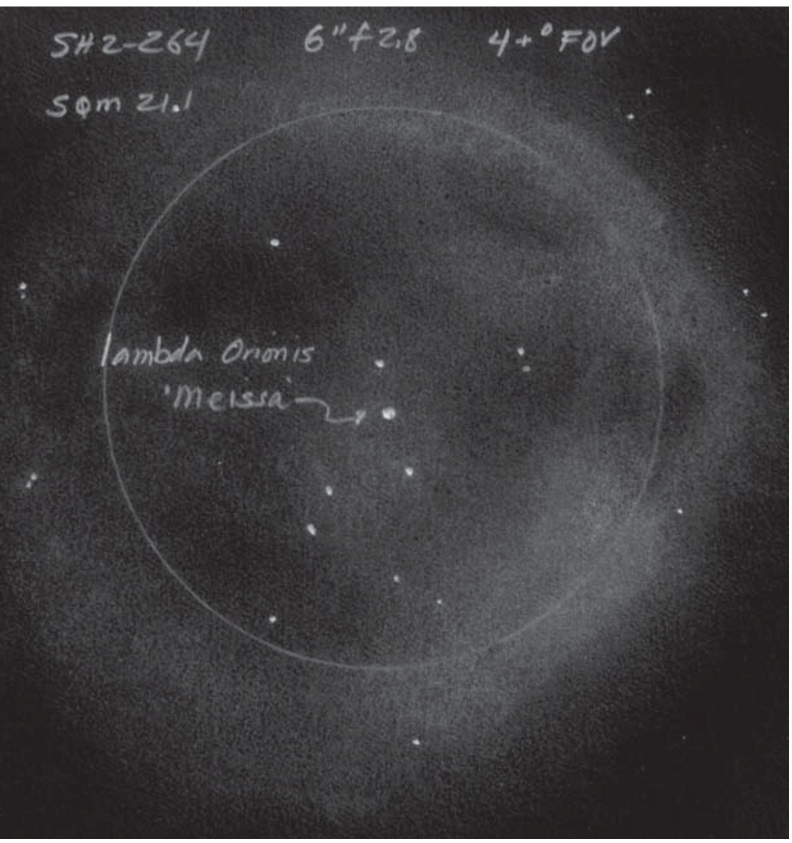
Finding Sh 2-245, also known as the Fishhook Nebula, was one of the easiest star-hops I've come across. Nu (ν) Tauri is an easy hop from the Hyades open cluster. It has a companion star that's not visible to the unaided eye. A little less than 3° below Nu (as seen in my telescope) is a fainter pair next to a 5.3-magnitude star (HD 25621). I aimed my 13-inch at the fainter pair, which according to deep digital images was adjacent to the brightest portion of Sh 2-245. There it was! There was the nebula! Instantly visible as a bright streak, there was no need for averted vision or careful studying of the field until whatever nebulosity present slowly came into view.

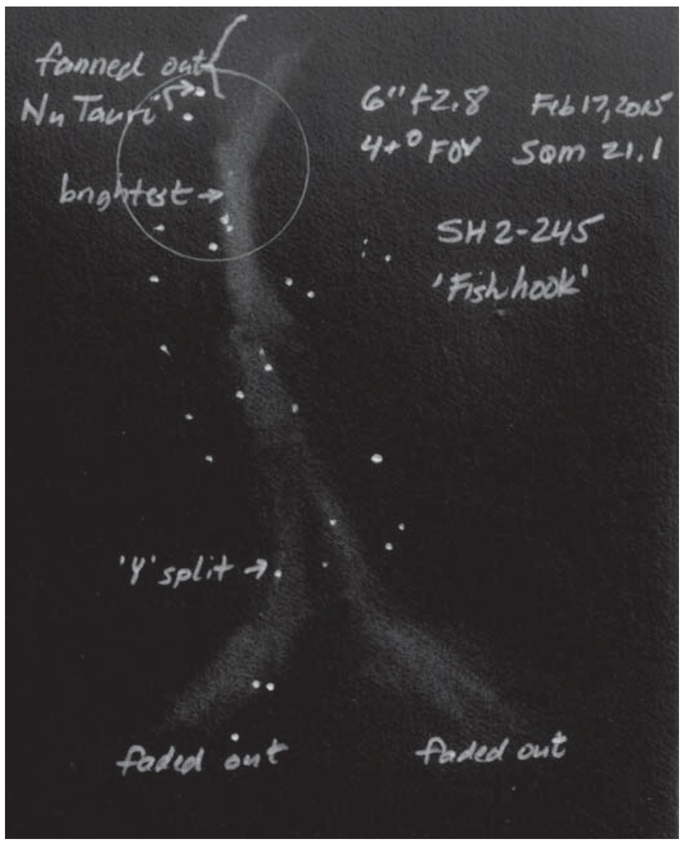
I returned to the 6-inch and was rewarded with an obvious streak, though not as bright. I followed the streak northward as it expanded in width, and then followed it southward for about 10°. Dimmer but still visible, I could trace the nebula through a split that looked like a Y. The eastern end faded into the background, while the western end faded into the zodiacal light.

# Sketching

I sketch to record my observations, what I see in the eyepiece. There's surprising variety in the visual appearance of astronomical objects across types and sizes of telescopes, and even across the eyepieces we carry in our telescope cases. Throw in filters and changing sky conditions and that image of the Dumbbell Nebula (M27) will look quite different, much as processing results in dramatically different images of the Dumbbell depending on the narrative that the imager wishes to tell. The process of sketching — how I go about each drawing, the tools I use, pencils and stumps — also influences the story I'm telling. Oftentimes stars are critical to the view, so I'll position them precisely, recording as many as I can manage. Sometimes, though,

▼ **BIT BY BIT . . .** Sketching a structure the size of the Orion–Eridanus Superbubble doesn't happen overnight. The author builds the master sketch by observing and sketching various features and then combining them in a final redrawing of the whole. Below at left is Sh 2-264 and at right Sh 2-245, the Fishhook Nebula.




MEL BARTELS (4)

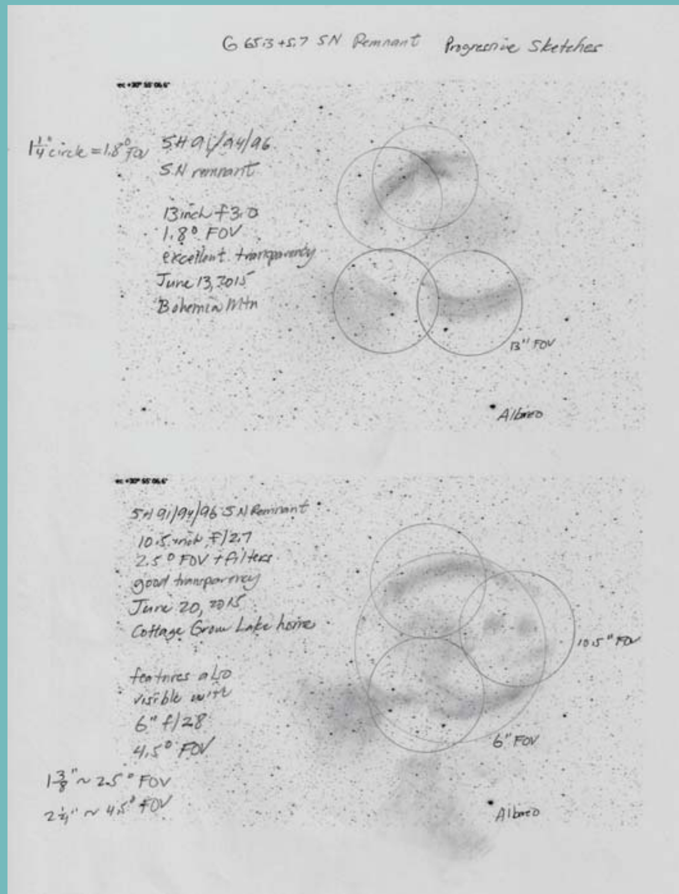
# Techniques

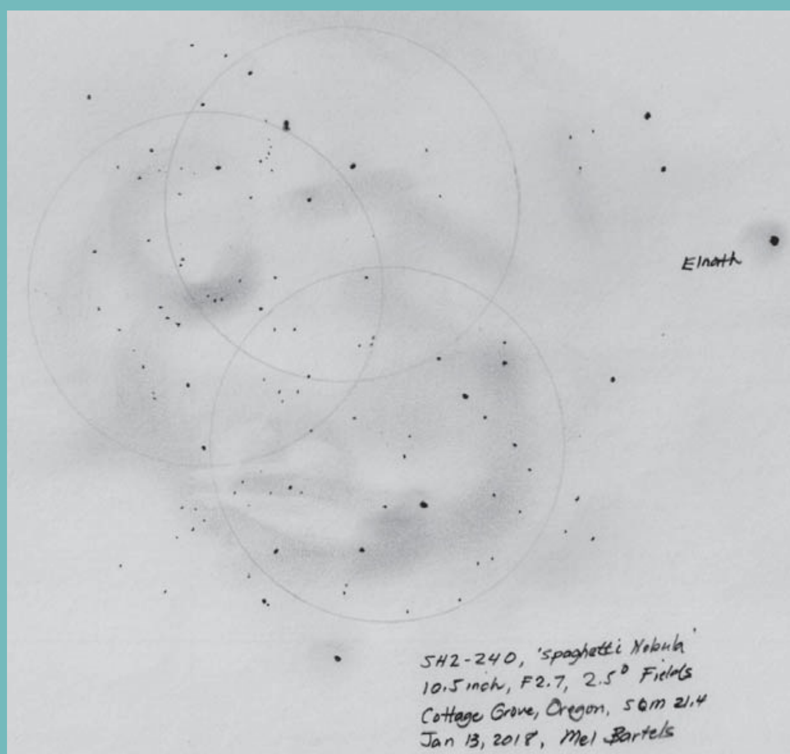
when stars aren't important, I'll only draw the asterisms that catch my eye as landmarks.

I enjoy the tremendous luxury of observing from my driveway under dark skies. I plan extensively for the night's action in order to maximize my time at the telescope. Since I don't need to drive any distance to set up, my observing sessions tend to be intense affairs. Although I do some quicker sketching at star parties, I find interruptions when working on my larger projects distracting. It reminds me of earlier days when one had to manually guide long-exposure astrophotographs.

Before I start multi-field drawings, I create a PDF of the star field with key stars and asterisms marked. This allows me to readily draw any broad nebulosity that spans many fields when I move my scope back and forth across the star field in sweeps.

To illustrate my technique, at right are two examples that show how my sketches develop. At top is a series of progressive sketches of the supernova remnant SNR G065.3+05.7. The circles represent my telescopes' fields of view: I used my 13- and 6-inch, as well as my 10.5-inch (27-cm) f/2.7 with 2.5° field of view. My drawing shows how each telescope contributes specific detail. At bottom is a sketch of three overlapping drawings of the supernova remnant Sh 2-240 (Simeis 147), known more whimsically as the Spaghetti Nebula, that straddles the border between Auriga and Taurus. The supernova from which this remnant sprang is thought to have occurred 40,000 years ago. It's considered a difficult observation due to its low surface brightness. Nonetheless, filamentary structure is visible in a circular shell. For sketching, I used my 10.5-inch telescope. Ahead of time, I printed out only a backdrop of stars and identified the key ones to use as markers. Outside, under the stars, I swung the telescope back and forth between the key stars to delineate the area to sketch, and then began filling in the sketch one field at a time. I also work on successive multi-field sketches to catch more of the faint nebulosity.



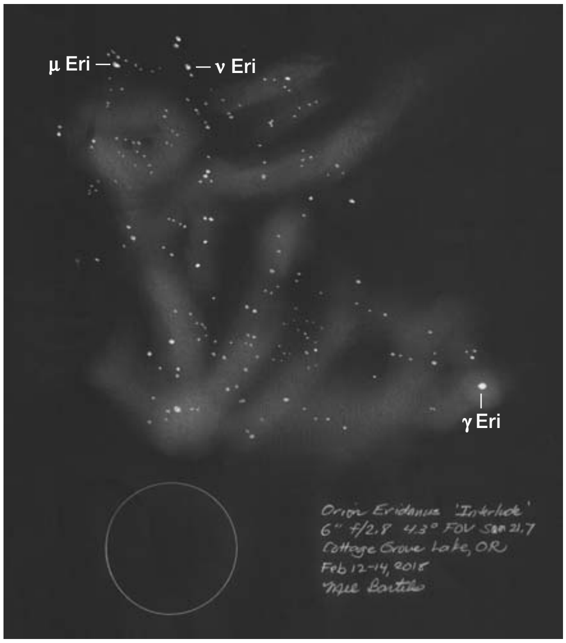



## The Superbubble

I began sketching the **Eridanus Superbubble** three years ago, concentrating on the brighter eastern side, where Sh 2-245 resides. In researching how to tackle the western side, I carefully selected four anchor stars from which to begin my explorations: Alpha (α) Ceti (Menkar), the southeast corner of Cetus's head; 10 Tauri to the east; Delta (δ) Eridani (Rana) to the south; and Gamma (γ) Eridani (Zaurak) to the extreme southeast.

I settled on Menkar and then slid half a field to the east. At that moment I knew I had the beginnings of a memorable night: The Eridanus Superbubble was immediately noticeable, and with good detail. In fact, there was so much relatively bright nebulosity to concentrate on that I opted not to track down the faint stuff. Particularly beautiful were the "Leaping Man" south of Rana, dark nebulae near 10 Tauri, the Y and X south of 10 Tauri, chaotic filaments southeast of Menkar, and the lacy great oblong area leading to 1 Eridani, southeast of Cetus. The brighter sections were obvious and easy, just a little fainter than Barnard's Loop; the fainter portions were about as bright as IC 434, the nebula associated with the Horsehead, but easier to see because of their larger scale. To the extreme western (left) edge of my final sketch on page 31 lies an interesting circular region of nebulosity and dark nebulae begging to be investigated with greater aperture and scale.

For sketching, I began by selecting two anchor stars — in this case they were Menkar and 10 Tauri. I centered on Menkar, then practiced sweeping to 10 Tauri and back. I verified that I crossed Kappa[1] (κ[1]) Ceti and its handle of three stars to the northeast.




**. . . BY BIT** This sketch of the area southwest of Orion that the author calls the "Interlude" was combined with the multi-field sketch of the central portion of the Eridanus Superbubble to create the final sketch on page 31.

I then penciled in the nebulosity, noting brightness, sharpness of edges, and shape. After that, I moved on to the next destination star or asterism, practiced sweeping back and forth, and recorded my observations. Following a number of sweeps, each encompassing many degrees of field of view, I gradually built up a sketch of the 15° × 20° Superbubble. When I was satisfied that I was finished, I compiled a final sketch, using my field sketches and notes accumulated over the three years of this project.

What greatly helped me with the Superbubble is that I've developed a super-wide-field observing technique that dissolves the eyepiece's field stop. It's critically important to properly position my eye with respect to my lowest-power eyepiece, which has a 100° apparent field of view. My eye executes a slow stop-and-go dance across the field, a combination of purposeful movements and focusing on interesting detail that catches my attention. This allows me to ferret out brighter and darker areas and their boundaries. Tighter eye movements yield smaller and more detailed detections. For very large objects, I move the scope back and forth. The eyepiece's field stop seems to disappear; at the same time, I perceive a much larger field of view. This "shakes loose" difficult, larger-scale objects.

It's funny where a great night takes you. I undertook a quest for new super-vast, wider-angle telescopes to see supernova remnants as never before. Then I found myself devising new observing techniques to capture the entire supernova remnant. Now when I look through the eyepiece, I instinctively move my eye to and fro and move the telescope back and forth, rendering the field stop invisible and opening up the sky to my imagination. Where will my pursuit take me next?

## Superbubbles in Space

The Orion–Eridanus Superbubble is a series of nested shells 1,200 light-years in size, likely generated by stellar winds and episodic supernova explosions 10–15 million years ago in the Orion OB 1 association (which consists of stars that belong to Orion's Belt, Sword, and Nebula, and stars to the Belt's northwest). It lies in the Orion Arm, a minor spiral arm of the Milky Way, the same one in which our Sun resides. Previously thought to be part of the outer wall of the Superbubble, recent findings suggest that Barnard's Loop might be a supernova remnant within the Superbubble.

During the day **MEL BARTELS** manages a software development team. On moonless clear evenings, he scans the skies with handcrafted richest-field telescopes. Visit Mel's homepage to read more about his observations and telescope making: **bbastrodesigns.com**.

**FURTHER READING:** See the October issue, page 20, for details on the MDW Sky Survey. For more on Mel Bartels's sketches of galactic cirrus, see Going Deep in the April 2019 issue.

MEL BARTELS

LEAH TISCIONE / *S&T*

Here's how to avoid buying an expensive doorstop.

# Hobby Ki

Every January my astronomy club hosts a workshop in which we help people learn how to use the telescopes they got for the holidays or tune up scopes that have been gathering dust in closets. And every year we face the same problem: how to gently tell some of them that what they've got is better suited for a boat anchor than for astronomy.

It may be hard to believe, but some telescopes are worse than having no scope at all. When you want to enjoy a night out under the stars, you're better off with a pair of binoculars or just with your naked eyes than with a telescope that can't be aimed easily and doesn't show a pleasing view of whatever you do manage to point it at. I've watched people spend all night trying to find something, *anything*, to look at, often spending their entire time fiddling with the scope rather than observing the sky. It only takes a couple of nights like that for a person to decide that astronomy isn't any fun — thus the term "hobby killer."

As with so many other things in life, education can help you avoid making frustrating mistakes. If you're a beginner, a few minutes reading this article before you buy a telescope can save you a lot of disappointment later. Making an informed choice can get you a scope that will provide you with many years of enjoyment.

So what makes a hobby killer? Many factors add together to make a lousy overall package. Chief among them are aperture, eyepieces, and the mount.

## Aperture

A telescope's primary job is to gather light and squeeze that light down into a small beam that it directs into your eye. It stands to reason that the more light you gather, the more you can see. So in general, the bigger the aperture (the diameter of the objective lens or primary mirror) the more useful the scope. That's true up to a point, but if you buy a scope that's too big and unwieldy, it could become a hobby killer simply because it's too difficult to take outside and set up. What you want is the right-size scope for your interest level and ability.

Anything below about 3 inches (76 mm) in aperture is likely to be too small to provide a pleasing view of anything more than the Moon and a few bright star clusters. Small scopes tend to be low-quality, too, with uncorrected objective lenses that display color fringing around bright objects and often won't even come to sharp focus. So as a general rule, stay above three inches in aperture. There are, of course, some very high-end small scopes, mostly optimized for astrophotography. The price tag will tell you which is which.

Most small hobby killers tend to be refractors (with an objective lens in front) rather than reflectors (with a mirror at the bottom). Mirrors are easier to make than lenses, so within any particular price range reflectors tend to be larger. So a typical low-end reflector will be 4″ or so in diameter. A very common size is 4.5″, and 4.5″ is plenty of aperture for a first scope. You can see hundreds of objects with a good 4.5″ scope.

The key word is "good." There are rotten reflectors as well as rotten refractors. What makes a reflector good? Most

# llers

important: Is the primary mirror parabolic or spherical? A spherical primary is cheaper to make but provides a less pleasing view. You can get away with a spherical mirror if the focal ratio is "slow" enough, say f/8 or more (i.e., the focal length of the scope is 8 times the diameter of the mirror), but even then a parabolic mirror will work better. If a manufacturer of a low-end telescope goes to the trouble to parabolize the primary mirror, then odds are it's a reasonably good telescope.

There's one design you should avoid at all costs: the "Bird-Jones" reflector. The Bird-Jones design uses a spherical primary, and a fast one at that, in an attempt to keep the tube shorter than average. Manufacturers of this design correct for spherical aberration and increase the focal length

**KILLING THE VIEW** While this scope may look pretty good, its equatorial mount, lousy finder, 60-mm aperture, 0.965″ eyepiece, and 3× Barlow make it a hobby killer.

**HARD TO HANDLE** Even a great scope can be a hobby killer if it's too difficult to carry.

UNLESS OTHERWISE NOTED ALL IMAGES COURTESY OF THE AUTHOR by placing a corrector lens at the inner end of the focuser. The corrector lens is supposed to make everything all right again, but it never does. The view through every Bird-Jones scope I've ever looked through has been uniformly awful. There might be a decent Bird-Jones telescope somewhere out there, but if there is, I've never seen nor even heard of it.

## Eyepieces

In the early days of telescopes, eyepieces were single pieces of glass that essentially acted as magnifying lenses that let you examine the image created at the focal plane by the objective lens or primary mirror. Modern eyepieces do the same job, but they use many more lens elements to correct for color fringing and other optical aberrations.

Different designs of eyepiece give you different fields of view. Some, such as the Orthoscopic design, are like looking through a soda straw, while other exotic wide-field designs are like sticking your head into the bubble-shaped observing port on the International Space Station.

Guess which kind you get with a hobby killer? Most of them come with "Huygens" eyepieces, which were state of the art when Christiaan Huygens invented them . . . in the 1660s. We've advanced a bit since then. You want at least Kellners, or better yet, Plössls. Plössl eyepieces are probably the best value you can get in an inexpensive eyepiece.


▲ **COMMON FORMATS** Avoid scopes that use 0.965″ eyepieces. *Left to right:* 0.965″, 1¼″, and 2″ eyepieces.

Also beware of teeny-weeny eyepieces. Good eyepieces are either 1.25″ or 2″ format, meaning their barrels are meant to fit into 1.25″ or 2″ focusers. A lot of hobby killers use 0.965″ eyepieces, which are almost always garbage and are hard to replace with better-quality designs due to this size limitation.

## Magnification

You'll want more than one eyepiece, because eyepieces are how you control the magnification of your telescope. You

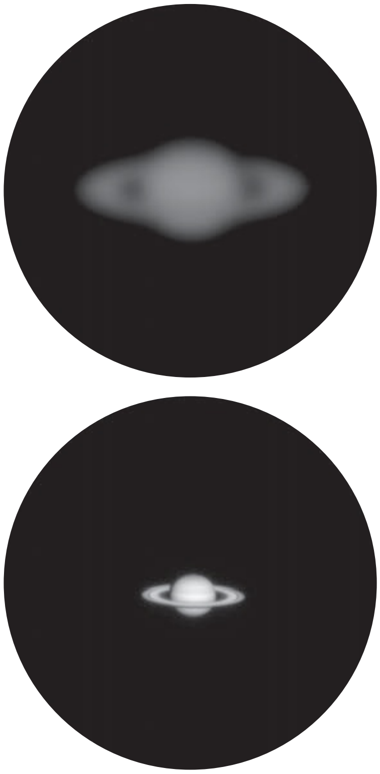
**STARTING OUT RIGHT** The Orion StarBlast 4.5 Astro Reflector Telescope is an excellent starter scope.

