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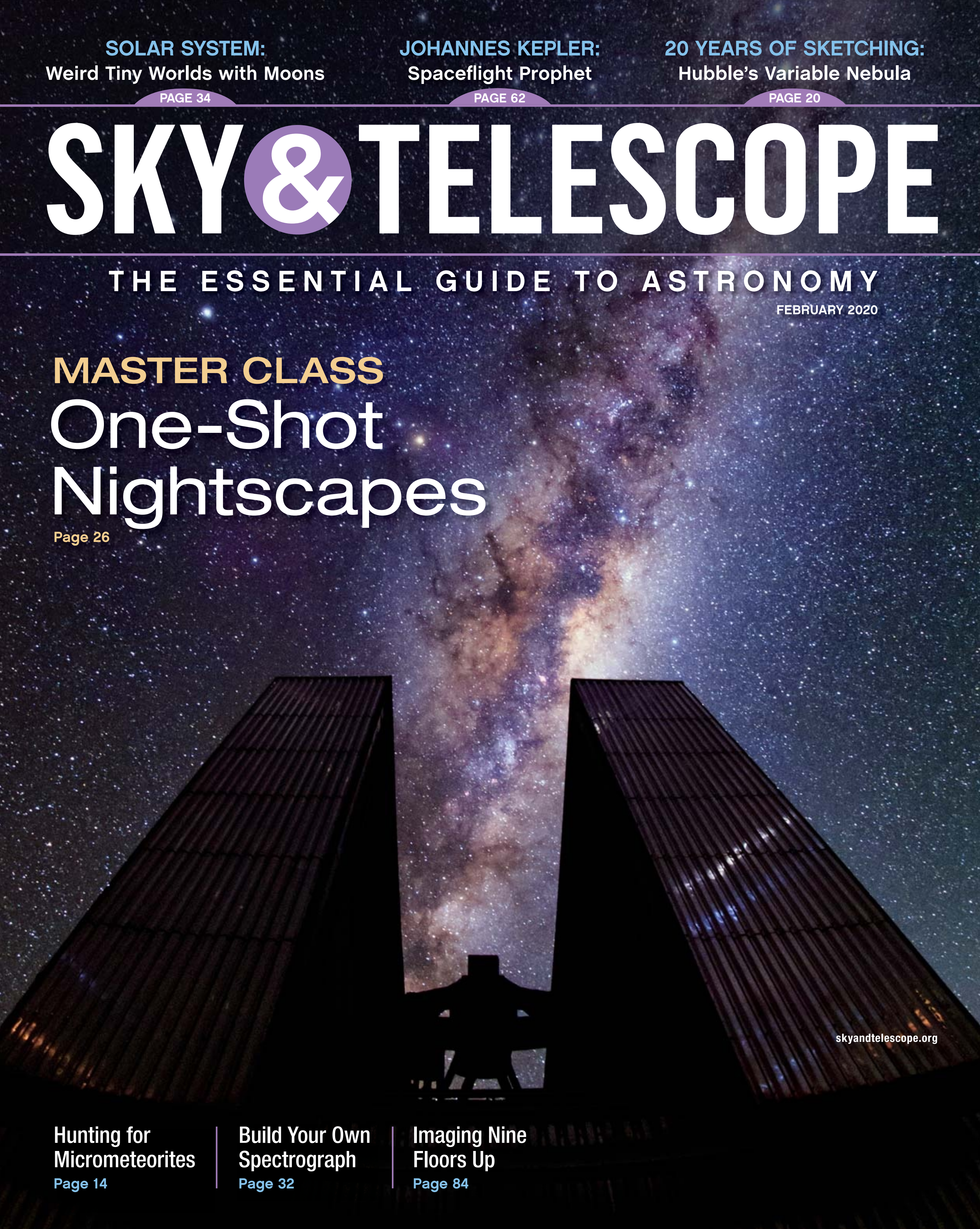

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THE ESSENTIAL GUIDE TO ASTRONOMY

February 2020 VOL. 139, NO. 2

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ON THE COVER

The Milky Way hangs over New Technology Telescope in Chile.
PHOTO: BABAK TAFRESHI

ONLINE

TIPS FOR BEGINNERS
New to astronomy? From learning the night sky to tips on buying your first telescope, here's everything you need to jump into the fun.
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Do It Yourself

IN AMATEUR ASTRONOMY, we often think of DIY as synonymous with ATM — amateur telescope making. But it's far broader than that. As this issue of *S&T* demonstrates, our community undertakes a wide range of individual pursuits to make the most of our hobby.