**STEPPING UP** A 6″ (seen below) or 8″ Dobsonian is a great step up from a 4.5″ StarBlast.

calculate magnification by dividing the eyepiece focal length into the telescope's focal length. For instance, a 900-mm telescope with a 25-mm eyepiece gives you 36× — (900/25 = 36).

You might think you want the highest magnification possible, but that's not so. The higher the power, the smaller the field of view, which means you'll only see a part of M45, the Pleiades star cluster, or M31, the Andromeda Galaxy. Also, the higher the power, the fuzzier the view. A good telescope lets you reach about 50× per inch of aperture before the fuzziness gets out of hand, so a 3″ scope would let you use 150×, but beyond that you're just magnifying the blur, a phenomenon known as empty magnification. That means a 3″ by 900-mm telescope can use a 6-mm eyepiece, at best — (900/6 = 150).

So there's a clue when you go shopping. Does the ad on the website or on the box tout the telescope's magnification? If it's a 3″ aperture and they're advertising that it will do "675×!!!" they're blowing smoke. Move on.



◀ **REALISTIC EXPECTATIONS** Saturn will look dim and blurry at 400× in a 70-mm refractor. A more modest 200× in a better telescope will produce a much more pleasing image.

Most hobby killers will come with a 4-mm eyepiece, which is nearly useless on its own, but it will also come with a Barlow lens, which increases the magnification of whatever eyepiece you put into it. Most Barlows multiply by 2×, so your 4-mm eyepiece plus Barlow on that 900-mm scope gives you a whopping 450×, or (900/4) ×2. Remembering our 50× per inch rule, you would need a 9″ diameter telescope to use 450× effectively.

What you want for your telescope is a good low-power eyepiece, probably a 32-mm or 25-mm Plössl, and a medium-power eyepiece, around a 10-mm Plössl. You can increase your collection as you gain experience.

## The Mount

This is the real killer. A great scope with the best eyepieces in the world can still become a hobby killer when it's put on a lousy mount.

I'll make an absolute statement here: An equatorial mount is a poor mount for a beginner. Later on, when your hobby has flourished, say you concentrate on planetary observing or have taken up astrophotography, you might happily consider paying tens of thousands of dollars for the best equatorial mount on the planet. But to start out with, equatorial mounts are simply awful. They're difficult to set up, difficult to use, and the cheap ones are shakier than a leaf in a breeze.

Equatorial mounts are not just difficult to use, they're difficult to even comprehend at first. Simply trying to figure out how to orient the thing has killed the enthusiasm of many would-be astronomers.

So don't get an equatorially mounted telescope until you've been in the hobby awhile. Or never: Most observers don't require an equatorial tracking mount.

Altitude-Azimuth (alt-az) mounts are the way to go. For refractors, that means a solid mount on a steady tripod that lets you tilt the scope up and down and swivel it left and right. The scope should move smoothly, and it should stop when you stop pushing without bouncing back and without wiggling. If you tap the end of the telescope tube and it takes more than 3 or 4 seconds to settle down, you don't want that mount.

For reflectors, the Dobsonian mount is the way to go (with one exception: the Orion StarBlast mentioned below). It's basically a cannon mount, and it works like a dream. It's stable, smooth, and intuitive. When John Dobson introduced this mount to the astronomical world back in the 1970s, he made this hobby truly accessible for the first time. See my column on page 72 on how to use Dobson's design to breathe new life into a poorly mounted hobby killer.

## Computerized Mounts

More and more lately you'll find hobby killers that have been computerized. The computer itself doesn't necessarily make it a hobby killer, although it can if the mount is a piece of junk, which most of the truly low-end ones are. It's just that putting a lousy little scope on a computerized mount doesn't make the scope perform any better.

▼ **EMPTY PROMISES** Ads can be deceptive. Don't be fooled by outrageous marketing claims!

**KEEP IT SIMPLE** An equatorially mounted telescope is a poor choice for a beginner.

**LIMITED USE** A 60-mm aperture is too small to provide a good view of much more than the Moon and bright open clusters like M45, the Pleiades.

"No knowledge necessary!" the ads will say. Aside from the fact that most of us get into astronomy to learn stuff, that's seldom true anyway. With a low-end Go To scope (which is what the computerized ones are called), you're likely to learn quite a bit of computer debugging and maybe even mechanical repair skills before you even get your first look through one. Seriously, I have seen people spend their entire night fiddling with the electronics, trying in vain to get the computer to work properly, and never once getting to look at anything in the sky.

On the other hand, a good computerized mount can be an amazing experience. Several manufacturers now build systems that recognize the star field when you power them on and reliably know where to go when you tell them what you want to look at. It's just that these good systems cost a fair amount of money, and you're unlikely to get a good one at a beginner's-scope price.

## Recommendations

There are too many awful scopes out there to name them all. But I can happily name some good ones. Over the years, I've narrowed it down to three I can endorse without reservation:

Since you get more bang for your buck with mirrors, I recommend that your first scope be a reflector. The Orion 4.5 StarBlast Astro Reflector Telescope is a good place to start. It's easy to carry, easy to set up, and easy to use. The Astronomical League and many individual astronomy clubs give these to libraries to loan out to patrons, and the scopes provide great views and survive a lot of use.

If you have a little more money and don't mind a bigger package, go for a 6″ or 8″ Dobsonian. I like the SkyQuest or SkyLine lines, also from Orion, but other manufacturers make good Dobs, too — Meade's LightBridge series telescopes are worth checking out. I recommend a 6″ as a good grab-and-go scope that you won't outgrow right away. If you've got enough muscle to carry something a bit larger, get the 8″ and it'll last you a lifetime. With the Dobs, get a 10-mm Plössl eyepiece to go with the 25-mm that often comes with it.

There are undoubtedly other good beginners' scopes out there. But there's a lot of dreck, too. Pay attention, and try to avoid buying something that you'll never use. If you want to get into astronomy, make sure you get a hobby *starter*, not a hobby killer.

■ Contributing Editor **JERRY OLTION** started with a hobby killer, but fortunately his astronomy club helped nurse his interest back to health.

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**Special thanks to Junia Clark for posing for the photographs.**

# OBSERVING
## December 2019

**1** **DAWN:** Start the month by spotting Mercury and Mars adorning the southeastern horizon before sunrise.

**1** **DUSK:** Saturn, Venus, and Jupiter form a string of pearls some 18° long above the southwestern horizon after sunset. The waxing crescent Moon overlooks the trio of planets from upper left.

**4** **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:18 p.m. EST (7:18 p.m. PST); see page 50.

**10** **DUSK AND EVENING:** Venus and Saturn are less than 2° apart — catch them before they sink below the southwestern horizon. Later on, find the waxing gibbous Moon in Taurus, upper right of Aldebaran.

**12** **DAWN:** Mars has been inching toward Alpha (α) Librae (Zubenelgenubi) in the southeast and on this morning is ¼° or less from the double star.

**13, 14** **NIGHT:** The Geminid meteor shower is expected to peak during the day of the 14th and is normally best viewed on both the preceding and following nights. However, this year the waning gibbous Moon will hide all but the brightest meteors; see page 48.

**17** **MORNING:** The Moon, almost at last quarter, is in Leo, some 3° to 4° from the Lion's heart, Regulus.

**20** **MORNING:** The waning gibbous Moon, now in Virgo, is around 5° from Porrima and about twice that distance from Spica.

**21** **THE LONGEST NIGHT OF THE YEAR** in the Northern Hemisphere. Winter begins at the solstice at 11:19 p.m. EST (8:19 p.m. PST).

**24** **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 9:02 p.m. PST.

**26** **DAYTIME:** A closer-to-apogee Moon passes in front of the Sun, giving rise to an annular eclipse visible from parts of the Middle East, southern India, and Indonesia; see page 49.
— DIANA HANNIKAINEN

▲ The December Sun rises behind the Temple of Poseidon near Sounion in southern Greece.
ANTHONY AYIOMAMITIS

# Lunar Almanac

# Northern Hemisphere Sky Chart


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

NASA / LRO

## MOON PHASES

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

| FIRST QUARTER | FULL MOON |
|---|---|
| December 4<br>6:58 UT | December 12<br>5:12 UT |

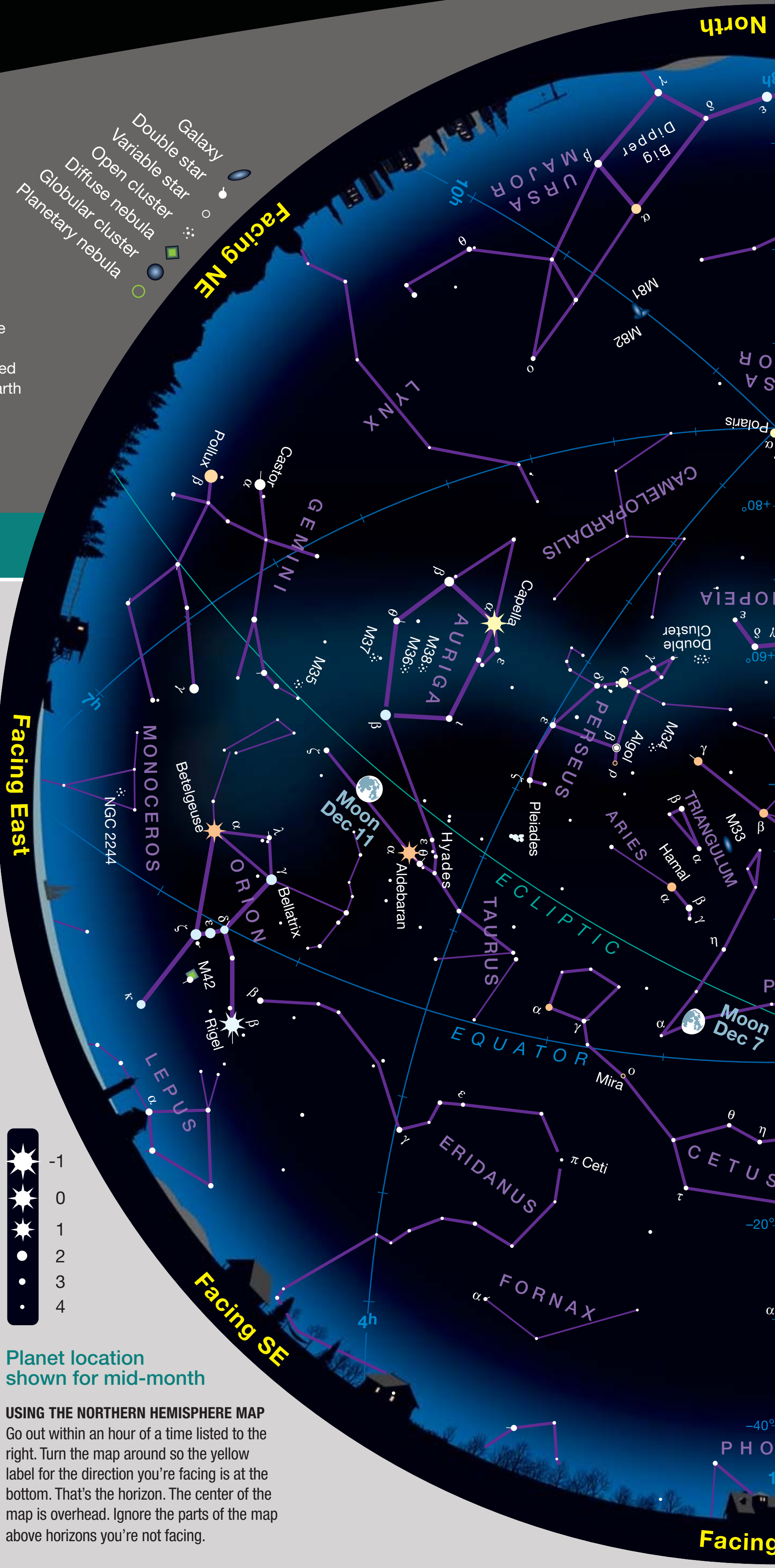
| LAST QUARTER | NEW MOON |
|---|---|
| December 19<br>4:57 UT | December 26<br>5:13 UT |

## DISTANCES

| | |
|---|---|
| Apogee<br>404,446 km | December 5, $04^h$ UT<br>Diameter 29′ 33″ |
| Perigee<br>370,265 km | December 18, $20^h$ UT<br>Diameter 32′ 16″ |

## FAVORABLE LIBRATIONS

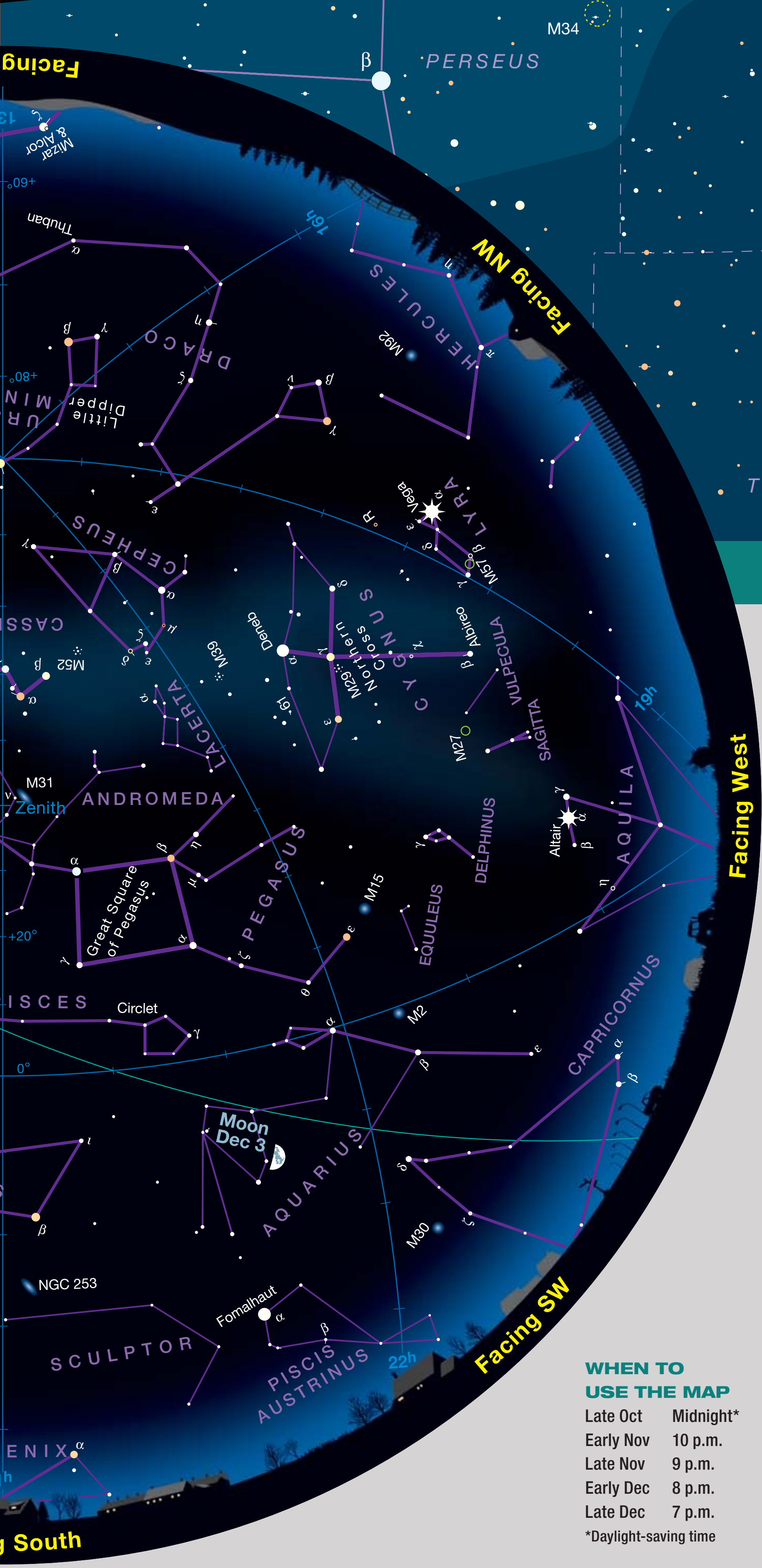
| | |
|---|---|
| • De Sitter Crater | December 5 |
| • Von Braun Crater | December 12 |
| • Lacus Autumni | December 14 |
| • Gauss B Crater | December 30 |

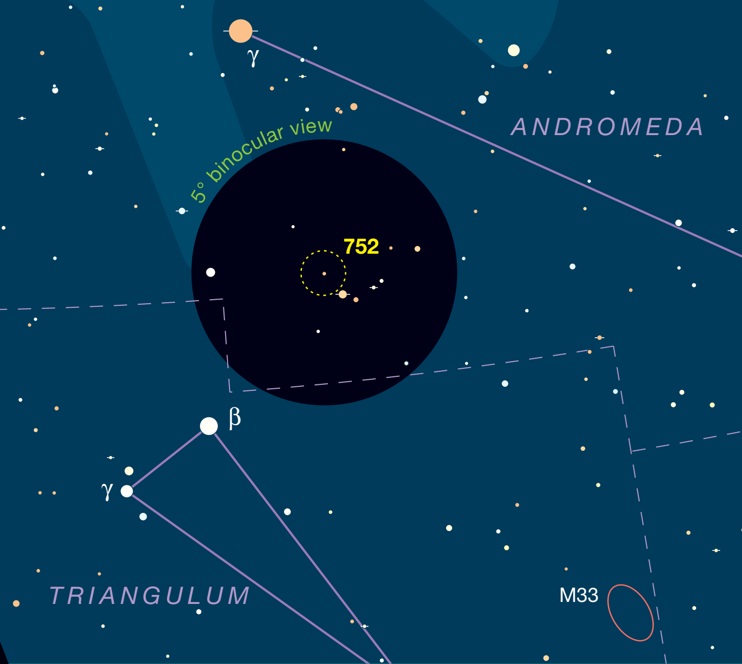



Planet location shown for mid-month

**USING THE NORTHERN HEMISPHERE MAP**

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




**Binocular Highlight** by Mathew Wedel

# Fireflies of Winter

I have always loved stargazing in late autumn and winter. The effect may be more psychological than meteorological, but the cold air seems clearer and the stars seem to shine more brightly. It's a great season for binocular observing, especially when it's too chilly for me to want to set up a scope.

One of my favorite targets this time of year is the open cluster **NGC 752** in the southeastern reaches of the constellation Andromeda. The cluster is a bright, easy catch, just west of an imaginary line between Gamma (γ) Andromedae and Beta (β) Trianguli. In my old logbook I described it as a "big diffuse ball of stars, like a swarm of fireflies."

As is often the case, that initial impression captured more reality than I knew at the time. If the stars of NGC 752 resemble fireflies, it's because so many of them are yellow-orange and orange subgiants and giants. NGC 752 is an aging cluster, a little more than 1 billion years old. It may seem strange to describe a cluster as "old" when it's only a quarter the age of our own solar system, but our Sun is a comparatively small star that will burn for billions of years yet. The small stars of NGC 752 are lost in the brighter lights of their larger, faster-burning siblings.

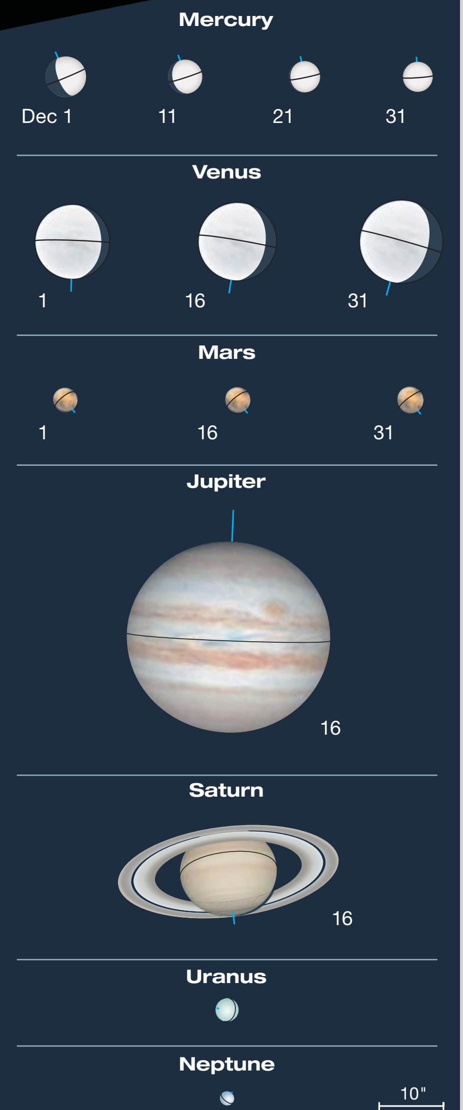
Here's a comparison for you to make: NGC 752 lies about 1,500 light-years away, almost exactly the same distance as M42 and M43, which together constitute the Great Nebula in Orion, the Hunter. A little more than a billion years ago, a similar nebula gave birth to NGC 752. The cluster prefigures M42's remote future, and the nebula embodies NGC 752's distant past. How wonderful that we can cross thousands of light-years and billions of years with instruments we hold in our hands.

■ **MATT WEDEL** is probably out in the cold and the dark, adrift in space and time, happy as a clam.