Observing is our top do-it-yourself activity, of course. What's more DIY than crouching at the eyepiece in the dark of night? That's why we cover everything from naked-eye and binocular viewing to deep-sky observing, plus fleeting events such as Comet PanSTARRS (C/2017 T2, page 48).

Imaging can be even more DIY than observing, as it usually involves both crouching outdoors and processing indoors. In our cover story, astrophotographer Babak Tafreshi, one of the best in the business, describes how to do what he calls "deepscape" photography (page 26). At the other end of the light-pollution spectrum, urban astronomer Ken Pilon gives tips on imaging from his 9th-floor, big-city balcony (page 84).

DIYer: Ted Kinsman collecting micrometeorites

TED KINSMAN

Sketching, as many *S&T* readers know, can help observers discern details they might otherwise miss. Howard Banich takes it a step further. In his impressive collection of sketches depicting Hubble's Variable Nebula, Banich shows how drawing can reveal changes in objects that no one — amateur or professional — has ever documented before (page 20).

Crafting is an honored tradition among amateurs, but it's not limited to building telescopes. Want to try your hand at spectrography? Jerry Oltion describes two nifty spectrographs that amateurs can make themselves (page 32).

Collecting is like breathing for amateurs, at least when it comes to photons. But Ted Kinsman explains how we can also collect actual bits of the solar system that regularly shower down onto Earth's surface (page 14).

Learning is intrinsic to our hobby. In this issue, brush up on two curious types of celestial objects: contact binaries (page 34) and dwarf carbon stars (page 58). Into the history of astronomy? See our piece on Johannes Kepler's little-known 17th-century book on spaceflight (page 62).

Traveling is key to the hobby for many amateurs. From star parties to astronomy expos to eclipse tours, our people like to get out there (page 81).

And that brings up *sharing*, which every issue of *S&T* is entirely about. It's in our mission statement and that of our parent, the American Astronomical Society: *to enhance and share humanity's scientific understanding of the universe*. And as we're reminded every time we attend a star party, members of our community are as much into sharing the wonders of the heavens with others as we are.

So do it yourself. We'll do it with you.

Peter
Editor in Chief

Editorial Correspondence
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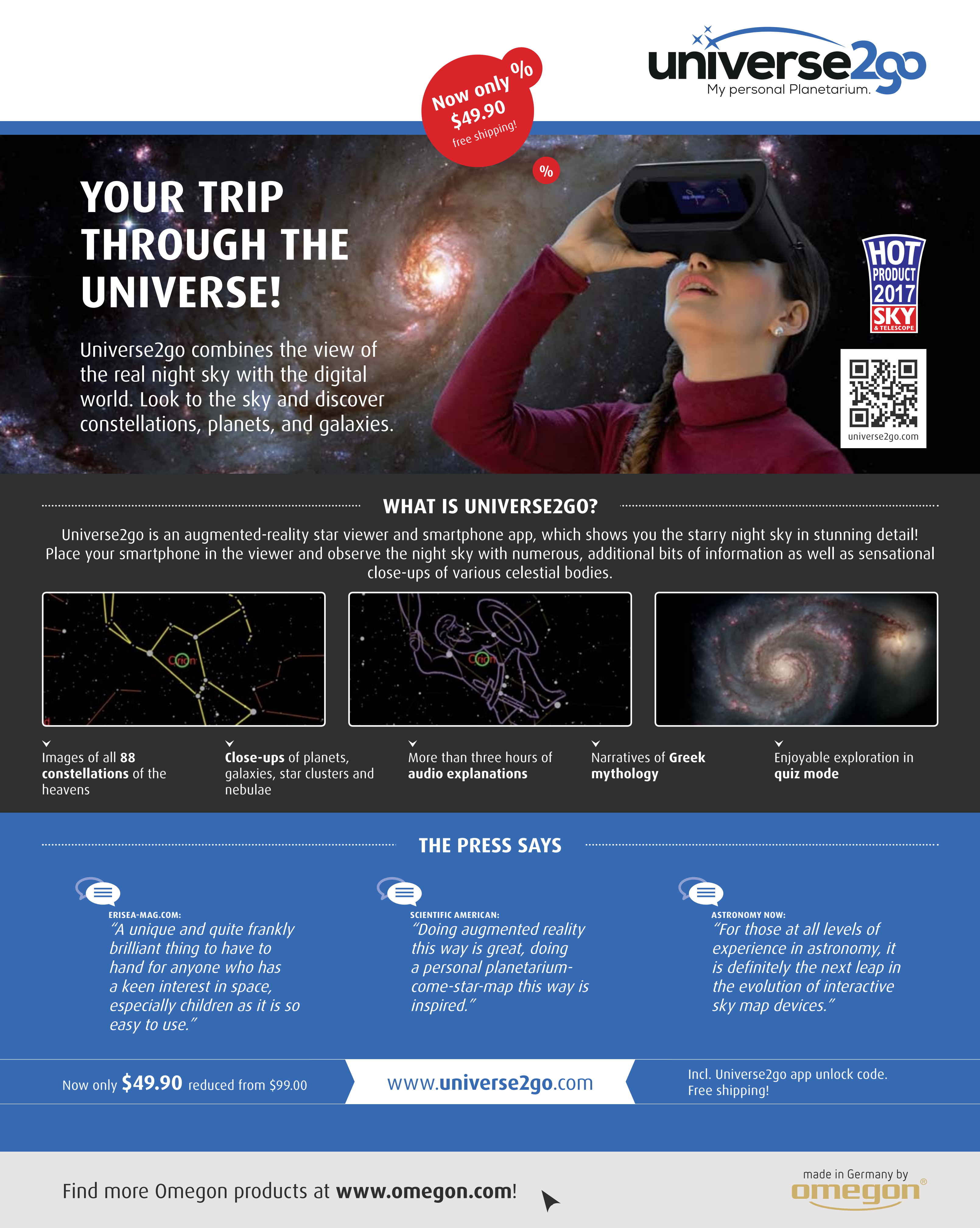