**WHEN TO USE THE MAP**

| | |
|---|---|
| Late Oct | Midnight* |
| Early Nov | 10 p.m. |
| Late Nov | 9 p.m. |
| Early Dec | 8 p.m. |
| Late Dec | 7 p.m. |

*Daylight-saving time




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

**PLANET VISIBILITY** **Mercury:** visible at dawn through the 17th • **Venus:** visible at dusk all month • **Mars:** visible at dawn all month • **Jupiter:** visible at dusk through the 12th • **Saturn:** visible at dusk until the 27th

## December Sun & Planets

| | Date | Right Ascension | Declination | Elongation | Magnitude | Diameter | Illumination | Distance |
|---|---|---|---|---|---|---|---|---|
| Sun | 1 | 16$^h$ 25.8$^m$ | –21° 40′ | — | –26.8 | 32′ 26″ | — | 0.986 |
| | 31 | 18$^h$ 38.0$^m$ | –23° 09′ | — | –26.8 | 32′ 32″ | — | 0.983 |
| Mercury | 1 | 15$^h$ 06.7$^m$ | –15° 13′ | 20° Mo | –0.6 | 6.3″ | 69% | 1.066 |
| | 11 | 16$^h$ 00.7$^m$ | –19° 30′ | 16° Mo | –0.6 | 5.3″ | 87% | 1.257 |
| | 21 | 17$^h$ 03.7$^m$ | –22° 56′ | 11° Mo | –0.6 | 4.9″ | 95% | 1.375 |
| | 31 | 18$^h$ 11.2$^m$ | –24° 36′ | 6° Mo | –0.9 | 4.7″ | 99% | 1.431 |
| Venus | 1 | 18$^h$ 26.0$^m$ | –24° 46′ | 28° Ev | –3.9 | 11.6″ | 89% | 1.438 |
| | 11 | 19$^h$ 20.2$^m$ | –23° 53′ | 30° Ev | –3.9 | 12.0″ | 87% | 1.390 |
| | 21 | 20$^h$ 13.0$^m$ | –21° 49′ | 32° Ev | –3.9 | 12.5″ | 85% | 1.338 |
| | 31 | 21$^h$ 03.7$^m$ | –18° 42′ | 34° Ev | –4.0 | 13.0″ | 82% | 1.284 |
| Mars | 1 | 14$^h$ 21.2$^m$ | –13° 24′ | 31° Mo | +1.7 | 3.9″ | 98% | 2.388 |
| | 16 | 15$^h$ 00.3$^m$ | –16° 32′ | 36° Mo | +1.7 | 4.1″ | 97% | 2.295 |
| | 31 | 15$^h$ 41.0$^m$ | –19° 13′ | 41° Mo | +1.6 | 4.3″ | 96% | 2.192 |
| Jupiter | 1 | 17$^h$ 57.1$^m$ | –23° 18′ | 21° Ev | –1.8 | 32.1″ | 100% | 6.147 |
| | 31 | 18$^h$ 26.9$^m$ | –23° 12′ | 3° Mo | –1.8 | 31.7″ | 100% | 6.210 |
| Saturn | 1 | 19$^h$ 16.7$^m$ | –22° 10′ | 40° Ev | +0.6 | 15.4″ | 100% | 10.779 |
| | 31 | 19$^h$ 30.8$^m$ | –21° 45′ | 12° Ev | +0.5 | 15.1″ | 100% | 10.993 |
| Uranus | 16 | 2$^h$ 02.5$^m$ | +11° 55′ | 129° Ev | +5.7 | 3.7″ | 100% | 19.184 |
| Neptune | 16 | 23$^h$ 09.1$^m$ | –6° 34′ | 82° Ev | +7.9 | 2.3″ | 100% | 30.049 |

**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-December; 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.

*Red Rose, proud Rose, sad Rose of all my days!*
*Come near me, while I sing the ancient ways: . . .*
~~~~~~~~~~~~~~~
*And thine own sadness, whereof stars, grown old*
*In dancing silver-sandalled on the sea,*
*Sing in their high and lonely melody.*
*Come near, that no more blinded by man's fate,*
*I find under the boughs of love and hate,*
*In all poor foolish things that live a day,*
*Eternal beauty wandering on her way. . . .*
~~~~~~~~~~~~~~~
*Sing of old Eire and the ancient ways:*
*Red Rose, proud Rose, sad Rose of all my days.*
—William Butler Yeats, excerpted from
*To the Rose Upon the Rood of Time*



# Perpetual Motion

Everything in the universe is constantly on the move.

Many consider Yeats to be the greatest English-language poet of the 20th century. His work contains some notable references to the stars. For instance, the final line of "Who Goes with Fergus?" reads: "And all dishevelled wandering stars." The planets have been called "wandering stars," but I think that in this line Yeats is referring to purely stellar objects. The line always makes me think of the Coma Star Cluster in Coma Berenices, for that irregular scattering of naked-eye stars reminds me, as it did the ancients, of the beautifully dishevelled hair of Queen Berenice. But Yeats is probably describing the dishevelled nature of the stars' twinkling, appropriate to the tone of the poem.

Now for the other potential astronomical references in the passages excerpted above. The explicit mention of stars dancing "silver-sandalled" on the sea and singing a high and lonely tune isn't the one that moves me the most. For me, the line that stirs cosmic thoughts — thoughts about the universe — is the line about "eternal beauty."

**Astronomical beauties wandering on their way.** I devoted much of the September and October installments of this column to the ancientness of most astronomical objects. But the central theme was eternity and what I called the interface of now and forever. We always live on this interface but very rarely become fully aware of it. Yet we can do so, and revel in the thrill of it, when we passionately undertake astronomical observation. Why? Because observing allows us to compress into one evening's, even one hour's, personal experience the millions or billions of years of our targets' ages, and the seconds or minutes to billions of years that their light has traveled to us across the cosmos.

There is, however, another aspect of what we see in the heavens that can increase our wonder and recognition of beauty in the universe. I'm talking about recognizing the glorious symphony of motion created by the movements of all the objects and collections of objects out there.

**A December night's symphony of motion.** On a calm and clear December night, all may seem wonderfully silent and still. But everything in the universe is really in motion. We don't live in a static cosmos. When we first try our hand at astronomical observing, we have to learn how our rotating and orbiting Earth affects our perception of the movements of celestial objects. Then we can start appreciating the one-apparent-Moon-width-per-hour eastward travel of the Moon, and the slower, statelier march of the planets in their orbits.

The mobility of the Moon and the planets is mostly gauged against the seemingly fixed background stars. But even that background is in richly complicated motion. At the time of our December sky map, the Andromeda Galaxy is overhead — and heading toward us in space. Aldebaran, in the east, is heading rapidly away from us in space. The Pleiades are flying like a flock of doves to the southeast. Runaway stars in Auriga and Columba are hurtling away from the central region of Orion where their partner stars went supernova millions of years ago, sending them flying.

All of these ancient astronomical objects — and we short-lived human beings who nevertheless perceive the universe — are all part of eternal beauty wandering on her way.

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

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

# Planetary Finale of the Year

Three planets depart to reset for an amazing year to come.

During this month, Jupiter drops ever lower in dusk and is eventually lost from view. Meanwhile at nightfall, Saturn's passage of Venus is dramatic through the first half of December — but the month ends with lowering Saturn becoming lost in the Sun's afterglow.

At dawn, Mars is getting higher as the month progresses, but Mercury, lower in the east-southeast, drops out of view after the first half of the month.

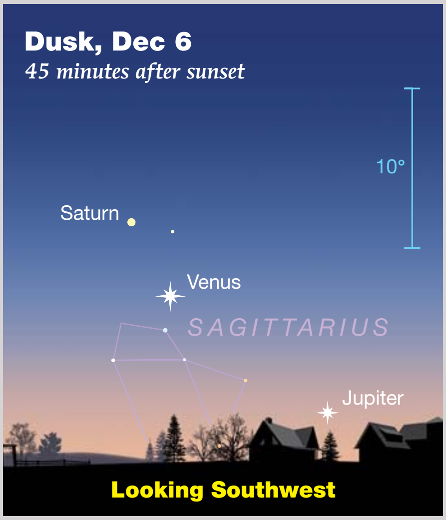
## DUSK INTO EVENING

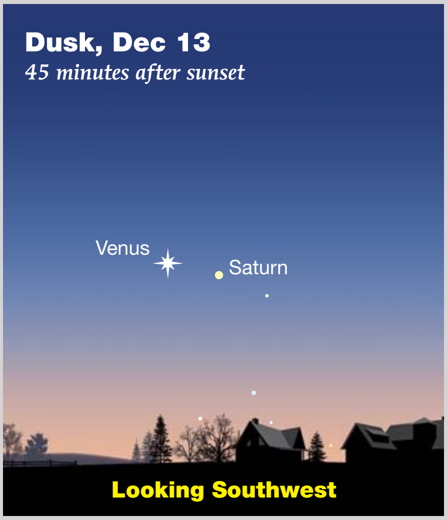
**Saturn**, **Venus**, and **Jupiter** start the month with Saturn about 10° upper left of Venus and Jupiter 7° lower right of Venus. On December 2–3, the three planets are evenly spaced, with 8° to 9° separating Venus from each of the gas giants, but by December 9th Jupiter is more than 15° lower right of Venus and setting less than an hour after the Sun. Magnitude –1.8 Jupiter is lost from view in bright twilight by about mid-month and reaches conjunction with the Sun on December 27th.

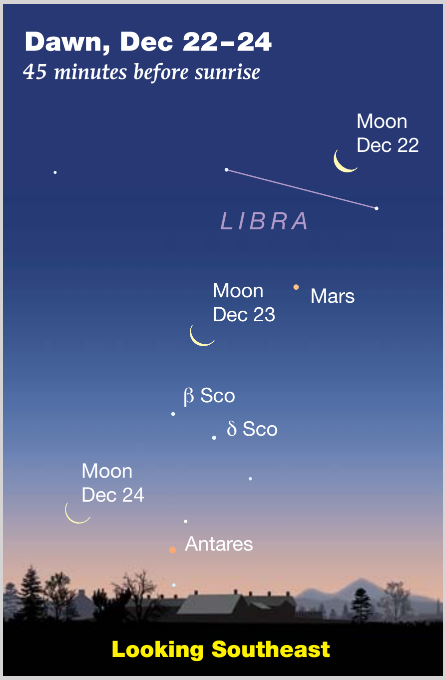
The big show for much of December is magnitude –3.9 Venus, getting higher with each night, passing magnitude +0.6 Saturn, which gets lower. On December 6th, Venus and Saturn are 5° apart, and binoculars help show 2nd-magnitude Nunki, or Sigma (σ) Sagittarii, less than 2° from Venus. On December 10th and 11th, Venus and Saturn are a little less than 2° apart, with Saturn to the upper right. In telescopes, Venus then displays a 12″-wide disk that is about 87% illuminated and Saturn a 15″-wide disk with 35″-wide rings. On these dates, Venus and Saturn set about 2 hours after the Sun. But over the next few weeks, Venus races away and up, improving its sunset and twilight altitudes, while Saturn sinks ever lower and finally disappears from view by late in the month. The gap between Venus and Saturn increases to 3° on December 13th, around 5° on the 15th, and almost 11° by December 20th. Venus ends the month setting a wonderful 2⅔ hours after the Sun, on its way to what will be an excellent apparition of Venus for observers at mid-northern latitudes in the opening months of 2019.

By the way, a curiosity is that on December 12th Venus is only 1.3° south of unviewably dim **Pluto** (18 magni-

▼▶ 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.



tudes fainter than Venus), and Venus, Saturn, and Pluto fit together within a circle just 2½° in diameter.

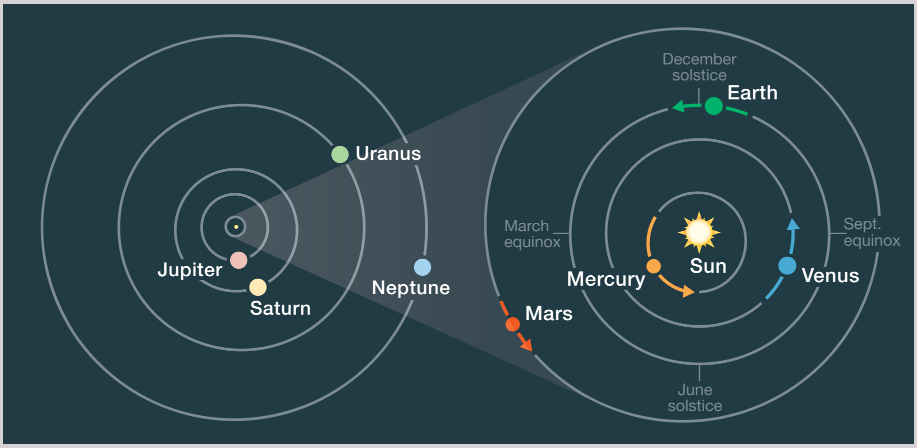
## EVENING

**Neptune** is at its highest in the south as evening twilight is ending and starts setting before midnight. **Uranus** is highest around mid-evening and doesn't set until a few hours after midnight. Finder charts for locating Neptune and Uranus are in the September issue and can also be accessed at **https://is.gd/urnep**.

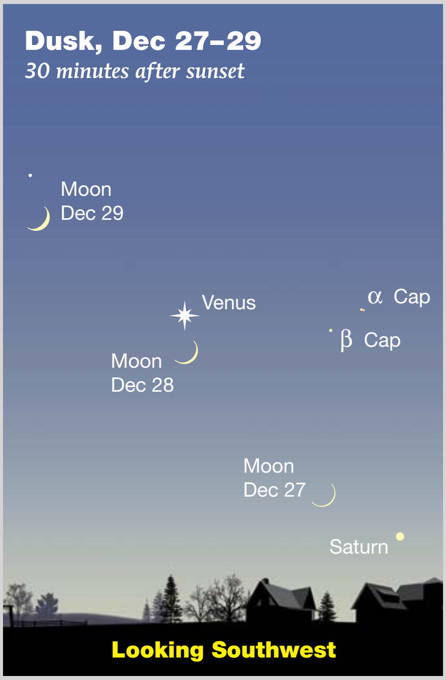
## EARLY MORNING AND DAWN

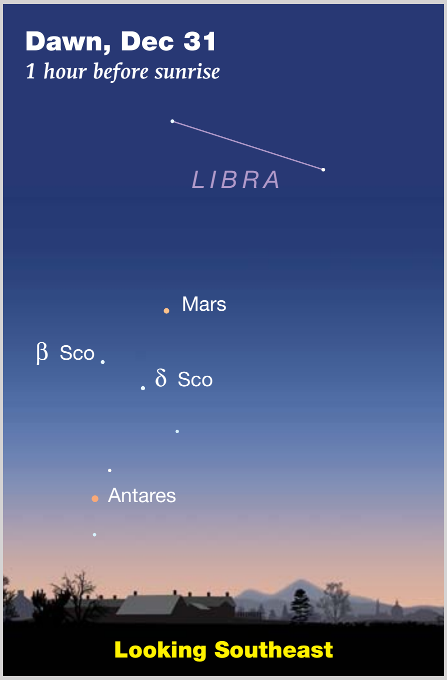
**Mars** rises less than 3 hours before the Sun as December opens but more than 3 hours before the Sun at month's (and year's) end. Mars brightens a bit — from magnitude 1.7 to 1.6 — this month, but its disk is only about 4″ wide. As December begins, Mars is almost 20° high in the east-southeast at mid-twilight and shines about halfway between high Spica and low Mercury. As the month ends, the Red Planet is still in Libra, but is nearing the head of Scorpius.

**Mercury** was at greatest western elongation on November 28th but continues with a fine morning apparition into the opening weeks of December. Mercury is bright, at magnitude –0.6, but its rise-time gets rapidly later. As December starts, the hot little world rises about 1½ hours before the Sun but by the 16th only about an hour. December 16th is also the day that Mercury, in Scorpius, is 5° northeast of 1st-magnitude Antares, though the red supergiant will be hard to see in the morning twilight. After December 17th, Mercury will be too low in bright twilight to see.




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




## SUN AND MOON

**The Sun** reaches the December solstice at 11:19 p.m. EST on December 21st. This is the shortest day and the beginning of winter in the Northern Hemisphere and the longest day and the start of summer in the Southern Hemisphere.

The Sun undergoes an annular eclipse visible from the Middle East, India, and Indonesia, with partial phases visible from most of Asia, northern and western Australia, and parts of the Pacific (see page 49 for more information on this event).

**The Moon** is full on December 12th, largely washing out the peak of the Geminid meteor shower the next few nights (but see page 48). On December 22nd the waning lunar crescent is some 8° to 9° above Mars, the next morning 5° to 6° lower left of it. On December 24th, low in the southeast about 45 minutes before sunrise, a very thin Moon is several degrees left or upper left of Antares. On December 27th the very thin waxing Moon is about 5° upper left of Saturn, which may be hard to find in bright evening twilight. On the next evening, December 28th, the lunar crescent is spectacularly close to Venus, a bit more than 2° below the planet.

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BRIAN TOMLINSON / CC BY 2.0

In 2017 the Geminids put on a great show (see above), with little or no interference from the Moon. The International Meteor Organization calculated the zenithal hourly rate to be 136 that year. (That's the number of meteors a keen-eyed observer could spot under a very dark sky with the shower radiant at the zenith.) Moonlight will hide the faintest Geminid meteors in 2019, but there are still many ways to enjoy this wonderful event.

# Plan Ahead

The Geminid meteor shower shares the sky with moonbeams this year, but a little preparation will help maximize your observations.

The year 2019 hasn't been great for major meteor showers. January's Quadrantids peaked during a dark window, but August's Perseids shared the sky with a waxing gibbous Moon. December's Geminids, considered by some to be the premier shower of the year, will also suffer from moonlight. The shower's maximum is predicted to fall around midday on December 14th in the Americas, less than two days after full Moon. The ideal viewing windows occur in the early morning and late evening of the 14th, but the fat (though waning) Moon shines near the shower's radiant at both times.

All is not lost, however. In 2016, the Geminids shared the sky with a full Moon near perigee, yet visual observers recorded meteor counts as high as 147, according to the International Meteor Organization (IMO). More typical counts were in the range of 30 to 80, however. That's not bad! If your sky is transparent, you could see more than 20 meteors per hour between midnight and 4 a.m., when the radiant is highest. The Geminids tend to be rich in bright meteors, which are often spectacular even under very bright skies. Turn your back to the Moon to protect your night vision; the Geminids can appear anywhere in the sky, so you needn't look toward Gemini.

Since the radiant (near Castor) rises just ahead of the Moon on the 14th, consider going out in the early evening. You might be lucky enough to catch a few *earthgrazers* — slow, bright meteors that angle upward from the eastern horizon — before or as the Moon makes its appearance.

The Geminids are intrinsically interesting thanks to their parent object. Unlike most meteor showers, which spring from dust and rock particles left behind by active comets, the Geminids are produced by the semi-dead "rock comet" 3200 Phaethon. Phaethon acts as if it's both an asteroid and a comet. Most of the time, it's inert like an asteroid and loses very little material as it hurtles through the solar system. However, when it approaches the Sun, Phaethon behaves more like a comet. Its rocky surface responds to the intense solar heat (as great as 800°C / 1,500°F) by cracking, which releases enough material to produce a modest dust tail. Only one other object in the solar system has been observed to act in a similar manner.

Despite being one of the most productive and reliable meteor showers, the Geminids remains a somewhat underreported event, possibly because December is often cold and cloudy over much of the Northern Hemisphere. The IMO encourages observers to watch a few nights before and after the predicted maximum, even under moonlit skies. For more detailed instructions regarding recording and reporting, visit the IMO Visual Observations page (**https://is.gd/IMOvisual**).

# Ring of Fire

**ON THURSDAY, DECEMBER 26TH,** weather permitting, parts of Africa, most of Asia, the western Pacific, and northern and western Australia will see a partial solar eclipse. The event lasts more than three hours, from the moment the Moon first brushes the Sun's face to when the Sun again appears perfectly round. For observers in western Asia and eastern Africa, the eclipse is already in progress as the Sun rises, with the final partial phase wrapping up while the Sun is still low in the morning sky. South and Central Asia see the eclipse begin in early morning and end before or near noon local time. Those on the eastern end of the eclipse path see a partial eclipse in the afternoon. Some Pacific islanders should see the Sun drop below the horizon before the eclipse concludes.

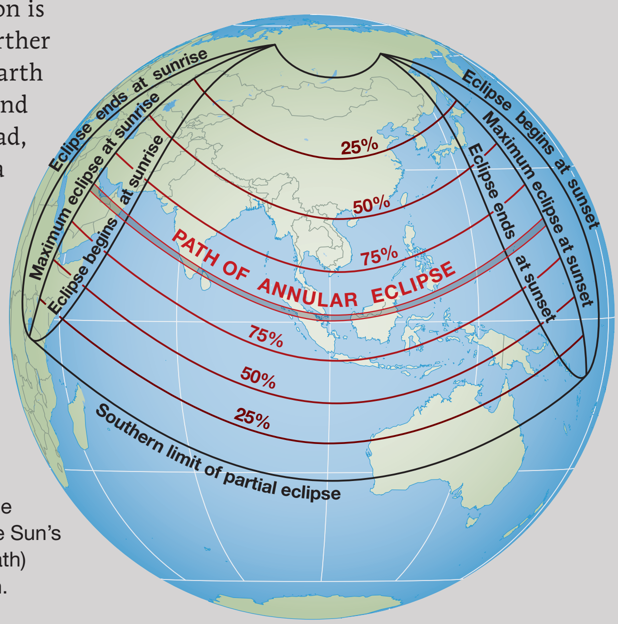
Observers situated along a narrow track that runs from Saudi Arabia through the United Arab Emirates, Oman, southern India, Sri Lanka, Indonesia, and Malaysia to the Philippines will see a special type of partial solar eclipse known as an *annular*, or ring, eclipse. Typically, when the Moon passes directly between the Sun and Earth, its *umbra* (shadow cone) reaches Earth's surface, with the Sun completely hidden. We experience this as a total solar eclipse. But if the Moon is closer to apogee, and so slightly farther from us, when it passes between Earth and Sun, its disk appears smaller and doesn't cover the entire Sun. Instead, the Sun's chromosphere shows as a brilliant ring of fire, blazing along the Moon's perimeter.

▲ Takeshi Kuboki used a Nikon D7000 to capture this image of an annular eclipse through clouds above Amagasaki, Japan, on the morning of May 21, 2012.

Because the Sun isn't fully blocked during an annular eclipse (in this case it's just 97% hidden at maximum), observers need proper eye protection, even when the Moon is centered in front of the solar disk. Certified eclipse glasses or a properly filtered telescope will provide excellent views of the action. Pinhole projectors and telescopic projection are also good options (see **https://is.gd/SolarProjection**).

The duration of annularity depends on the observer's location along the central path of the eclipse. Greatest eclipse occurs over eastern Sumatra (Indonesia) at 05:18 UT; annularity lasts 3 minutes and 40 seconds for that spot. For more detailed information, visit **https://is.gd/2019annular**.

Lunar eclipses often take place two weeks before or after a solar eclipse. This final solar eclipse of 2019 is followed by a penumbral lunar eclipse on January 10, 2020.




▶ The annular eclipse begins at sunrise in Saudi Arabia, crosses the United Arab Emirates, Oman, southern India, and Sri Lanka in the morning and the Bay of Bengal, Malaysia, and Singapore through most of the day, then finishes late in the afternoon and at sunset for parts of the Pacific. Interpolate between the horizontal red or black lines to find the approximate maximum percentage of the Sun's diameter (up to 97% along the central path) that the Moon covers for a given location.

# A Star Dims

**ON THE EVENING OF DECEMBER 6TH,** the faint asteroid 55 Pandora will block the light of a 6.5-magnitude star in Auriga as seen from a narrow path across the southern United States and northern Mexico. The *A*-type main-sequence star 18 Aurigae is on the edge of naked-eye visibility, so the occultation should be obvious through hand-held binoculars, though a telescope will provide a much better view. When Pandora passes in front of the star, their combined brightness will drop to Pandora's own magnitude of 11.1 for up to 6 or 7 seconds. A telescope at high magnification should also show the asteroid sneaking up on the star, as well as a 12.5-magnitude companion just 4 arcseconds from the primary star.

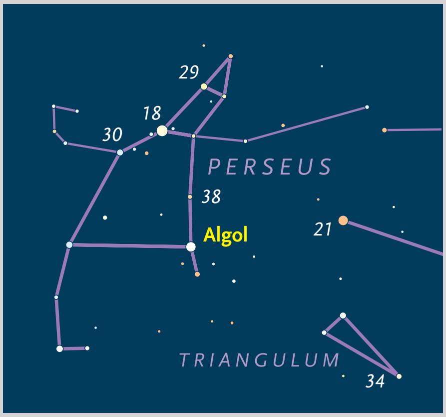
As its formal moniker suggests, Pandora was the 55th minor planet discovered by astronomers. George Mary Searle, observing from Dudley Observatory in Albany, New York, spotted Pandora on September 10, 1858. Typically, naming rights are awarded to the discoverer; however, in this case, credit for the official name has been awarded to Blandina Dudley, benefactor of the observatory, who considered Pandora an accurate personification of the tumultuous conditions in Albany, where the observatory's trustees were embroiled in battle with its director, Benjamin A. Gould.

The occultation will occur around 11:49 p.m. EST December 6th in northern Florida, around 10:51 p.m. in southern Texas, and 9:52 p.m. MST in Baja California Sur. Make sure you set up with plenty of time to spare! For a map of the path and finder charts for the star, visit **https://is.gd/Pandora2019**.

## Minima of Algol

| Nov. | UT | Dec. | UT |
|---|---|---|---|
| 3 | 14:19 | 2 | 6:29 |
| 6 | 11:08 | 5 | 3:18 |
| 9 | 7:57 | 8 | 0:07 |
| 12 | 4:46 | 10 | 20:56 |
| 15 | 1:35 | 13 | 17:45 |
| 17 | 22:24 | 16 | 14:34 |
| 20 | 19:13 | 19 | 11:23 |
| 23 | 16:02 | 22 | 8:12 |
| 26 | 12:51 | 25 | 5:02 |
| 29 | 9:40 | 28 | 1:51 |
| | | 30 | 22:40 |

These geocentric predictions are from the recent heliocentric elements Min. = JD 2445641.554 + 2.867324*E*, where *E* is any integer. For a comparison-star chart and more info, see **skyandtelescope.com/algol**.




▲ Perseus floats near the zenith on December evenings as seen from mid-northern latitudes. Every 2.7 days Algol (Beta Persei) dips slowly from its usual magnitude of 2.1 to 3.4 and back. The entire event takes about seven hours. Use this chart to estimate its brightness with respect to the comparison stars Gamma Andromedae (2.1) and Alpha Trianguli (3.4).

● FIND YOUR CLUB: skyandtelescope.com/astronomy-clubs-organizations.

# Action at Jupiter

**JUPITER IS IN CONJUNCTION** with the Sun — on the opposite side of the star from Earth — on the 27th. You may be able to spot it low in the southwest at dusk through the 12th or so. Look for it to reappear in the dawn sky around January 12th.

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

All of the December interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Look for events timed shortly after sunset.

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

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

**December 1:** 0:07, 10:03, 19:59; **2:** 5:55, 15:50; **3:** 1:46, 11:42, 21:38; **4:** 7:34, 17:30; **5:** 3:25, 13:21, 23:17; **6:** 9:13, 19:09; **7:** 5:05, 15:01; **8:** 0:56, 10:52, 20:48; **9:** 6:44, 16:40; **10:** 2:36, 12:31, 22:27; **11:** 8:23, 18:19; **12:** 4:15, 14:11; **13:** 0:07, 10:02, 19:58; **14:** 5:54, 15:50; **15:** 1:46, 11:42, 21:37; **16:** 7:33, 17:29; **17:** 3:25, 13:21, 23:17; **18:** 9:12, 19:08; **19:** 5:04, 15:00; **20:** 0:56, 10:52, 20:47; **21:** 6:43, 16:39; **22:** 2:35, 12:31, 22:27; **23:** 8:23, 18:18; **24:** 4:14, 14:10; **25:** 0:06, 10:02, 19:58; **26:** 5:53, 15:49; **27:** 1:45, 11:41, 21:37; **28:** 7:33, 17:28; **29:** 3:24, 13:20, 23:16; **30:** 9:12, 19:08; **31:** 5:03, 14:59.

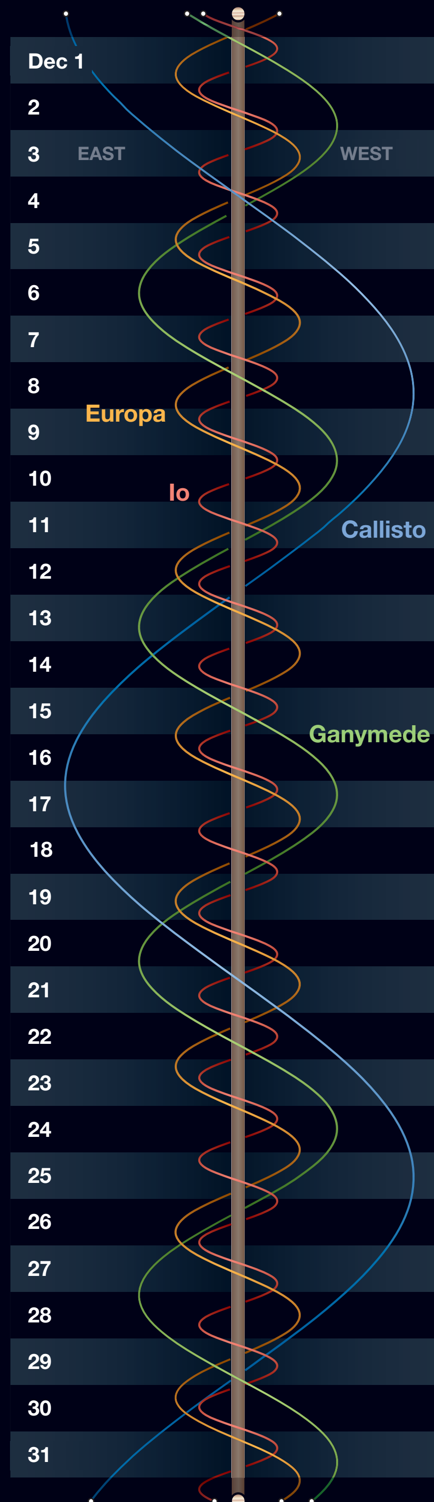
These times assume that the Great Red Spot will be centered at System II longitude 315°. If the spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 315° and 1⅔ minutes later for each degree more than 315°.

## Phenomena of Jupiter's Moons, December 2019

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

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

# Limb Huggers

These interesting craters require a strong northwest libration and steady atmospheric conditions.

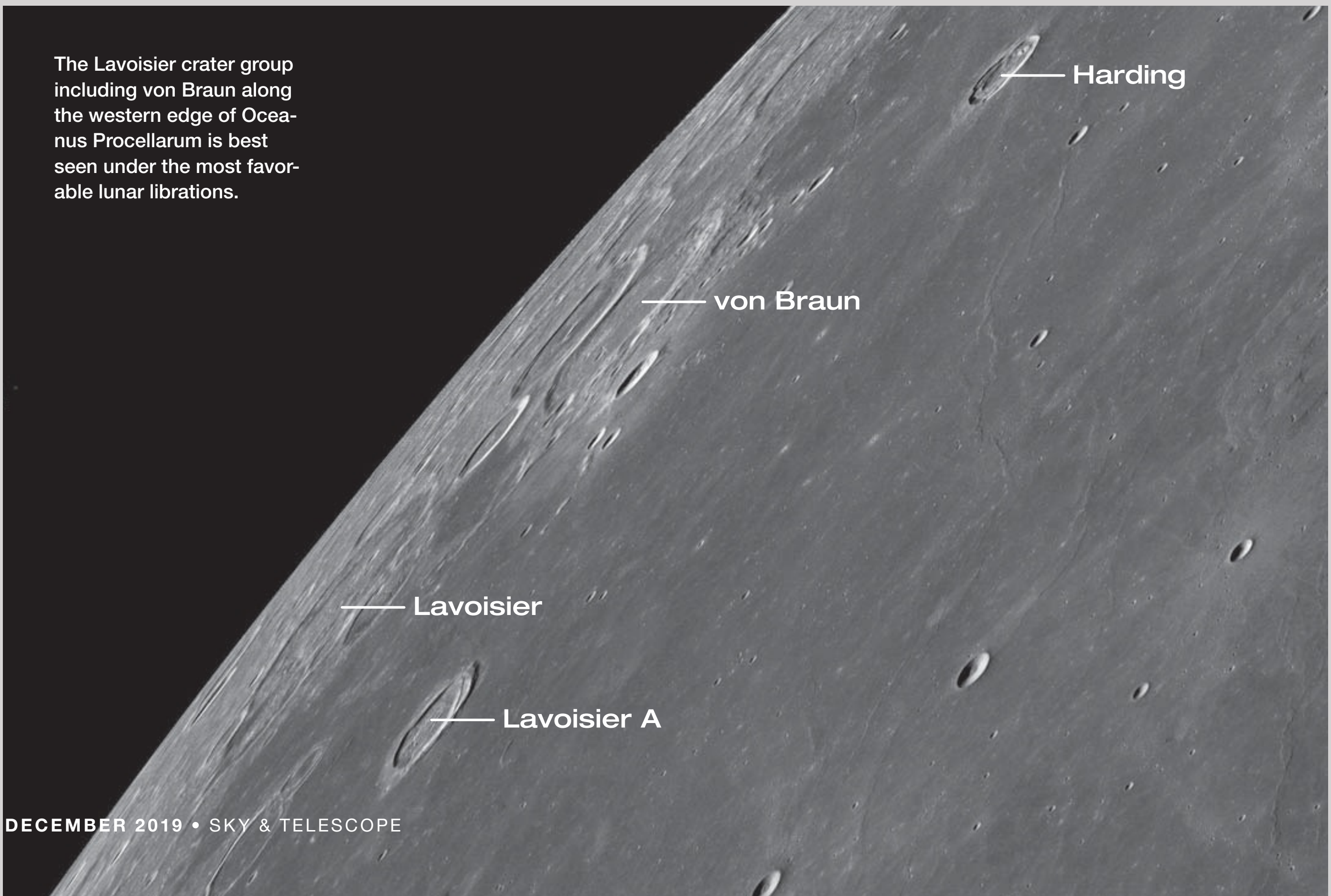
Is **Lavoisier** the only lunar crater named for a scientist who faced the guillotine? The brilliant French chemist famed for his recognition that oxygen is a chemical element, Antoine-Laurent Lavoisier was one of many nobles who lost their heads during the French Revolution. But the crater Lavoisier remains along the western limb of the Moon, ironically near **von Braun**, another noble who supported a deposed regime.

These two craters are so near the limb (about 80°W longitude) that they appear as foreshortened ellipses and are rarely observed. Yet the larger craters **Gauss** and **Humboldt** are both near 80°E longitude and frequently targeted by observers. The latter two craters are twice as big as Lavoisier and von Braun, and are readily observed in early evenings, while the western limb craters are best seen from full Moon until almost new Moon, progressively later in the night and early in morning. But there are other possible explanations for the slight. Most observers may not realize how interesting these noble craters are and thus haven't tried to find them.

The Lavoisier region is just inland from the western reaches of **Oceanus Procellarum**. Two 20- to 30-km-wide craters on this vast mare, **Harding** and **Lavoisier A**, are conspicuous markers to the area of interest just to their west.

The group contains five main craters of interest. The largest is Lavoisier, a roughly 70-km-wide, 600-meter-deep degraded crater bearing many classic features of a floor-fractured crater. Lavoisier's floor contains a concentric inner ridge, concentric rilles, and an annular swath of mare lava, as well as a small but beautiful concentric crater. Von Braun is next biggest at 60 km diameter and 1.6 km deep. Less degraded than Lavoisier, von Braun's rim is best seen just before full Moon. The Lunar Reconnaissance Orbiter *QuickMap* (**https://is.gd/SM5NY1**) shows that von Braun has a domed central floor elevated by about 300 m. The eastern half of the floor is smooth but not dark, while the western floor is sliced by eight non-concentric rilles.

Next is 51 km **Lavoisier E**, another classic floor-fractured crater with a high eastern rim that abuts von Braun. It contains a broad wreath of concentric rilles circling a lava-flooded inner floor surrounding a central peak. The mare patch is visible in mid-sized telescopes.




The Lavoisier crater group including von Braun along the western edge of Oceanus Procellarum is best seen under the most favorable lunar librations.

NASA / GSFC / ARIZONA STATE UNIVERSITY

This image captured August 6, 2010, just a few days before new Moon, hints at the rich features that await patient observers and imagers with moderately large-aperture telescopes.

**Lavoisier H**, just to the east of Lavoisier is 29 km across and has a 400-m-high domed floor cut by fractures and rilles. The center of the crater floor is higher than the rim facing Oceanus Procellarum.

The last concentric crater in the group is **Lavoisier B**, a relatively normal crater at first glance — at 25 km it's almost a larger morphological twin of 16-km-wide Bessel — but its western side is wreathed in concentric rilles. Located right between the two main craters, Lavoisier B is distinctly visible because its eastern rim is bright when the lunar phase is waning — even appearing as a complete bright ring at high Sun illumination.

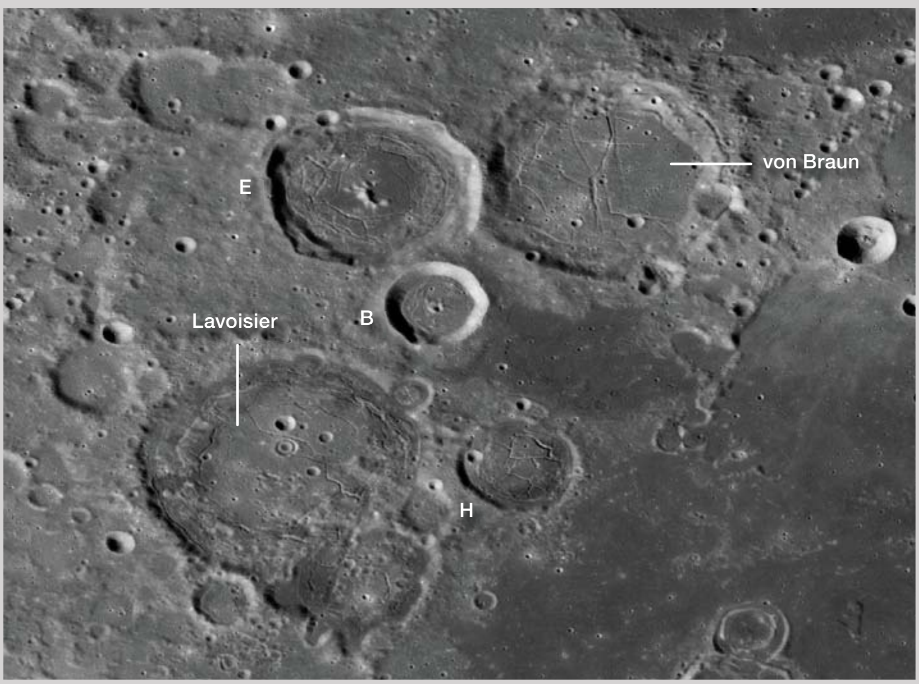
This group of floor-fractured craters might seem exceptional, but such craters occur frequently along the western edge of Oceanus Procellarum, from Damoiseau at 4°S to Repsold at 51°N. Elsewhere on the Moon, floor-fractured craters almost always occur near impact-basin margins, where deep crustal fractures provide conduits for magma to rise and push crater floors up, creating concentric ridges and rilles, and often leaking onto the surface as lava flows and pyroclastic deposits.

Oceanus Procellarum itself does not fill a recognized impact basin. However, in 1981 Ewen Whitaker proposed a controversial basin boundary defined by Procellarum's semi-circular western shoreline (*S&T:* Sep. 2005, p. 63). This putative basin would be huge — 3,200 km wide — underlying Oceanus Procellarum, Mare Imbrium, Mare Nubium, and Mare Serenitatis. Its existence has been neither convincingly confirmed nor refuted, though most lunar scientists don't support it. However, the occurrence of so many floor-fractured craters along Procellarum's shoreline adds another morphologic piece of evidence consistent with a long arc of deep fractures, as would be expected under a basin rim. Additionally, recently discovered long gravity highs (*S&T:* Dec. 2018, p. 52) coincide with Whitaker's proposed Procellarum edges, and the thorium-rich, radioactive Procellarum KREEP Terrane (*S&T:* Oct. 2018, p. 52), the source of most lunar volcanism, lies within it.

For the terrestrial observer, the Lavoisier group is hard to study even though it is theoretically visible every lunation from full to almost new Moon. Yet only the dark annular ring of Lavoisier and the dark inner floor of Lavoisier E appear to be visible from Earth during average libration angles. Perhaps a lunar-imaging pro with a large scope and 5° to 8° of favorable libration can begin to reveal this neglected area of the Moon.

Oh, the answer to the question at the beginning of this article is "no." In addition to Lavoisier, the astronomer Jean Sylvain Bailly also lost his head during the French Revolution's Reign of Terror and is honored with a large crater bearing his name on the southeastern limb. At least they have an eternal home on the Moon.

▼ Most craters surrounding Lavoisier display fractured, mare-flooded floors.




LRO OVERHEAD: NASA / GSFC / ARIZONA STATE UNIVERSITY; LIMB PHOTO: YURI GORYACHKO

■ Contributing Editor **CHUCK WOOD** often explores the lunar limb hunting for overlooked treasures.

# The Darkling Fish

## Dim Pisces teems with fine galaxies and double stars.

*This way a goat leaps, with wild blank of beard;*
*And here fantastic fishes duskly float.*
— Elizabeth Barrett [Browning],
A Drama of Exile

▲ Messier 74 is by far the most photogenic galaxy in Pisces. Its spiral arms are stunning in this NASA / ESA Hubble Space Telescope image, but they can be hard to discern through the eyepiece of a backyard telescope.

NASA / ESA / HUBBLE HERITAGE (STSCI / AURA) – ESA / HUBBLE COLLABORATION

Although Pisces, the Fishes, floats ever so duskly upon the sky, rural stargazers can swiftly espy the constellation's western fish. It swims beneath the Great Square of Pegasus and includes the asterism known as the Circlet of Pisces. But the eastern fish presents no distinctive pattern and glimmers more feebly as it nudges Andromeda's waist. Though lacking bright guide stars, its celestial waters serve up many deep-sky wonders.

Let's work our way toward the eastern fish by starting in the ribbon of stars that joins the Fishes together. Our springboard will be the pretty double star **Zeta (ζ) Piscium**. My 4.1-inch (105-mm) refractor at 17× reveals a white, 5th-magnitude primary cozied up to a yellow, 6th-magnitude companion east-northeast.

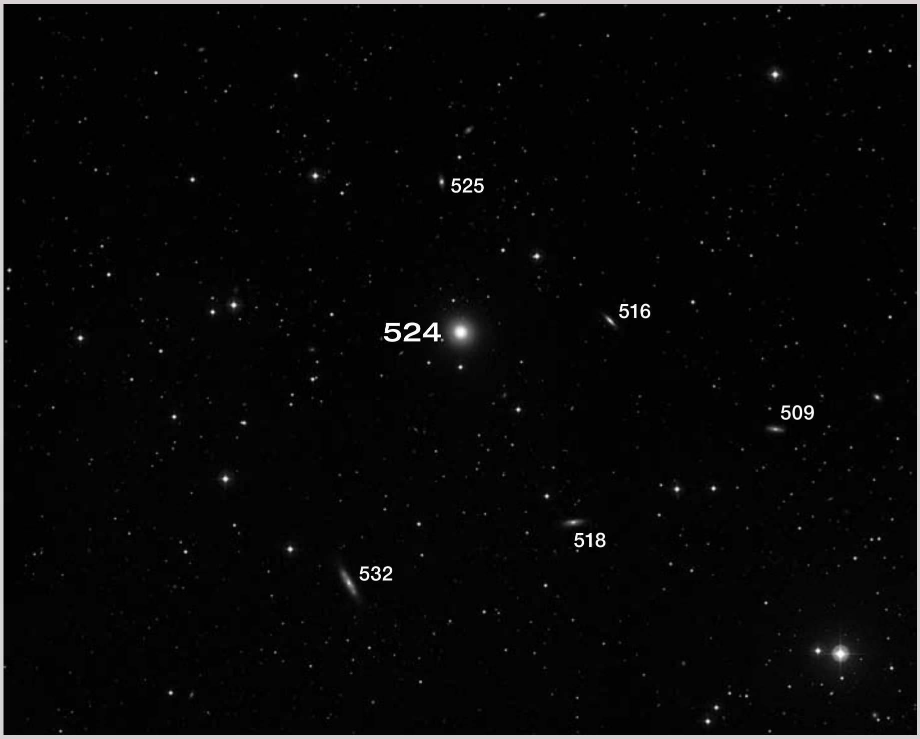
The galaxy **NGC 524** is 3.4° north-east of Zeta. Trying to hide in a patch of 9th- to 12th-magnitude stars, it's nonetheless easy to spot through my little refractor at 47×. There's a filled-in wedge of stars east of the galaxy and a more haphazard scattering near it and to the west. A wide, yellow-white and orange star pair sits off the south-western edge of the group. NGC 524 is small, round, intensifies toward the center, and has an 11th-magnitude star near its southern edge. At 87× two more stars are visible north-northeast and southeast of the galaxy. They join the first to make an isosceles triangle, with NGC 524 occupying much of its western side. The galaxy grows sharply brighter toward a tiny nucleus.

In my 10-inch reflector at 115×, NGC 524 spans about 2.5′ and holds a faint star at its east-southeastern edge. It sits in a westward-pointing V of five dimmer galaxies that would share the field of view, but I see only three little smudges at this magnification. NGC 525 sits 10′ north, NGC 516 the same distance west, and NGC 518 is 15′ south-southwest. Boosting the power to 213× lets me spot NGC 509 at the point of the V and NGC 532 at the end of its southern branch, but the field is now too small to encompass all six galaxies. The NGC 524 Group is about 90 million light-years away and incorporates several additional galaxies in the immediate area.

On the opposite side of the Fishes's ribbon, 1.5° west of 95 Piscium, we find **NGC 488**, a beautiful galaxy that displays tightly wound spiral arms in astrophotos. In my little refractor at 47×, it's simply a softly glowing north-south oval that becomes considerably more luminous toward the center. At 87× I catch glimpses of an elusive star-like nucleus. Four stars, magnitude 10 to 13, form a tangent to the galaxy that slopes east-northeast. The line's second-brightest star touches the galaxy's south-southeastern edge. Regrettably, I see no trace of the lovely spiral arms even in my 10-inch scope. Can you detect them?