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Universe2go is an augmented-reality star viewer and smartphone app, which shows you the starry night sky in stunning detail! Place your smartphone in the viewer and observe the night sky with numerous, additional bits of information as well as sensational close-ups of various celestial bodies.
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Are You Seeing Things?

▲ Compare this sketch of a tiki-like face on the Moon with the actual terrain seen telescopically.

JIM MICHNOWICZ / NASA / ARIZONA STATE UNIVERSITY

I really enjoyed Charles Wood's discussion of lunar pareidolia (*S&T:* Oct. 2019, p. 52). While working on my Astronomical League Lunar 100 award and NASA Apollo 50th Anniversary award over the summer, one such structure really caught my eye: what I call the "Lunar Tiki God" near Fra Mauro and the Apollo 14 landing site. Its elongated, Simpson-esque head was immediately evident to me, and the lighter material in the "eyes" seemed to glow, ready for the lunar luau. Evidence of Parrotheads on the Moon? No idea, but I check out my new acquaintance every chance I get.

Jim Michnowicz
Holly Springs, North Carolina

Charles Wood's article brought to mind something I've experienced a few times while observing the Moon through a Celestron C-14 with a 26-mm eyepiece. I turn away for a minute or two, and when I look back I'm astonished to find that my brain has "reversed" the contours of topography. Craters no longer look depressed but instead seem to rise above the lunar plains. Their floors now look like smooth mesa tops.

The first time this happened I was startled and baffled, but upon realizing what had occurred I was able to maintain the "reversed" image. Turning away from the eyepiece and then looking back returned me to the correct image.

This has recurred only a few times over the past 20 years or so. On a couple of occasions, I have been able to "force" the transition from crater to mesa, back and forth; most times, however, I can't get the reversal no matter how hard I try. I'm wondering if others have experienced this.

Ed Wagner
Olean, New York

More About O. M. Mitchel

Trudy E. Bell's article on Ormsby MacKnight Mitchel (*S&T:* Nov. 2019, p. 30) nailed a subject of growing interest for me. In recent years, I have acquired copies of Mitchel's old books and started a file with miscellaneous notes, with the object of writing an article to offer *Sky & Telescope*.

Now I don't need to — Bell's writing is fascinating, and I appreciate the sidebar about his books and suggestions for further research.

Some aspects of Mitchel's work caught my attention, particularly Central High School in Philadelphia. Sadly, the school and its observatory burned down later in the 19th century, and apparently most of its astronomical records were lost.