Sweeping 1.9° east-northeast of Nu (ν) Piscium brings us to **NGC 676**, which makes a nice isosceles triangle with golden 8th-magnitude stars 30′ east-northeast and 19′ south-southeast. The galaxy is very easy to overlook because there's a 10.5-magnitude star smack-dab in the middle of it. The mag-

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



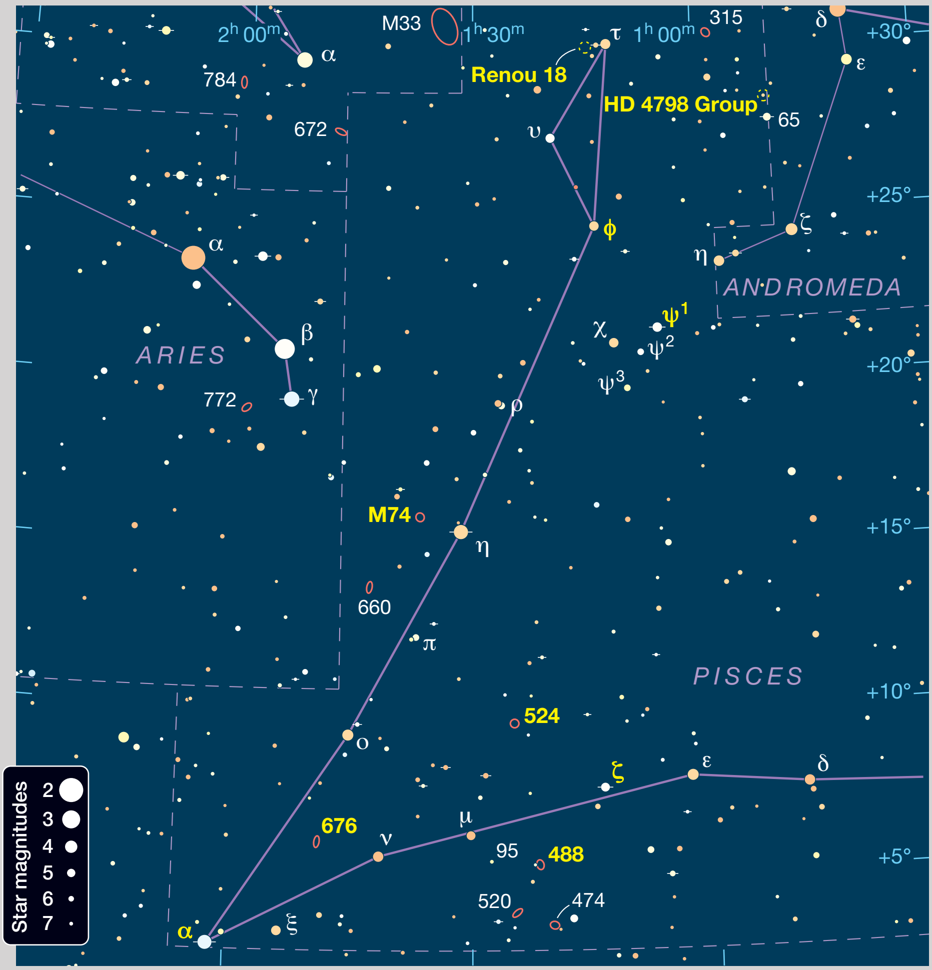

▶ The *New General Catalogue* includes five other galaxies within 25′ of NGC 524. This image, synthesized from red and blue plates from the Second Palomar Observatory Sky Survey, also shows several galaxies too faint to be visible when the NGC was compiled.

POSS-II / STScI / CALTECH / PALOMAR OBSERVATORY

nitude listed in the table excludes this star. In my 4.1-inch scope at 87×, the galaxy is a faint, 2′-long streak tipped a little west of north. There's an 11th-magnitude star 5′ east-southeast and a fainter star a bit closer and a shade east of north. Through my 10-inch scope at 216×, NGC 676 brightens near the core, and a dim star is intermittently visible just off the galaxy's side, approximately east of center.

**Alpha (α) Piscium** marks the bend in the ribbon connecting the Fishes. It consists of a pair of white stars, magnitudes 4.1 and 5.2, only 1.8″ apart. My little refractor at 122× splits this pair by a hair's breadth, showing the companion west of its primary. An 8.1-magnitude orange star lies 14′ west, and I see slightly fainter, yellow stars 6.7′ east-northeast and 7.2′ north-northwest. The three form a straight line, and the last two are listed as components C and D in the Washington Double Star Catalog, though they are probably not physical members of the star system.

The only Messier object in Pisces is the galaxy **M74**. Because it lies only 1.3° east-northeast of Eta (η) Piscium and has a total magnitude of 9.4, novices often expect that M74 will be easy to spot. Not so! The galaxy's light is spread over a comparatively large area of the sky, so its surface brightness is low. Keep your eyes peeled for a sizeable ghostly glow. Having seen M74 many times, I no longer find its phantom fuzz difficult to nab from my semirural home. My 4.1-inch refractor at 17× reveals a faint halo enfolding a relatively large, brighter core. At 47× I see a faint star at M74's eastern edge, which puts the galaxy's apparent size at 8′. A magnification of 87× shows a second star 1½′ south of the first and a superposed star 3′ southwest of the galaxy's center. M74 is subtly patchy, and with careful study I can trace some spiral structure — especially an arm



▲ Technically classified as a ringed spiral galaxy, NGC 488 has extraordinarily subtle and tightly wound spiral arms that are extremely difficult to detect in amateur scopes.

◀ Look for the telescope asterism HD 4798 Group 40′ north of 65 Piscium. Named by amateur observer Bob Douglas, this group of 7th- to 13th-magnitude stars appears to form a "flying wing" in the eyepiece.

that seems to start north and then wrap outward to the east.

With my 10-inch scope at 213× I can make out a second spiral arm opposing the first. M74's halo is slightly oval north-south and grows progressively brighter toward the center. The heart of the core is a very short bar with the same orientation, but the arms spiraling into the core make it look elongated east-west farther out. Two nearly parallel lines of three stars each cut through the outer reaches of M74 west and northeast. A two-star line closer to the galaxy's center parallels the latter, its northern star placed squarely on a spiral arm.

According to some pictorial atlases, we reached the tail of the eastern fish at Eta Piscium, but others show it beginning at Rho (ρ) or Chi (χ). In any case, the multiple stars **Psi¹ (ψ¹)** and **Phi (φ)** are well within the fish's domain. Through my little refractor at 17×, Psi¹ shows as a pair of white, 5th-magnitude stars with the companion wide to the south-southeast of its primary. The 11th-magnitude third component is three times as distant to the east-southeast. At 68× Phi displays a 5th-magnitude deep-yellow star with a 9th-magnitude companion, perhaps reddish, nestled closely against it to the southwest.

California amateur Bob Douglas informed me of a charming asterism in the far western side of the fish. It's named the **HD 4798 Group** after its brightest star, but Douglas likes to call it the Flying Wing. Look for it 40′ north of 65 Piscium. Through my 4.1-inch scope at 47×, I see seven stars outlining a southward-pointing triangle. The "wing" spans 5.6′ tip to tip and is composed of stars ranging from magnitude 7.2 to 12.8, with the namesake star boasting a deep yellow hue. In light-polluted skies you may need a larger scope to see the dimmest star, which marks the western wingtip.

Our final target is the asterism **Renou 18**, named after Alexandre Renou, who wrote for the French journal *Astronomie Magazine*. It lies in the eastern fish 37′ east of Tau (τ) Piscium and marks the eastern point of a 20′ triangle formed with two yellow stars, magnitudes 6.2 and 6.7. I can see about 25 stars scattered across 18′ in my little refractor, but it's the view in my 10-inch scope that catches my imagination. Half the stars are gathered into a shape that strongly reminds me of the S shape in the iconic emblem of the fictional character Superman. The S covers 10′ × 8½′, and the top (wider half) is to the east. Maybe the planet Krypton circled one of these stars.

## Pleasures of Pisces

| Object | Type | Mag(v) | Size/Sep | RA | Dec. |
|---|---|---|---|---|---|
| ζ Piscium | Multiple star | 5.2, 6.2 | 23″ | $1^h\ 13.7^m$ | +7° 35′ |
| NGC 524 | Galaxy | 10.3 | 2.8′ | $1^h\ 24.8^m$ | +9° 32′ |
| NGC 488 | Galaxy | 10.3 | 5.2′ × 3.9′ | $1^h\ 21.8^m$ | +5° 15′ |
| NGC 676 | Galaxy | 11.9 | 4.0′ × 1.0′ | $1^h\ 49.0^m$ | +5° 54′ |
| α Piscium | Multiple star | 4.1, 5.2, 8.3, 8.6 | 1.8″, 6.7′, 7.2′ | $2^h\ 02.0^m$ | +2° 46′ |
| Messier 74 | Galaxy | 9.4 | 10.5′ × 9.5′ | $1^h\ 36.7^m$ | +15° 47′ |
| ψ¹ Piscium | Multiple star | 5.3, 5.5, 11.2 | 30″, 91″ | $1^h\ 05.7^m$ | +21° 28′ |
| φ Piscium | Multiple star | 4.7, 9.1 | 7.8″ | $1^h\ 13.7^m$ | +24° 35′ |
| HD 4798 Group | Asterism | — | 5.6′ | $0^h\ 50.1^m$ | +28° 22′ |
| Renou 18 | Asterism | 7.0 | 18′ | $1^h\ 14.5^m$ | +30° 00′ |

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

■ Contributing Editor **SUE FRENCH** penned this column for the December 2008 issue of *Sky & Telescope*.

HD 4798 GROUP: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY;
NGC 488: ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

# A Fresh Look

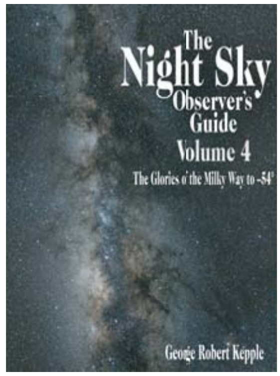
## THE NIGHT SKY OBSERVER'S GUIDE, *Volume 4: The Glories of the Milky Way to –54°*

**George Robert Kepple**
**Willmann-Bell, 2018**
**497 pages, ISBN 978-1-942675-06-8**
**$34.95, hardcover.**

**FOR THE LAST COUPLE OF DECADES,** most of my astronomical observations have been made with a camera rather than an eyepiece. Recently, I've been making a concerted effort to return to visual observing, and perhaps even take it a bit more seriously than I had in the past. Volume 4 of *The Night Sky Observer's Guide*, which bears the subtitle *The Glories of the Milky Way to –54°*, has been a wonderful resource on this journey. This book was my introduction to the series, and I was so impressed by it that I purchased the first two volumes, which cover the whole sky for Northern Hemisphere observers, as well. (Volume 3 addresses the southern skies.)

Volume 4 easily stands on its own, apart from the rest of the series. There's some overlap with the content of previous volumes in the objects covered, but here the author, George Robert Kepple, focuses more intently on the Milky Way region. He's added more than 1,000 new objects not previously covered, including E. E. Barnard's entire *Catalogue of Dark Markings of the Sky*, a great many planetary nebulae, the van den Berg reflection nebulae, and Beverly Lynds' *Catalogue of Dark Nebulae*. More than 800 objects listed in the earlier volumes were also updated with new notes and/or photographs.

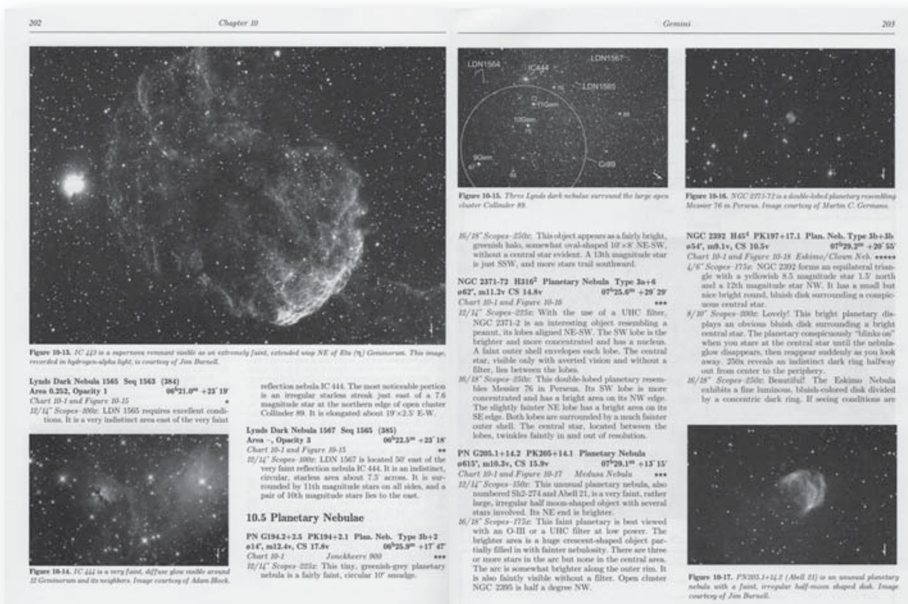
I found the first chapter to be a satisfying refresher and primer on visual observing basics. It covers the characteristics and nature of the different kinds of astronomical targets, conventions for making observing logs, and some advice on record keeping, sketching, eyepiece usage, and so on. This book is an excellent place to start for any beginning observer, and the Milky Way is a buffet of delicious objects for telescopes of all sizes as well as for binoculars.




Advanced observers will also appreciate the remainder of this book, and, in fact, it would be a mistake to think it isn't useful for imagers. Each chapter focuses on a specific constellation with annotated charts, photographs, or sketches of each object. The observing notes are rich, not tedious, and frequently show how the target will look through different instruments: 8×50 binoculars, 8- to 10-inch scopes at 100×, or 12- to 14-inch scopes at 125×, for example. When appropriate, Kepple also describes the effects of using a UHC, O III, or H-Beta visual filter. In addition to "faint fuzzies," a plethora of interesting star clusters (977 in total) that should be accessible even with modest optics at moderately light-polluted locations are included in the target list.

I've seen my share of observing guides for which the images were reaped from an old set of photographic plates, typically with large areas completely blown out or saturated. As an imager, I was pleased with the high-quality photographs and sketches provided for all of the discussed objects. In fact, just leafing through the book, I've discovered many dozens of new targets that I want to photograph . . . I mean . . . observe with my Dobsonian.

■ **RICHARD S. WRIGHT, JR.** is a senior software engineer and imaging evangelist for Software Bisque. Occasionally, though, when no one's looking, he will peek through a neighbor's eyepiece.

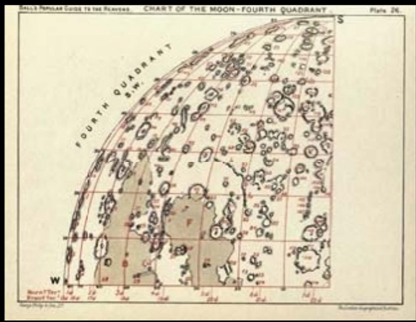


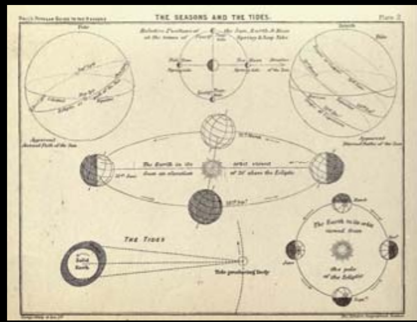
 by Klaus Brasch

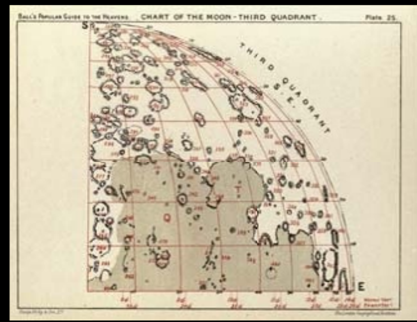
# Just Over a Century Ago

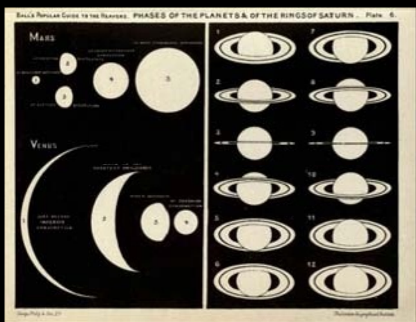
What could the reading public know about astronomy in 1900?

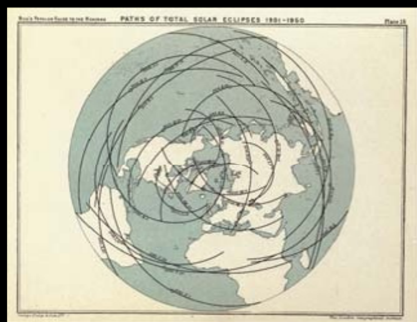
ROBERT BALL, *A POPULAR GUIDE TO THE HEAVENS* (1904) / PUBLIC DOMAIN (15)



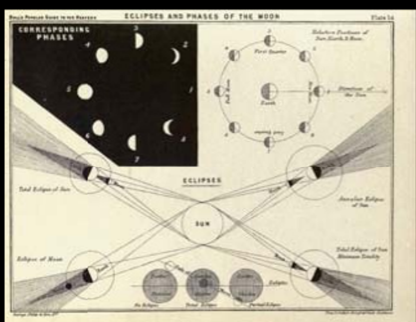



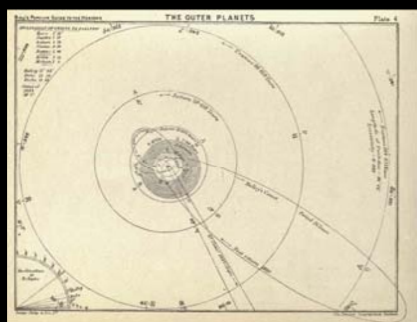



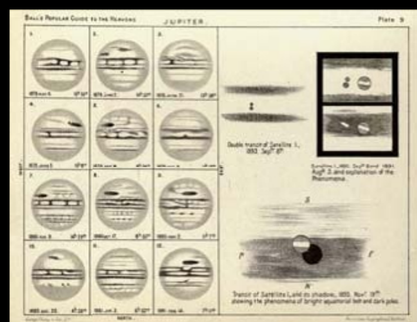



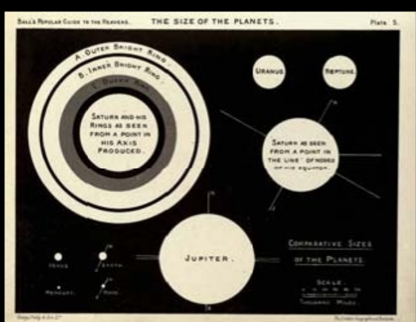





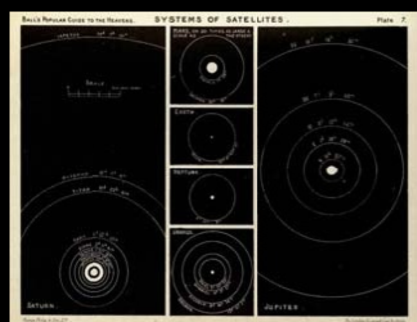


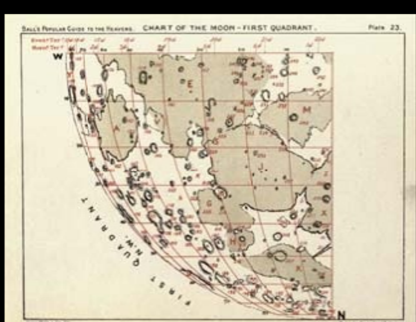



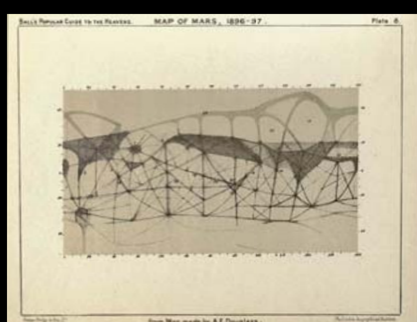



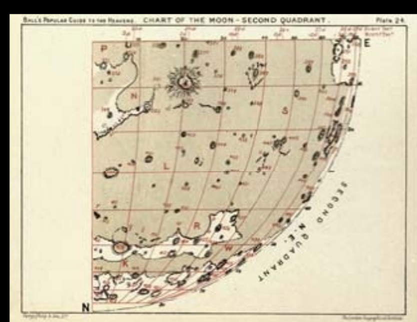




> *"We do appear to be fast reaching the limits of our knowledge."*
>
> — Simon Newcomb, *The Sidereal Messenger*, February 1888



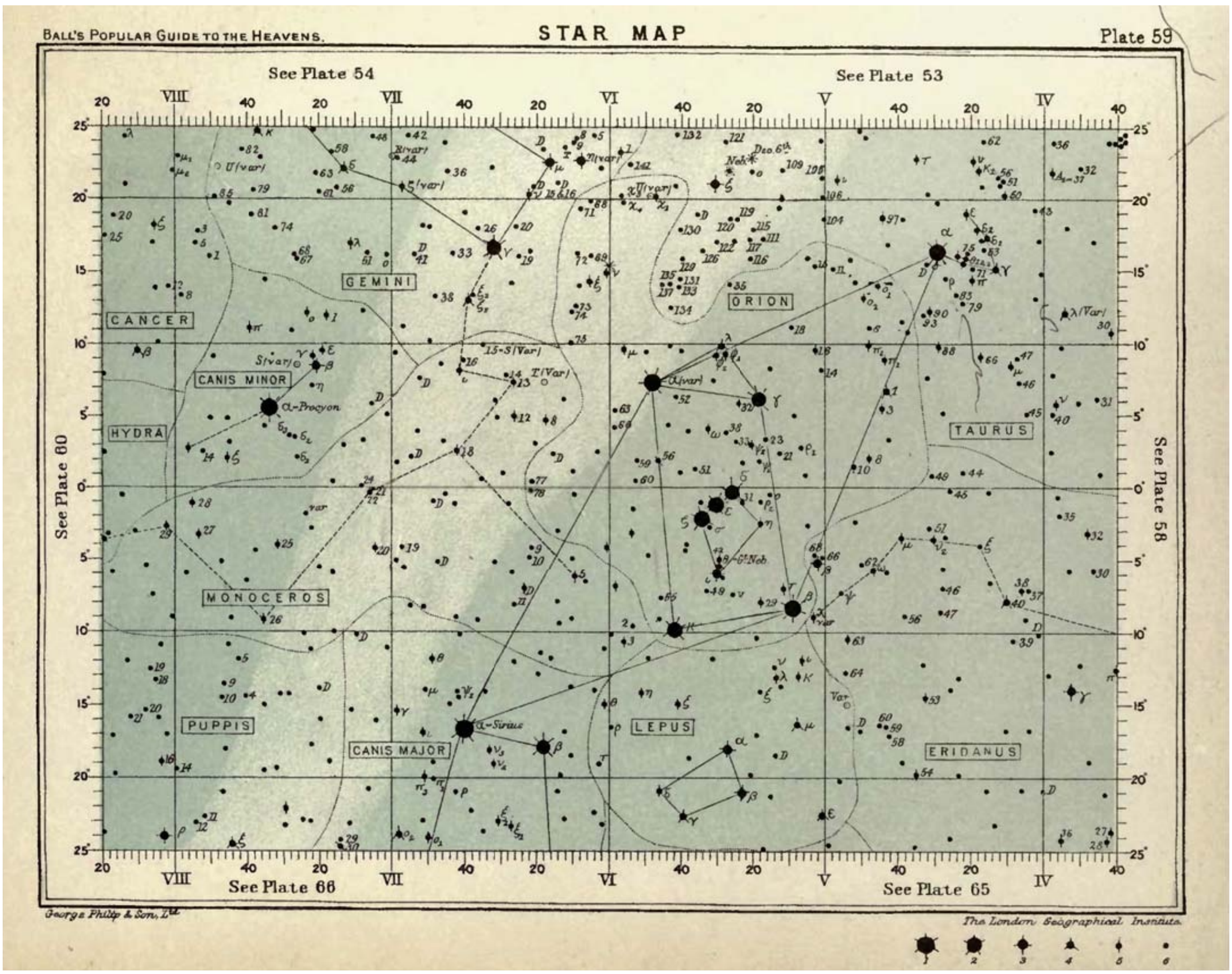



As we ponder today's remarkable advances in science and technology, it's instructive to look back a century or so to fully appreciate just how far we've come. A few years ago, it was said that the sum total of human knowledge doubled every five years, but today it seems more like exponential growth. Take terms like *exoplanet* and *exobiology* or, more commonly now, *astrobiology*. All were coined decades ago but remained largely theoretical, or "sciences without subject matter," until recently. Exoplanets now prompt some of the most exciting studies in astronomy, and astrobiology has become a driving force of modern space exploration.

How does this compare to our state of knowledge at the turn of the 20th century? What could the interested public know about the universe in the early 1900s? Much insight is provided by such contemporary publications as *L'Astronomie*, a popular French astronomy review published from 1883 to 1894 and edited by prolific author Camille Flammarion; *Astronomy for Everybody*, penned in 1902 by Simon Newcomb, the just-retired director of the U.S. Naval Observatory in Washington, DC, and aimed at a non-expert audience; and lastly, the 1906 edition of *A New Astronomy*, a textbook by David Todd, professor of astronomy and director of the Amherst College Observatory in Amherst, Massachusetts. All three authors were devoted astronomers and science popularizers, and their texts are good indicators of the ideas and theories that moved from academic science into the popular realm.

Before proceeding, we must consider the state of 19th-century scientific knowledge, as well as the technological advances of the time. Most astronomical work was done visually and was devoted to solar system and positional astronomy, time keeping for naval and transportation purposes, and establishing precise ephemerides. Questions about cosmol-



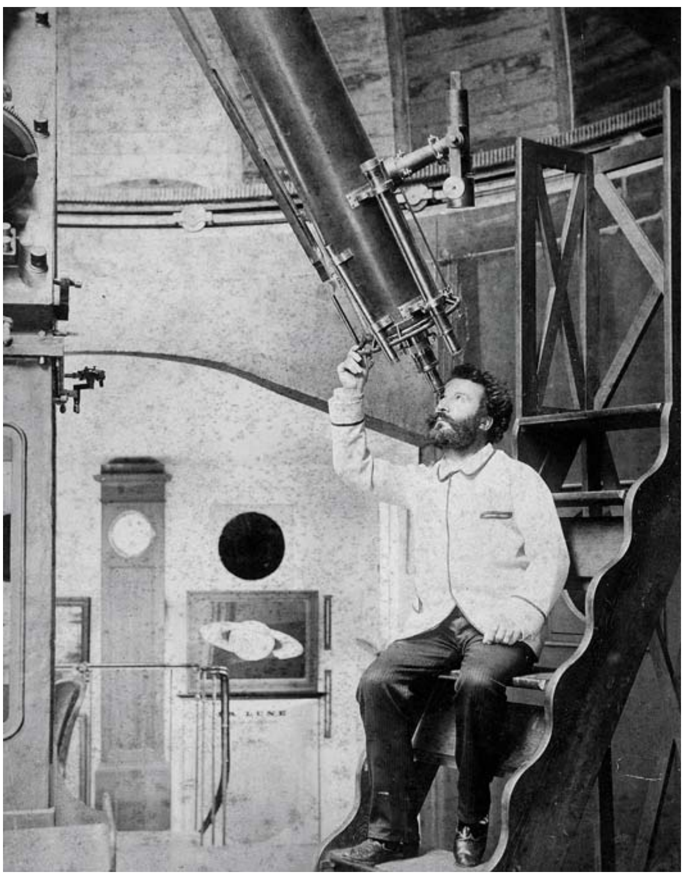

▲ **STATE-OF-THE-ART CHART** In 1904, Robert Ball, professor of astronomy and geometry at the University of Cambridge, updated the finder charts from a late-19th-century celestial atlas. In addition to these new charts, Ball's *A Popular Guide to the Heavens* also included recent maps of the Moon and Mars, photographs of sunspots, prominences, and the solar corona during eclipse, and explanations of the latest astronomical research.

ROBERT BALL, *A POPULAR GUIDE TO THE HEAVENS* (1904) / PUBLIC DOMAIN

> **“What lies before us is an illimitable field, the existence of which was scarcely suspected ten years ago . . .”**

ogy and astrophysics were still in their infancy, and of little “practical” interest to most astronomers. Moreover, powerful new tools like spectroscopy and photography were just beginning to hit the scene. Of the 333 pages in Newcomb’s *Astronomy for Everybody*, nearly 200 were devoted to the solar system, while some 40 covered such basics as time, longitude, the celestial sphere, and the seasons. An additional 40 or so pages fell under the heading “The Fixed Stars.” Just six pages dealt with cosmology. Similarly, of Todd’s *A New Astronomy*’s 480 pages, only the last 50 (excluding the index) covered subjects beyond navigation and the solar system in a chapter titled “The Stars and the Cosmogony.”

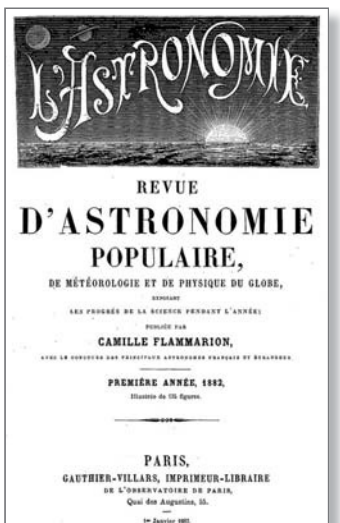
In an 1887 speech that was reprinted in the January and February 1888 issues of *The Sidereal Messenger*, Newcomb confessed that so far as astronomy was concerned, “we do appear to be fast reaching the limits of our knowledge.” Yet by 1902, when he addressed the Astronomical and Astrophysical Society of America, he made clear that his views had changed. “What lies before us is an illimitable field,” he averred, “the existence of which was scarcely suspected ten years ago. . . .” Perhaps astronomical knowledge was not so bounded after all!



## What Fuels the Sun?

What was known about the physics of our Sun at the opening of the 20th century? Not a lot, it would seem. Beyond its overall dimensions and evident surface features, virtually nothing was known of our star’s real age and inner workings. Flammarion, Todd, and Newcomb all dealt expansively with visible solar phenomena, especially sunspot frequency, size, and shape, in their public writings. For instance, issue No. 4 in 1894 of *L’Astronomie* featured many beautiful lithographs of major sunspots, as well as a paper on the physical properties of the Sun that detailed its rotational aspects and what sunspots might tell us about the solar interior. Since features like prominences and the corona were only visible during relatively rare total eclipses, not much was known of them, and based on early spectroscopic data, Newcomb described them as “. . . large masses of incandescent vapour burst forth from every part of the Sun.”

The fundamentals of nuclear fusion wouldn’t become clear until the 1920s and 1930s when Arthur Eddington suggested, and later Hans Bethe and others showed, that the Sun’s main source of energy involved the fusion of hydrogen to helium. Prior to that, vague theories of meteoric impacts, solar contraction, and heat output were proposed, which, if true, would make the Sun at most a few million years old, something most scientists knew couldn’t be the case. As Todd noted, “Only one possible explanation remains; if the Sun is contracting upon himself [sic], no matter how slowly, gases composing his volume must generate heat in this process. The eminent German physicist, von Helmholtz first proposed this theory of maintenance about 1850, and it is now universally accepted.” Agreeing that the Sun’s heat was maintained by uniform contraction, Todd speculated that the Sun, then thought to be about 20 million years old, would’ve shrunk to half its present diameter in 5 million years and “might continue to emit heat sufficient to maintain certain types of life on our earth” for an additional 5 million years. He figured the solar system life expectancy at 30 to 40 million years.


L’ASTRONOMIE

REVUE
D’ASTRONOMIE
POPULAIRE,
DE MÉTÉOROLOGIE ET DE PHYSIQUE DU GLOBE,

CAMILLE FLAMMARION,

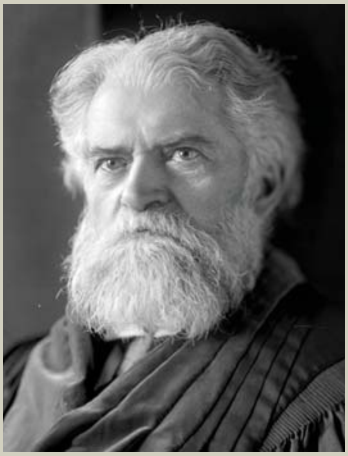
PREMIÈRE ANNÉE, 1882,

PARIS,
GAUTHIER-VILLARS, IMPRIMEUR-LIBRAIRE
DE L’OBSERVATOIRE DE PARIS,
Quai des Augustins, 55.

◀◀ **AT THE EYEPIECE** Camille Flammarion perches before the 240-mm (9½-inch) Bardou refractor at his observatory in Juvisy-sur-Orge, c. 1885.

◀ **FIRST RELEASE** The first issue of *L’Astronomie*, the cover page for which is shown here, came out in January 1883 (though it was written in 1882). The popular magazine was printed monthly through 1894, after which time it merged with the *Bulletin mensuel de la Société Astronomique de France*, the official journal of the French Astronomical Society.

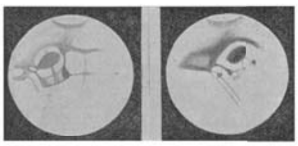
CAMILLE FLAMMARION: PUBLIC DOMAIN; TITLE PAGE *L’ASTRONOMIE*: *L’ASTRONOMIE* (1882) / PUBLIC DOMAIN



◀ **POPULAR POPULARIZER** Simon Newcomb became professor of astronomy at the U.S. Naval Observatory in 1861. Newcomb was a prolific writer and frequently penned popular astronomy columns for *McClure's Magazine*, some of which served as the basis for his 1902 book *Astronomy for Everybody*.

134 *Publications of the*

The accompanying cut reproduces two of the plates there given. The left hand drawing was made by Mr. CAMPBELL, August 14, at $11^h 15^m$ P. s. t. *Ganges* was at that time single. The right hand drawing was made by Mr. HUSSEY, August 17, at $11^h 15^m$ P. s. t., and it shows *Ganges* to be doubled. This was also shown by entirely independent drawings by Messsrs. SCHAEBERLE and CAMPBELL on the same night.



The LICK Observatory intends to print an octavo volume at some future time, giving all the observations of *Mars* made here in 1892, with a selection of the best drawings. The present number of the *Publications* contains four plates already made for the volume in question. Plate $S^1$ was made from drawings by Mr. SCHAEBERLE. Plates $H^1$, $H^2$, $H^3$ were made from drawings by Mr. HUSSEY. When the pictures of Dr. BARNARD and of Mr. CAMPBELL are added to those now given, some idea of the number and excellence of the drawings made here can be had. A very great number of micrometer measures were obtained by the different observers during the summer. Considering the very low altitude of the planet, the number and the detail of the pictures is remarkable. The planet was almost continuously under observation for several months. I think there is no doubt that no other series of observations of *Mars* of anything like equal importance were obtained elsewhere. E. S. H.

NOTICE REGARDING ASTRONOMICAL PHOTOGRAPHS.

A paragraph in the *Mon. Not.*, R. A. S., Vol. 53, p. 350, states that arrangements have been made by means of which any person can procure copies of photographs, etc, in the possession of the Royal Astronomical Society by application to Messrs. EYRE and SPOTTISWOOD, East Harding Street, Fetter Lane, London E. C., at a fair price. This very liberal provision will enable any of our members to provide themselves with astronomical photographs

▲ **ASTUTE OBSERVER** Simon Newcomb was openly skeptical of Percival Lowell's claim that a canal network, constructed by intelligent beings, existed on Mars. Though he included Lowell's map of Mars with its supposed canals in *Astronomy for Everybody*, he also directed the reader to look attentively at the drawings of Mars made at Lick Observatory by W. W. Campbell *(left)* and W. J. Hussey *(right)* during the 1892 opposition.

"The reader will excuse me from saying anything about the possible inhabitants of Mars."

## The Moon: Volcanism or Impacts?

The origin and nature of lunar craters was a long-standing mystery for astronomers and wasn't fully resolved until the 1960s when geologist and planetary scientist Gene Shoemaker showed definitively that most craters were due to meteoric impacts. Prior to that, consensus was that lunar craters were volcanic in origin. As Newcomb stated, "There is an almost exact resemblance between them and the craters of our great volcanoes." This point of view stemmed in large measure from the "fountain model" of volcanic eruptions on the Moon proposed by James Nasmyth and James Carpenter in 1874 and illustrated by their magnificent if fanciful plaster-of-Paris models of the lunar surface in their book *The Moon: Considered as a Planet, a World, and a Satellite*.

Comparing Nasmyth and Carpenter's models of lunar "volcanoes" with the Vesuvius region of Italy, Todd stated unequivocally that the volcanic origins of both sites were "self-evident." In describing the prominent lunar crater Tycho and its extensive system of ejecta rays, Newcomb also opined that it appeared "as if the moon had been cracked and the cracks filled with melted white matter." It would be decades before definitive evidence shattered the volcanic theory of lunar crater formation.

## Shrouded Venus

Much early discussion centered on the rotation periods of both Mercury and Venus and the illusive appearance of their respective visible features. Todd had a longstanding interest in Venus in particular. Indeed, he was responsible for a sizeable fraction of the approximately 1,380 measurable photographic plates taken by U.S.-based expedition teams formed to observe the 1882 transit of Venus. Curiously, after sharing typical illustrations of "dull, indefinite markings" on Venus with readers of *A New Astronomy*, Todd went on to emphasize "new" observations by Percival Lowell and Andrew Douglass of prominent radial streaks on Venus — all of which were later shown to be illusory.

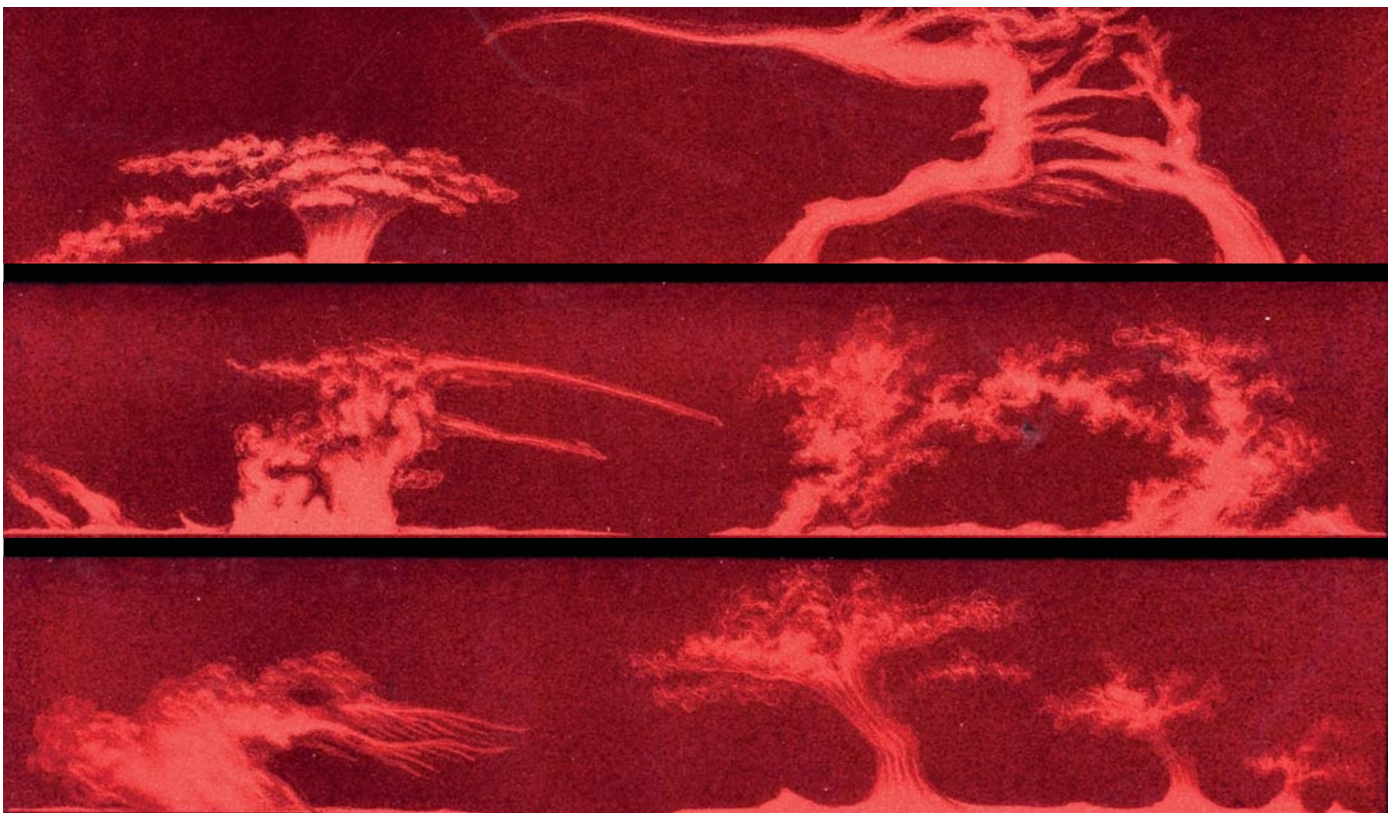
Newcomb also described his observations of the transit of Venus in *Astronomy for Everybody*, concluding that the planet's atmosphere is "so full of vapour that we cannot see the light of the Sun by direct refraction through it." Instead, we see "an illuminated stratum of clouds or vapour floating in an atmosphere. Such being the case, it is not at all likely that astronomers on Earth can ever see the solid body of the planet through these clouds." Finally, he dismissed reports of a putative Venusian moon, as well as occasional claims of a faint glow on the unilluminated portion of the planet's hemisphere at inferior conjunction, as an optical illusion. This latter phenomenon, also known as the *ashen light*, remains a point of contention to this day.

## Mars: Canals or Illusions?

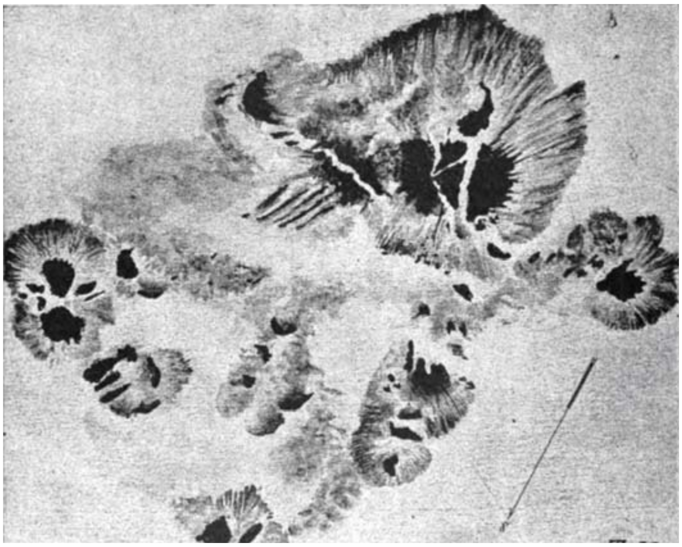
When they turned to Mars, all three authors had much to say. Since visual observing, principally with large refractors, was at its peak, speculation about Mars, its alleged canals, and possible inhabitants was at a fever pitch with the general public. This obsession was triggered in 1877, after celebrated Italian astronomer Giovanni Schiaparelli reported seeing linear structures on the planet he termed "canali" (*S&T:* July 2018, p. 28). A perusal of virtually any 1894 issue of *L'Astronomie*, Flammarion's 1892 epic *La planète Mars et ses conditions d'habilité*, or Percival Lowell's 1906 book *Mars and its Canals*, provides a full sense of how widespread and hotly debated the canal issue was at the time. Like Lowell, Flammarion very much believed in the reality of the canals and that they were the work of intelligent beings. Similarly, Todd, while being more cautious about intelligent Martians, seemed fully on board with depictions of the extensive canal networks as artificial in nature, with the following caveat: "By only long continued observations . . . of Mars, can we hope for a rational solution of the question of life in another world than ours."

In contrast, Newcomb took a totally analytical approach. After evaluating reports by numerous observers concerning the visibility and possible nature of the putative canals, he noted that renowned Lick Observatory astronomer E. E. Barnard, whom he described as "one of the most cautious observers," had studied Mars with "the largest and finest telescope in the world . . . under the best possible conditions," yet didn't draw features that "quite correspond[ed] to the channels of Schiaparelli and Lowell." Newcomb pointed out that "all recent observers are in agreement that, if Mars has any atmosphere at all, it is much rarer than our own and contains little or no aqueous vapour." In other words, there was nothing in Mars's atmosphere that would obscure Barnard's view of the planet's topography. If Barnard didn't see it — it wasn't there. As far as Lowell's presumed intelligent Martians were concerned, Newcomb acerbically concluded that "The reader will excuse me from saying anything about the possible inhabitants of Mars. [The reader] knows just as much on the subject as I do, and that is nothing at all."

◀ **ASTRONOMER IN CHARGE** David Peck Todd started his professional career at the U.S. Naval Observatory in Washington, DC, but joined the faculty of Amherst College, Massachusetts, in 1881. Todd helped organize and led several eclipse expeditions and was head astronomer for observations of the 1882 transit of Venus from Lick Observatory.



▲ **OTHERWORLDLY OUTBREAKS** Although Todd's discussion of the Sun's chromosphere and prominences centered on the use of the spectroheliograph to capture images on dry plates, he used lithographs by the noted French artist and astronomer Étienne Trouvelot to illustrate the discussion.