A few years back, during a visit to Central High (which now occupies a building away from its original site), I discovered that the school still has a collection of 19th-century physics apparatus for demonstration purposes. No one there knew anything about these devices (including a refractor on a tripod, which I could not examine because it was in a corner with lots of stuff stacked against it).

The librarian showed me a leather-bound guest book titled "Autographs Observatory Kensington." It had nothing to do with the school observatory but instead had come from the United Kingdom. It was the guest book of Sir James South — perhaps the preeminent gentleman amateur astronomer of the day in London. It contained the signature of Mitchel, who had apparently visited South's observatory during a trip to England.

Alas, this autograph book was later sold to a private collector (to raise funds for Central High), so it is no longer available for study.

Robert D. Hicks
Philadelphia, Pennsylvania

I was an assistant professor in the physics department at the University of Cincinnati for a few years in the early 1980s and, as its "token astronomer," was put in charge of the observatory. Along with Paul Nohr, I kept both telescopes operational and hosted "Astronomy Thursday" public viewing sessions. But I never got around to learning much about the observatory's history, so Bell's article was especially interesting.

Nate Krumm
Pearblossom, California

Grateful for Imaging Tutorial

I enjoyed reading Ron Brecher's "Demystifying Image Calibration" (*S&T:* Nov. 2019, p. 36). As I'm a total novice interested in astrophotography, his explanation and ideas have encouraged me to improve my images. Brecher put in a nutshell what would otherwise have taken me years to figure out!

Colleen Ansley
Toronto, Ontario

Eager Reader

I would like to thank everyone at *Sky & Telescope* for publishing such a wonderful magazine for both experienced astronomers and beginners. I love how the articles are not too detailed yet still include up-to-date research in an easy-to-read style. Reading *S&T* has helped me learn more about astronomy and also inspired me to get deeper into observing the night sky.

I have always liked watching the night sky, especially the Moon. I can't afford to buy a telescope, but I truly enjoy reading about different telescopes in *S&T*. Also, the monthly observing charts for stars, planets, and the Moon's phases are extremely helpful. I'm always excited about getting the next month's issue!

Alexandra Zovi
Menomonee Falls, Wisconsin

The Eyes Have It

Don Ferguson's article about double stars (*S&T:* June 2019, p. 36) reminded me of an interesting phenomenon: Our eyes have better horizontal resolution than vertical resolution. This distinction only applies when you observe close to the resolution limit of your telescope.

Here's a case in point: Epsilon Lyrae consists of two star pairs oriented 90° with respect to each other. If observed with one pair separated horizontally near the threshold of resolution, it will be split — but the second pair won't. Rotating your head 90° resolves the second pair but not the first.

I suspect this is due to our greater need, as hunter-gatherers, to resolve detail around the horizon and a lesser need for gauging the heights of trees.

Robert Dick
Ottawa, Ontario

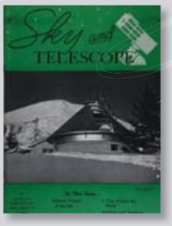
FOR THE RECORD

- When Venus was seen and sketched with spots on April 17, 1940 (*S&T:* Sept. 2019, p. 53), it was near greatest eastern elongation, not superior conjunction.
- Regarding the rate of growth of human knowledge (*S&T:* Dec. 2019, p. 60), a doubling every five years is considered exponential growth.
- Date labels in the light curve of T Ursae Majoris (*S&T:* Dec. 2019, p. 10) aren't quite correct. See **https://is.gd/T_UMinoris** for a revised graph.

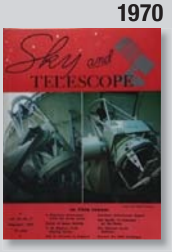
SUBMISSIONS: Write to *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, USA or email: letters@skyandtelescope.com. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

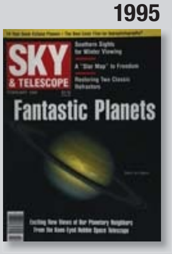
1945



1970



1995



February 1945

Flower Refractor "W. H. Pickering has argued that in 1924 better views of Mars were obtained with small apertures than with ones exceeding 20 inches. [W. F.] Denning [believed] the optimum aperture for planetary work is *about* 15 inches . . .

"From 1941 to the present, I have made some such observations with the 18-inch Brashear refractor at the Flower Observatory . . . in suburban Philadelphia. . . .