▲ **BAD BREAKOUT** Flammarion regularly included dramatic sketches of large sunspots in *L'Astronomie*, including this one of the great spot of November 1893 as sketched by Théodore Moreaux of Bourges.

## Jupiter: A Small Sun?

Jupiter's cloud features and its prominent satellites naturally received ample attention at the dawn of the 20th century, but only Newcomb showed much insight into the planet's inner workings, drawing comparisons between it and the Sun. He came to the conclusion that Jupiter could be a small Sun based on simple calculations that showed the planet's density must be much less than Earth's, in fact, "only about one third greater than the density of water," while its surface gravity was "between two and three times that at the surface of the earth." That is, greater compression due to gravity resulted in greater density. From this he concluded that Jupiter's "outer portions at least were composed of aeriform matter." Combining his argument on density with evidence of rotation, Newcomb suggested that Jupiter had "a greater or less resemblance to the Sun in its physical constitution." On the whole, he viewed Jupiter as "a small sun of which the surface has cooled off till it no longer emits light." Newcomb would have prized brown dwarfs!

## Is the Milky Way All There Is?

To illustrate the then-known extent of the universe, Newcomb took the reader on an imaginary voyage from Earth to the "inconceivable" distance of 100,000 light-years. "So far as we know," he revealed, "we should at this point find ourselves in utter darkness, a black and starless sky surrounding us on all sides. But, in one direction, we should see a large patch of feeble light spreading over a considerable part of the heavens like a faint cloud or the first glimpse of dawn. Possibly, there might be other such patches in different directions, but of those we know nothing." Newcomb imagined the observer flying toward one of those light patches, watching as it spread over more and more of the sky with each passing moment.

Interestingly, Newcomb's concept of the cosmos didn't extend much beyond William Herschel's 1785 depiction of the Milky Way, which was based on star counts and positional measurements of clusters and nebulae, and Herschel's proposed position of the Sun. Oddly as well, Newcomb made no mention of "island universes" (galaxies), an idea proposed in the 18th century by philosopher Immanuel Kant, and instead described the Milky Way as ". . . a girdle apparently spanning the sky and perhaps, in reality, spanning the entire universe of stars, uniting them, as it were, into a single system, one stupendous whole." This collection of "millions of stars," some of which had bodies (planets) associated with them, comprised the knowable universe.

In contrast to that of Newcomb, Todd's perspective was significantly more developed, probably reflecting the difference in their ages. Newcomb was retired and approaching 70 at the turn of the 20th century while Todd was still in his mid-40s and an active scientist when he wrote *A New Astronomy*. Consequently, he used the term "galaxy" in reference to the Milky Way and clearly hinted that the Great Nebula in Andromeda was different from many of the other nebulae that had been cataloged by then. "Its spectrum shows that it is not gaseous," he wrote, yet "still no telescope has yet proved competent to resolve it."

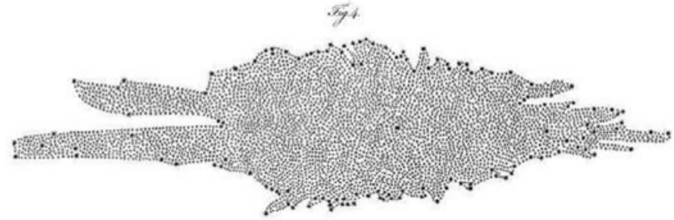
Keeping in mind that the term "universe" at the time referred only to what had been mapped of the Milky Way, which also was thought to encompass all stars and assorted

▶ **AIMING FOR VERACITY** James Nasmyth took up astronomy after a successful career as a mechanical engineer. In 1874, he co-wrote *The Moon: Considered as a Planet, a World, and a Satellite* with the professional astronomer James Carpenter. The pair illustrated their discussions with photographs of elaborate plaster-of-Paris models based on drawings that "were again and again repeated, revised, and compared with the actual objects" in an attempt to represent the lunar surface as accurately as possible.


SUNSPOTS: *L'ASTRONOMIE* (1894) / PUBLIC DOMAIN; LUNAR MODEL: RIJKSMUSEUM / PURCHASED WITH THE SUPPORT OF THE MONDRIAAN STICHTING, THE PRINS BERNHARD CULTUURFONDS, THE VSBFONDS, THE PAUL HUF FONDS/ RIJKSMUSEUM FONDS AND THE EGBERT KUNSTFONDS / PUBLIC DOMAIN

## “Are, then, the inconceivable vastnesses of space tenanted with other universes than the one our telescopes unfold?”

“nebulae,” it’s remarkable that Todd dared to venture further in his final section, titled “Other Universes than Ours.” Asking what lies beyond, he stated that “outside the realm of fact, imagination alone can answer,” and wondered, “Are, then, the inconceivable vastnesses of space tenanted with other universes than the one our telescopes unfold?”



▲ **TAKING MEASURE** William Herschel’s depiction of the sidereal universe in his 1785 paper “On the Construction of the Heavens” was based on star counts and positional measurements (“star gages”). The central star marks the presumed position of the Sun.

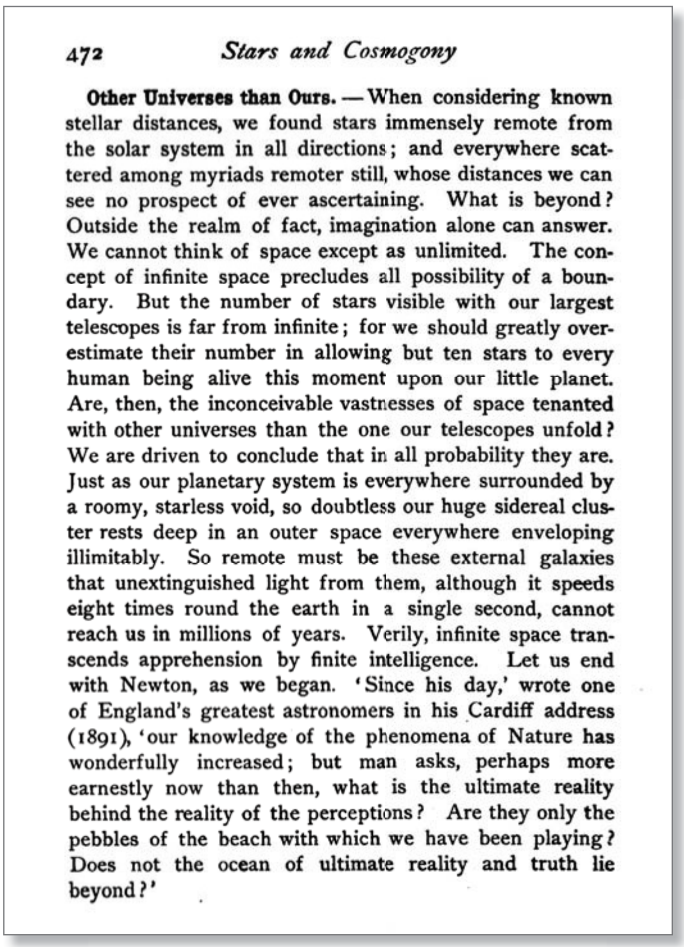
### Technology: Refractors Rule

Probably no chapter in *Astronomy for Everybody* shows more clearly how much things have changed in the past 100 or so years than the one titled “Astronomical Instruments.” In 1902 refractors still reigned supreme even though it had become clear by then that the 40-inch Yerkes behemoth would never be topped. In its day, building anything larger than a 40-inch was no doubt equivalent to producing 8-meter-class telescope mirrors today. There were several reasons for this, including the immense mechanical challenges in supporting such an ungainly and heavy instrument, and the fact that a much larger objective would sag under the force of gravity, thereby distorting its finely configured shape. This was amply demonstrated by the Great Paris Exhibition Telescope of 1900, which had a 49.2-inch (1.25-meter) diameter lens and had to be fixed horizontally to overcome gravitational distortion. It was subsequently abandoned.

Despite such clear limitations, Newcomb extolled the virtues of refractors and had little use for reflectors. He called them “contrivances” and maintained (fairly enough) that “the great difficulty in using a large mirror is that it bends under the influence of its own weight” when exceeding four feet in diameter, and therefore “[The] performance of reflectors generally . . . has not corresponded to their size.” Little did he realize that just a few years later the great 60-inch at Mount Wilson Observatory would lay all those objections to rest for good.

It’s also sobering to recall that beginning in 1905, just three years after Newcomb’s book came out, Albert Einstein would publish a series of groundbreaking papers, including the one that detailed his special theory of relativity, which would shake the foundations of modern physics and forever change our views of space, time, and matter. Likewise, in the following decades, the reflectors at Mount Wilson Observatory and Dominion Astrophysical Observatory in British Columbia would revolutionize our understanding of the size of the universe and the nature of galaxies.

▼ **HOW DOES IT ALL WORK?** In considering stellar distances, Todd ventured to propose that space was unlimited, without boundary, and populated with unseeable universes like our own.



472 *Stars and Cosmogony*

**Other Universes than Ours.** — When considering known stellar distances, we found stars immensely remote from the solar system in all directions; and everywhere scattered among myriads remoter still, whose distances we can see no prospect of ever ascertaining. What is beyond? Outside the realm of fact, imagination alone can answer. We cannot think of space except as unlimited. The concept of infinite space precludes all possibility of a boundary. But the number of stars visible with our largest telescopes is far from infinite; for we should greatly overestimate their number in allowing but ten stars to every human being alive this moment upon our little planet. Are, then, the inconceivable vastnesses of space tenanted with other universes than the one our telescopes unfold? We are driven to conclude that in all probability they are. Just as our planetary system is everywhere surrounded by a roomy, starless void, so doubtless our huge sidereal cluster rests deep in an outer space everywhere enveloping illimitably. So remote must be these external galaxies that unextinguished light from them, although it speeds eight times round the earth in a single second, cannot reach us in millions of years. Verily, infinite space transcends apprehension by finite intelligence. Let us end with Newton, as we began. ‘Since his day,’ wrote one of England’s greatest astronomers in his Cardiff address (1891), ‘our knowledge of the phenomena of Nature has wonderfully increased; but man asks, perhaps more earnestly now than then, what is the ultimate reality behind the reality of the perceptions? Are they only the pebbles of the beach with which we have been playing? Does not the ocean of ultimate reality and truth lie beyond?’

HERSCHEL’S UNIVERSE: *PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY OF LONDON* (1785) / PUBLIC DOMAIN; TODD’S “OTHER UNIVERSES”: TODD, *A NEW ASTRONOMY* (1906) / PUBLIC DOMAIN

### Such a Short Time

Can this brief retrospective on the status of astronomical knowledge at the turn of the 20th century provide some insight as to where we will be 100 years hence? Simon Newcomb had some advice on that score as well, pointing out that “one of the greatest problems of astronomy is, when and how did this journey begin and when and how will it end? Before this question our science stands dumb.”

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

# GSO's New 10-Inch Classical Cassegrain

*This scope melds 21st-century technology with an optical plan nearly 350 years old. Some amateurs may find the results pleasantly surprising.*

▲ GSO's 10-inch classical Cassegrain is a solidly built instrument that excels for viewing the Moon, planets, double stars, and many deep-sky objects. It does, however, require a solid mount to take advantage of its high-magnification performance.

ALL PHOTOS BY THE AUTHOR

## GSO 10-inch f/12 Classical Cassegrain

U.S. Price: $2,795

agenaastro.com

### What We Like

First-class mechanical construction

Excellent optics

A reminder that classic optical designs are still viable for amateur astronomy

### What We Don't Like

While the focuser is very good for many visual and photographic applications, an upgrade would be desirable for some critical uses with heavy eyepieces and cameras.

**EVERYTHING ABOUT THE NEW** 10-inch f/12 classical Cassegrain from Taiwan-based Guan Sheng Optical (GSO for short) says 21st century. There's its carbon-fiber truss-tube design, quartz optics, mirror coatings with 96% reflectivity, cooling fans, and a dual-speed, 3¼-inch Crayford-style focuser for starters. But to understand where my head was at while testing the telescope we borrowed from Agena AstroProducts for this review, you need to turn the calendar back to a time well before the Apollo Moon landings and indulge me for a bit of nostalgia.

Back then American amateur astronomy was very different from now. The big-aperture Dobsonian revolution and its emphasis on deep-sky observing wouldn't begin for more than another decade. The same was true for the astrophotography boom that followed the introduction of popularly priced Schmidt-Cassegrain telescopes. Owning a 6-inch Newtonian reflector marked you as a serious amateur, and we usually spent our time at the eyepiece staring at the Moon, planets, a handful of double stars, and the brighter deep-sky objects culled mostly from the Messier catalog.

Forget the internet, personal computers, smartphones, and social media flooding us with instantaneous astronomical information. Back then we got our astronomy fix once a month when *Sky & Telescope* showed up in the mailbox — you know, the metal kind on a post out by the end of the driveway. As I'd walk from the mailbox to the house the world around me seemed to fade into the background as I pulled the magazine from its manila envelope and began flipping pages.

The advertisements were as fascinating as the articles. Those slick Unitron ads on the back cover were mesmerizing since then, as now, refractors held a special place in the hearts of amateurs. Big reflectors also captivated my imagination. And then there were the Cassegrain reflectors. Most of the major telescope manufacturers offered them — Cave, Tinsley, and Optical Craftsman, to name a few. They were expensive, and that alone made them seem special. I'm sure I wasn't the only young amateur to dream about observing with one.

As the years passed, I learned a lot more about telescopes and observing than I knew then, but that didn't stop those early memories from surfacing as I unpacked the 10-inch GSO Cassegrain. And the best part? It was a fantasy fulfilled — the views through the scope surpassed what I'm sure I was imagining back in the '60s, even with the now-critical eye of an experienced observer.

## What's Special About a Classical Cassegrain?

Given the plethora of modern telescope designs, it's reasonable to ask if an optical configuration from the 17th century has anything special to offer today. The short answer is that for many visual observers and some types of astrophotography it offers a lot. Like a Newtonian, it has only two mirrors so it is highly efficient at transmitting light, and it's 100% achromatic, focusing all wavelengths from ultraviolet through infrared to a single point. There's no need to tweak the focus when using different color filters, either for visual observing or astrophotography. There's also no front corrector plate that can dew up, and for many of us that's a huge plus.

The scope's f/12 focal ratio is very forgiving of eyepiece designs. One stop on my trip down memory lane involved digging out a couple of 1963-vintage Edscorp Orthoscopic eyepieces from Edmund Scientific. They performed beautifully with the scope even though they can't come close to competing with modern designs that have larger apparent fields, which translate into larger true fields of view for a given magnification on any telescope.

It shouldn't be necessary to remind readers today, but it's still worth repeating that a telescope's f/number only affects the brightness of extended objects (think anything other than stars) focused onto an imaging detector. Stars appear the same brightness visually in any 10-inch telescope regardless of its f/number. And likewise, extended objects appear the same brightness for any 10-inch telescope regardless of its f/number as long as you are viewing with the same magnification.

## Notes on Using the Scope

The GSO 10-inch classical Cassegrain is a first-class instrument. The optics proved to be excellent. They were perfectly collimated out of the box (Agena AstroProducts says it checks every telescope optically before it's shipped.) Images would snap into focus the moment you hit the sweet spot when focusing an eyepiece. The scope's mechanics are well designed and manufactured. But there are some things to consider when it comes to using this scope. Foremost is its relatively long focal length of 120 inches (3,048 millimeters), which, for visual use, makes it a high-magnification telescope. For example, I typically do low-power observing with a Tele Vue 35-mm Panoptic eyepiece, which on this scope yields a substantial 87× and a true field about ¾° wide — big enough to show the entire Moon, but still too small for some splashy open star clusters and showpiece nebulae and galaxies. The maximum field possible with a 2-inch eyepiece (limited by its barrel diameter) is only 53 arcminutes.

For the other end of the magnification spectrum, I used a Tele Vue 3.7-mm Ethos eyepiece yielding 824× and an 8-arcminute field. That's beyond the oft-recommended top magnification of 75× per inch of telescope aperture, and it's a testament to the scope's fine optics. I resorted to this seemingly ridiculous magnification when splitting some of the challenging double stars listed in Phillip Kane's article on finding a telescope's Dawes limit (*S&T:* September 2016, p.30). For the record, the scope easily split SST 359 in Hercules with a separation of 0.75 arcsecond, so I have little doubt that under good observing conditions it would

▼ *Left:* More so than with some optical designs, a Cassegrain's performance is sensitive to optical collimation. The scope was perfectly collimated out of the box, in part thanks to its rigid secondary-mirror assembly. *Right:* Well-made light baffles keep extraneous sky light from the scope's focal plane on axis, but a small annulus of light around the secondary mirror can reach the edge of some 2-inch eyepieces. It did not present a problem during the author's visual and photographic testing.

*Far left:* The mounting base for the focuser has tip/tilt adjustments to aid with precision collimation and squaring equipment to the scope's optical axis. A trio of small fans powered by a supplied battery holder for eight AA batteries helps acclimate the primary mirror to ambient air temperature. *Left:* Heavy-duty, tight-fitting plastic dust covers for the primary and secondary mirrors protect the optics when the scope is stored.

split doubles at its Dawes limit of 0.46 arcsecond even though poor seeing and clouds foiled my attempts to prove that by observing 51 Aquarii.

The basic scope weighs 38 pounds (17 kg), and a finder, star diagonal, and eyepiece add a couple more. As such, it needs a solid mount, and I found it a good match for my 12-year-old Astro-Physics Mach 1 German equatorial. But here's the rub. For last January's lunar eclipse I put that mount on a temporary aluminum pier made from 5-inch electrical conduit. It was fine for the small scopes used for the eclipse but totally inadequate for the 10-inch Cassegrain. High-magnification views jiggled like a bowl of Jell-O. I had to switch the Mach 1 to a permanent pier made from a scavenged steel streetlight pole 8 inches in diameter. It simply drives home the point that you need a very solid support to enjoy using this scope at high magnification.

There are two Losmandy-style dovetail mounting bars on the GSO scope. Equipped for typical observing or photography, the scope's balance point falls near the center of these dovetails, but be aware that the bars are only 10 inches long. When the scope was balanced in the long saddle of my Mach 1 mount, neither of the saddle's two clamps would engage the scope's dovetail bar. This might not be a problem for short saddles or ones with three or more clamps, but I had to mount my own long dovetail bar to the scope to make it work with my setup.

The scope's focus falls a generous 9½ inches (about 240 mm) outside the rear cell. The tip/tilt adjustable mounting base for the focuser consumes 1½ inches of this back focus, and the focuser another 3½ inches, but that still leaves plenty of space for a complex camera setup with a filter wheel and off-axis guider. The scope comes with three extension tubes (a pair 1 inch long and one 2 inches long), giving you a huge amount of flexibility in positioning the focuser the right distance from the rear cell for various visual and imaging setups. The downside is that the focuser has only 2 inches of travel. This was adequate for most of my eyepieces and a star diagonal without using extension tubes. But adding a Barlow lens often meant having to add one of the extensions — a bit of an inconvenience.

The first quarter Moon nearly fills the long dimension of a full-frame DSLR thanks to the scope's relatively long, 3,048-mm focal length.

For much of my observing the dual-speed focuser was fine. But some of my heavier eyepieces required putting a fair amount of tension on the focuser's drive shaft to keep it from slipping, and that made the fine-focus knob feel spongy and even slip at times. It wasn't a show-stopper, but for critical high-magnification observing with heavy eyepieces it would be nice to have the precision control that a quality rack-and-pinion focuser offers. The same goes for imaging with heavy camera setups.

## Photographic Performance

Speaking of imaging, this classical Cassegrain is superb for lunar and planetary work, but for wide-field deep-sky photography, it has limitations that go beyond its relatively slow f/number. Even at the edge of the 40-arcminute-wide field captured by a full-frame DSLR camera, stars showed the noticeable effects of a Cassegrain's inherent coma. There are more reasons than just faster f/numbers that make modern optical designs preferred by today's deep-sky photographers working with large-format cameras. Even so, as the images here prove, for some of the smaller and brighter deep-sky objects, especially open and globular star clusters, the 10-inch GSO Cassegrain does a great job. Had I shown up at

While some might consider f/12 slow for deep-sky imaging, the 10-inch Cassegrain made up for its lack of photographic speed by offering substantial resolution for small, bright objects. These views of M13 (left) and M27 (above) were each assembled from a stack of ten 5-minute exposures with a Nikon D700 DSLR camera set to ISO 400.

an astronomy-club meeting with these images in the '60s, people would have been flabbergasted. I would have been flabbergasted too, and to prove that point to myself I made the images with a DSLR set to ISO 400 — homage to the cameras and Kodak Tri-X film that was state of the art back then.

## Observing Impressions

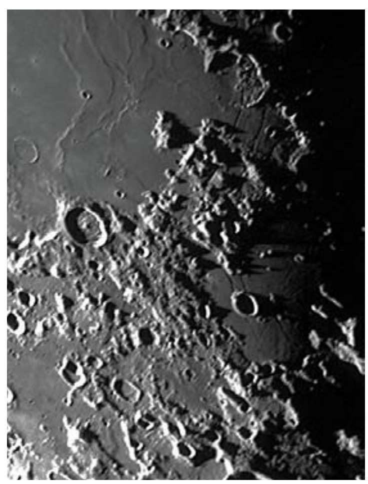
This is a hardware review and not an observing article, so I can't take a lot of space to wax poetic about the time I spent observing with the GSO Cassegrain. But it was a lot of fun. On several sultry nights last summer, armed with *Sky & Telescope's Pocket Sky Atlas,* I tracked down hundreds of targets along the Milky Way from Sagittarius to Cassiopeia. My light-polluted sky took its toll on faint nebulae, but many double stars and star clusters were simply beautiful at magnifications of about 150×, showing subtle star hues with unusual purity. Bumping the magnification up to 305× with a Tele Vue 10-mm Delos eyepiece made easy work of distinguishing many tiny planetary nebulae from surrounding stars — something that isn't as easy using the same eyepiece on my 12-inch f/5 Dobsonian, because the magnification is barely half that of the 10-inch Cassegrain.

From my backyard observatory this past summer, Jupiter and Saturn were only visible as they skimmed the treetops after dusk when the heat of the day was still shimmering up from the foliage. As such, the seeing was poor, but there were still moments when the views were excellent. Those and the success I had observing the Moon in a higher sky make it clear to me that the scope is a superb planetary instrument.

For the types of observing and imaging mentioned above, I can highly recommend the 10-inch GSO classical Cassegrain. There are other choices for wide-field observing and astrophotography, but in many respects those instruments can't compete with a Cassegrain when it comes to the Moon, planets, double stars, and star clusters that have been hallmarks of observers for several hundred years. For these objects a classical Cassegrain really does excel.

One reason **DENNIS DI CICCO** finds astronomical nostalgia intoxicating is because observing the night sky remains every bit as exciting now as it was when he was a teenager.

The scope is a superb instrument visually and photographically for the Moon and planets. These images of Copernicus (left), Gassendi (middle), and the southern shore of Mare Humorum with crater Vitello (right) were made with a Celestron Skyris 618M video camera at the scope's f/12 focus.



## ▶ FULL-FRAME CMOS

QHYCCD announces the QHY600U3 ($5,000), a 16-bit, back-illuminated CMOS camera for deep-sky astrophotography. The camera is designed around the 35-mm-format Sony back-illuminated IMX455 CMOS sensor, which has a 60-megapixel array measuring 36×24 mm with 3.76-micron-square pixels. Its dual-stage thermoelectric cooling is capable of stable temperatures of 35°C below ambient, combined with its ultra-low 1e- read noise to produce smooth, noise-free images. The QHY600U3 is available with monochrome or color detectors and is capable of recording 2.5 full-resolution, 16-bit frames per second through its USB 3.0 interface. An internal 1-gigabyte DDR3 image buffer ensures no frames are dropped during downloads. Each camera comes with a 1-meter, 12-volt threaded power cord, a 1.5-m USB 3.0 cable, and a CD with camera drivers and control software.

**QHYCCD**
qhyccd.com


## ◀ DUAL SOLAR FILTER

DayStar Filters announces the Quark Gemini Hydrogen-Alpha Filter ($1,995). This specialized solar Hα filter fits between your refractor's star diagonal and eyepiece, allowing you to see prominences, filaments, and active regions in the solar chromosphere. The Quark Gemini incorporates two separate Fabry-Perot Etalon elements that can be slid safely in the optical path. One Etalon provides a wide passband that reveals prominences along the solar limb, while the other has a narrower passband that excels in displaying features across the solar disk. Each filter is tunable across an entire angstrom in 0.1-angstrom increments. The Quark Gemini includes a combination 1¼- to 2-inch nosepiece and accepts 1¼-inch eyepieces. The unit is an electrically stabilized filter and includes a 90-to-240-volt wall-current adapter with international connectors.

**DayStar Filters**
149 Northwest OO Hwy., Warrensburg, MO 64093
866-680-6563; daystarfilters.com

## ▶ BIG ED REFRACTOR

Sky-Watcher adds a 6-inch ED apochromat to its affordable line of Evostar refractors. The Evostar 150 APO Refractor ($2,350) is a 5.9-inch f/8 (1,200-mm focal length) doublet that includes one extra-low dispersion (ED) element to produce color-free views at the eyepiece. The telescope weighs 20½ lbs. and is 50½ inches long. Each scope includes a 2-inch dual-speed Crayford-style focuser with 1¼-inch eyepiece adapter and accepts the company's quick-release finder brackets. Additional accessories include tube rings, a Vixen-style dovetail mounting bar, and an aluminum case. A deluxe version (Evostar 150DX) with a 3.4-inch rack-and-pinion focuser, Losmandy D-style mounting plate, and heavy-duty tube-rings is available for $3,200.

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


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

# Revive a Hobby Killer

*Breathe new life into an old monstrosity.*

**PRACTICALLY ALL AMATEUR ASTRONOMERS** are familiar with the term "hobby killer" (see my article on page 36). Those cheap little scopes on wobbly equatorial mounts have dimmed the enthusiasm of countless beginners for decades, yet manufacturers keep spewing them out, especially around the December holiday shopping season. Come January, thousands of people are shivering out in the cold, wondering if something is wrong with them because they just can't get that &@#! thing to work. The scope goes in a closet, the would-be astronomer goes into model railroading, and years later your astronomy club gets the remains (usually missing parts) as a donation.

Sometimes the whole setup is a pile of poo. In that case, it's best used as a boat anchor. (Hey, at least the counterweight is useful!) But often the scope itself is okay; it's just the mount that, shall we say, disappoints.

Fortunately, turning an equatorially mounted Newtonian into a Dobsonian is a piece of cake.

First build a wooden box to go around the tube. Make its inside dimensions ⅛″ larger than the tube so you can put a little padding in there, just enough to hold the tube snug but loose enough to let you move it up and down to fine-tune its balance.

Find something round to use for the altitude bearings. I like pipe end caps. The 5″ black ones work well. I cut them down so they only stick out an inch or so. Sand the back flat so they fit tight against the box.

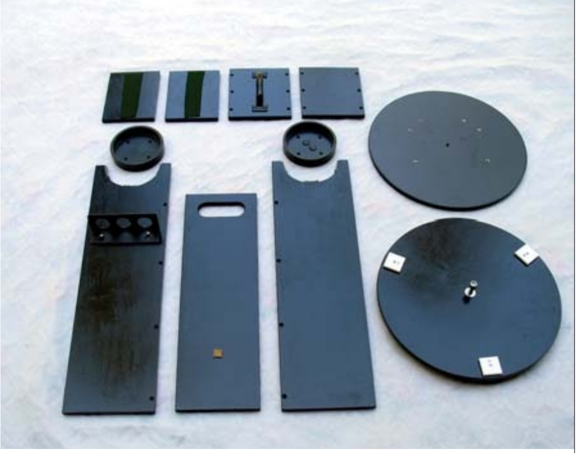
The rocker box is just three upright boards, the two on either side holding the scope tube box and the third one providing support for the other two. Make this middle piece ⅛″ to ¼″ wider than your tube box so the tube box will move inside the rocker box without scraping. Be sure the center piece is short enough to let your scope reach the horizon, and also ensure the whole works is tall enough for the back of the scope to clear the center bolt at the bottom when the scope is balanced with the heaviest eyepiece you expect to use. (The bottom of the scope will get closer to that bolt when you rebalance.) You also want it tall enough to put the eyepiece at a comfortable height, so don't be shy here. A few extra inches of clearance at the bottom won't hurt.

You can cut notches or circles for the altitude bearings to rest in. With a light scope, Teflon is usually too slick against the pipe-cap bearing, so I prefer thick felt instead. A curved cutout will let you position the felt for optimum friction — the higher up around the curve you put the felt, the tighter it holds the scope. With V-shaped notches, the angle of the V determines where the felt rests.

The base needs to be wide enough to be stable. For a typical 4″ to 4½″ f/10

▼ *Left:* Despite its sturdy appearance, this mount was way undersized for the scope, which had pretty decent optics. *Right:* The same Edmund scope on a Dobsonian mount. Much easier to use!

ALL PHOTOS BY THE AUTHOR



▲ The parts for a Dobsonian base are simple and easy to make.

reflector, I've found that a circle 15″ to 16″ in diameter works well. You'll need one circle for the base of the rocker box and either another circle or a triangle for the ground board.

Cover the bottom of the circle with Formica. Wilson Arts stopped making the popular Ebony Star that Dob-builders have been using for years, but Formica brand 909-42 Crystal Finish is emerging as a worthy successor.

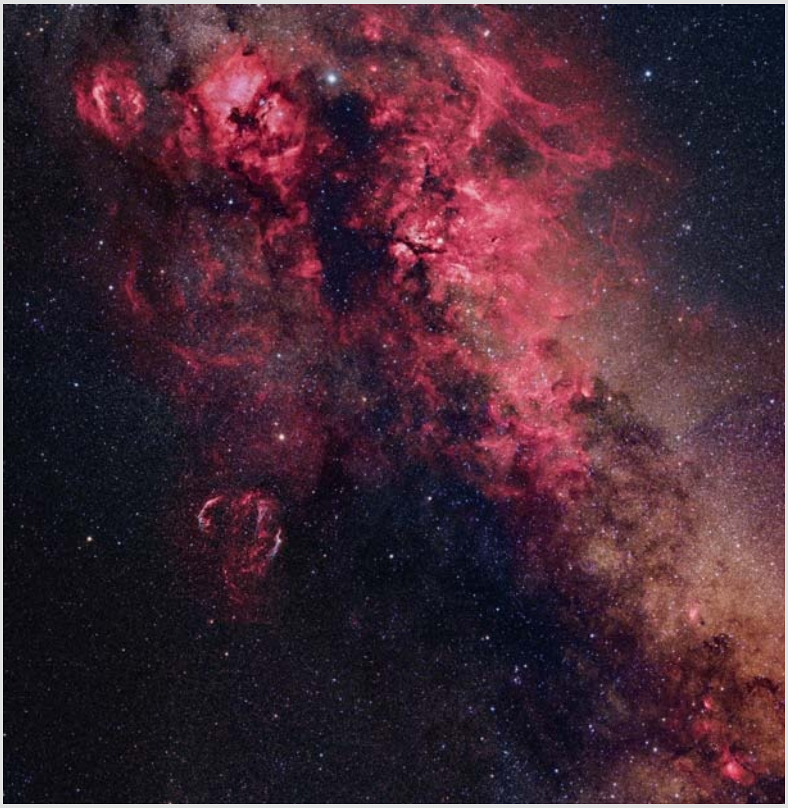
Put three Teflon pads on the ground board, facing the Formica. Install the feet directly beneath the Teflon pads. Run a bolt upward through the center of the ground board and rocker box, making it a snug but not tight fit. Use a stop nut to keep from overtightening the bolt.

Take everything apart, paint it, then put it back together again and use it! My club, the Eugene Astronomical Society, likes to put these refurbished scopes into our lending library and also to give them away to deserving young kids. We figure we're offsetting the hobby killer juju with a hobby starter. With decent eyepieces (replace the Huygens and Ramsden eyepieces that typically come in the package with a decent pair of Plössls), these little scopes are seriously fun, easy to use, and intuitive. You can just imagine the look on the face of the child who gets to take one of these home from a star party.

Hobby-killer refractors and Go To nightmares are tougher to revive, but it can be done. Look for more on that in a future column.

■ Contributing Editor **JERRY OLTION** likes to kill time, not hobbies, in his home workshop.

ELEPHANT’S TRUNK
Rathijit Banerjee
A thick column of dust and gas within the large emission nebula IC 1396 in Cepheus conceals several embryonic stars in the early stages of formation.
**DETAILS:** *Celestron EdgeHD 1100 with ZWO ASI1600MM Pro CMOS camera. Total exposure: 62.1 hours through narrowband filters.*



◁ CYGNUS NEBULOSITY

Alistair Symon

This deep composite image displays most of the northern constellation Cygnus. Several popular emission nebulae are visible, including NGC 7000, the North America Nebula, at top left and the Veil Nebula at lower left.

**DETAILS:** *Takahashi FSQ-106 and TOA-130 refractors, Canon 70-mm lens, and SBIG STF-8300M CCD camera. Total exposure: More than 90 hours through hydrogen-alpha and RGB filters.*

▽ ATACAMA SPLENDORS

Jeff Dai

The Milky Way arcs from the central bulge in Sagittarius at left through Puppis at right as seen from the Atacama Desert in Chile. Bright Jupiter shines in Scorpius at upper left, while the Small (center) and Large Magellanic Clouds (center right) appear through thin bands of yellowish air glow above the mountains to the south.

**DETAILS:** *Canon EOS 6D Mark II with 16-to-35-mm lens. Total exposure: mosaic of fifteen 1-minute exposures at ISO 6400.*

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## △ BIG DOMES

Howard Eskildsen

Volcanic domes Mons Gruithuisen Gamma (middle left) and Delta (middle right) stand high above the lunar landscape south of Mairan crater (upper middle).

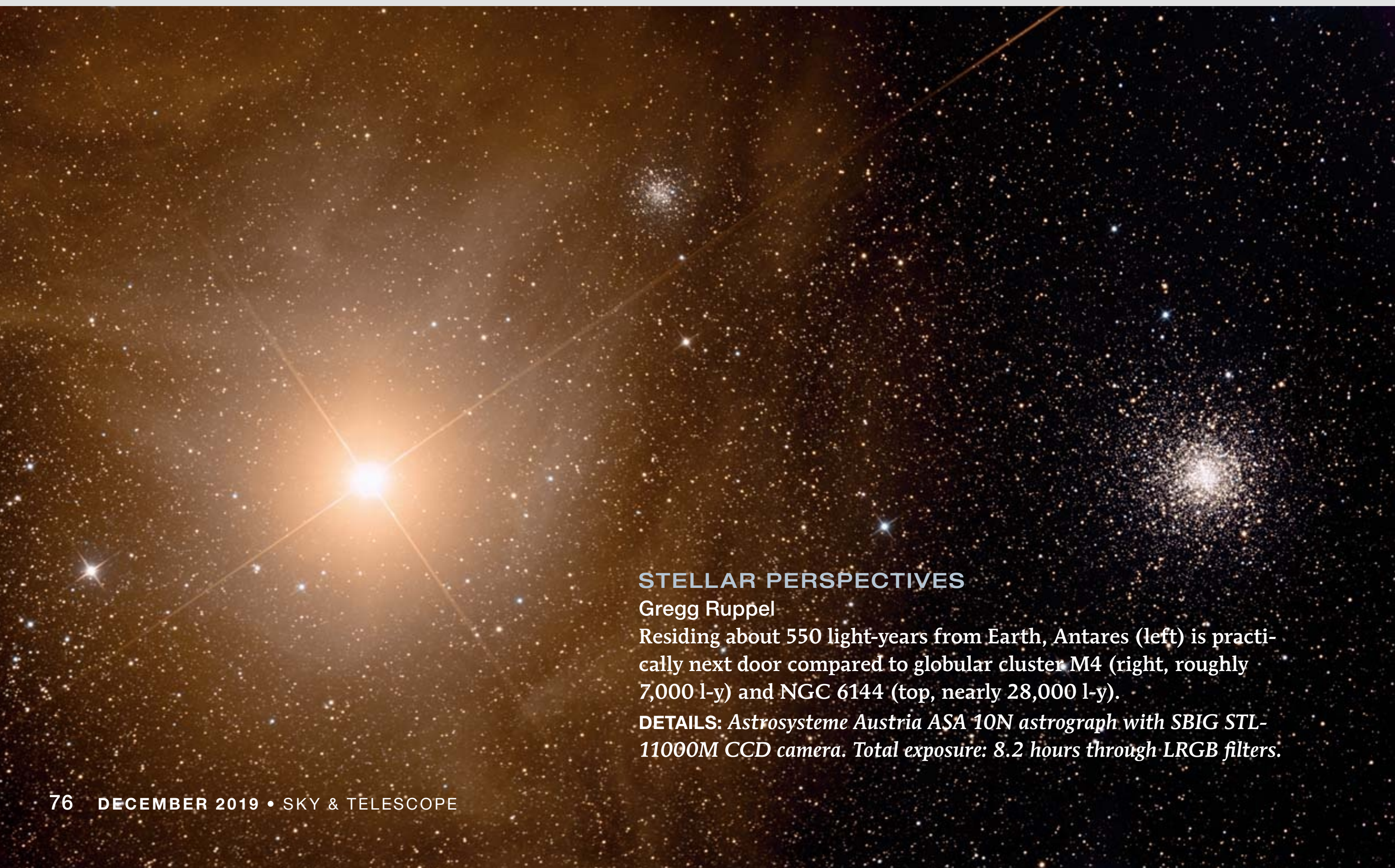
**DETAILS:** *6-inch f/8 Explore Scientific refractor with Imaging Source DMK 41AU02.AS video camera. Stack of several hundred video frames recorded through a yellow filter.*

## △ A BRIEF MOMENT IN TIME

Dario Giannobile

Lenticular clouds rise above the active volcano Mount Etna in Sicily. Hot lava casts a reddish glow on the underside of the clouds, which block most of the light from the old crescent Moon. A bright meteor flashes to the left.

**DETAILS:** *Canon EOS 6D with 20-mm lens at f/2. Total exposure: 13 seconds at ISO 3200.*

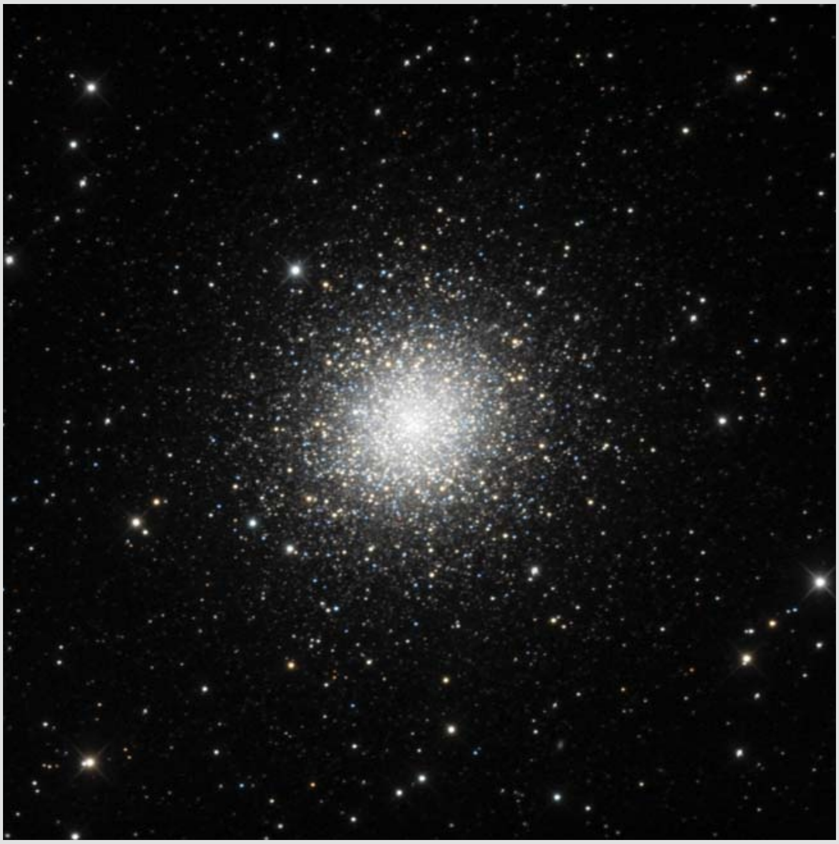


## STELLAR PERSPECTIVES

Gregg Ruppel

Residing about 550 light-years from Earth, Antares (left) is practically next door compared to globular cluster M4 (right, roughly 7,000 l-y) and NGC 6144 (top, nearly 28,000 l-y).

**DETAILS:** *Astrosysteme Austria ASA 10N astrograph with SBIG STL-11000M CCD camera. Total exposure: 8.2 hours through LRGB filters.*



◁ STELLAR SPHERE

Dan Crowson

Spanning roughly 175 light-years in diameter, densely packed globular cluster M2 in Aquarius is one of the largest globulars known. Though located 55,000 l-y away, M2 is just visible to the unaided eye under extremely dark skies.

**DETAILS:** *Astro-Tech AT12RCT Ritchey-Chrétien telescope with SBIG STF-8300M CCD camera. Total exposure: 6 hours through LRGB color filters.*

▽ IN THE COMPANY OF POLARIS

Sérgio Conceição

Stars of the northern sky appear to arc above the chapel of the medieval Castle of Noudar in Barrancos, Portugal.

**DETAILS:** *Canon EOS R Mirrorless camera with 14-mm lens at f/2. Total exposure: 25 minutes at ISO 2000.*

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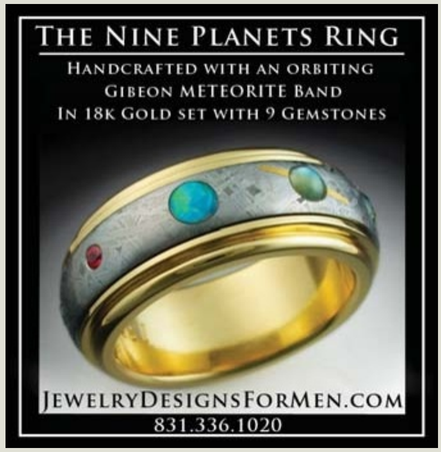


## MOUNTS


## OBSERVATORIES/DOMES (cont.)



## OBSERVATORIES/DOMES


## OPTICS



## CLASSIFIEDS

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

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

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Atik-Cameras.com

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**QHYCCD / Light Speed Vision CO. Ltd** (Page 15)
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# An Astral Epiphany

*For this teenager, a visit to Lick Observatory kindled a fascination with the cosmos and the community that studies it.*

**I PEERED THROUGH THE BACK** window of the van making its way up the winding road to Mount Hamilton, home of the iconic Lick Observatory. Looking down, I could see the city lights below, but as I glanced up, the view graduated into an unadulterated panorama of the sky awash with stars.

That warm summer night, my love for astronomy was awakened — my intellectual self burned with curiosity, my spiritual self felt awestruck. Crazy as it sounds, that was the first time in my 16 years that I'd *really* seen the night sky. I've traveled a cosmic path ever since.

This eye-opening visit took place after my sophomore year of high school, when I had the good fortune to work with researchers at the University of California, Santa Cruz as a summer intern. I'd applied to the Science Internship Program, which matches high schoolers with research projects based on their strengths and interests. I was one of two interns assisting my mentor, Clayton Strawn, a graduate student of physics professor Joel Primack.

For the next ten weeks, we tackled multiple projects simultaneously, but our primary goal focused on developing a software tool that can help astrophysicists study metals in the *circumgalactic medium* (the diffuse, nearly invisible gas that surrounds the disks of galaxies). In principle, researchers can use our software, combined with absorption line spectroscopy, to map the abundance of ions across the circumgalactic medium.

During my internship, I soaked up a lot of material not found in your typical high school classroom, from the importance of a Lyman-alpha forest to how an adaptive mesh refinement code works! More importantly, I got a sense of what it's like to be a working scientist, and I liked it — a lot.

From my limited experience so far, what I like most about scientific research is tackling the unknown alongside others who share a vision of tangible findings and progress. I lived by that mindset that summer. On the round-trip bus commute to and from campus, I dove into various astrophysics texts and tuned into astronomy podcasts. I studied software packages and Python libraries at home, devouring papers relevant to my project. I walked into the lab with questions and left with new ones.

In January 2018, I got the chance to present my work with fellow intern Rishi Dange at the American Astronomical Society's 233rd meeting in Seattle, Washington. It was thrilling to see our humble contributions to research being recognized. At the convention center, I met astrophysicists and astronomers of all backgrounds and interests. At discussion panels and keynote speeches, I grasped these scientists' deep commitment to learning, collaboration, and discovery. When I discussed our research with academics or engineers, I felt that shared curiosity for the cosmos and its unfathomable mysteries.

As I prepare to head off to college next year, I'm not sure how astrophysics and astronomy will play out in the grand scheme of my academic aspirations. But that drive up to Lick Observatory two summers ago certainly triggered what has become a passionate enchantment with the subject as well as a strong attachment to the devoted community behind it.

■ **BRYAN WANG** is a senior at the Harker School in San Jose, California. Besides pursuing research in astrophysics, he runs the school's programming club and a six-person jazz combo.

▼ A night drive up to Lick Observatory at age 16 opened entirely new vistas for the author.