"Encke's division [in Saturn's rings] has often escaped skilled observers using good telescopes, but the Flower refractor usually reveals it clearly. . . . The close 'canals' on the northwest inner wall of the lunar crater Aristillus have been divided when conditions were favorable."

Author Walter H. Haas went on to found the Association of Lunar and Planetary Observers in 1947. The Flower 18-inch objective, after being mothballed since 1954, has been fully restored as part of a new observatory dedicated in 2019 near Lake Tekapo in New Zealand.

February 1970

Bad-Seeing Fix "Most astronomers at one time or another have wished for a way to sharpen a blurred photograph, that is, to undo the results of imperfect focus, trailing, optical aberrations, and atmospheric turbulence. Two ways for doing just that were described by George W. Stroke, State University of New York at Stony Brook. . . .

"Dr. Stroke uses a variant of the aperture-synthesis techniques of radio astronomers. They employ high-speed computers to combine mathematically the signals from many small antennas into one signal that has the same resolution as a big antenna filling all of the space between the smaller ones. But because of the much greater amount of information contained in an optical image, one such aperture synthesis at optical wavelengths could take months of computer time."

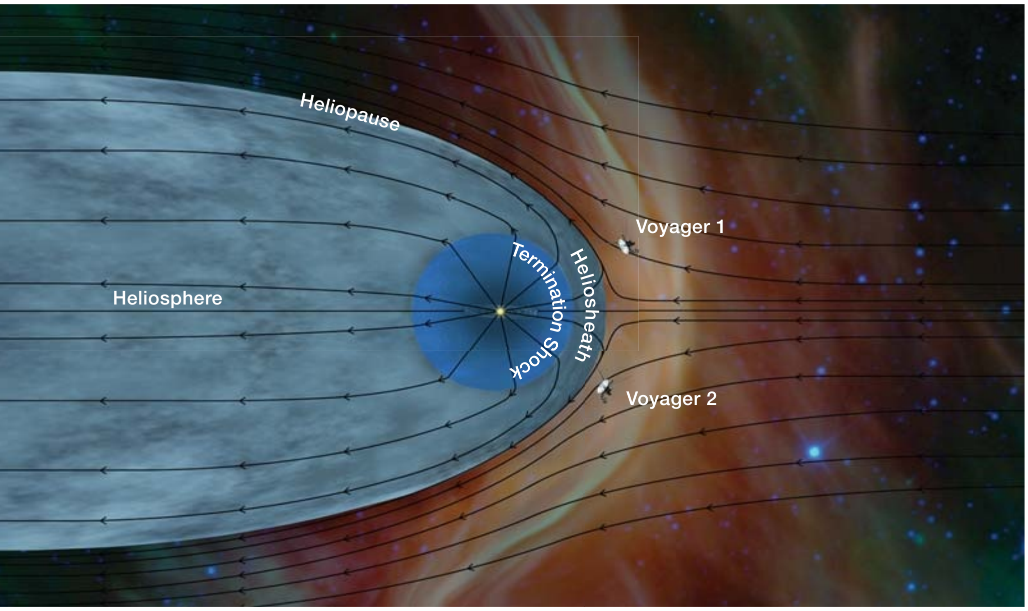
Astronomers were starting to foresee today's many techniques for sharpening their astronomical images.

February 1995

Drinking Gourd "In 1912 an amateur folklorist named H. B. Parks accidentally overheard an African-American singing a folksong in North Carolina that was new to him. . . . The cryptic lyrics, Parks learned, described a sky and land map directing slaves [northward] out of the South and toward freedom. . . . The term 'Drinking Gourd' is masked language for the Big Dipper. . . .

"Escaping slaves . . . concealed their awareness of the sky. As a result, . . . African-American songs and stories on celestial topics are scarce. 'Follow the Drinking Gourd' survives as a beautiful and rare exception."

In 1928 Parks published a few stanzas of the song as he knew it, based on a sketchy oral tradition. The song quickly became a folk standard, thanks to the Weavers and other artists at the height of the civil-rights movement. We may never know whether, as author Gloria D. Rall contends, it actually guided fleeing slaves northward.



SOLAR SYSTEM

Voyager 2's View of the Solar System's Frontier

▲ Voyager 1 crossed the heliopause in August 2012; heading in a different direction, Voyager 2 crossed in November 2018. The lines mark the direction of plasma flow both inside and outside the heliopause.

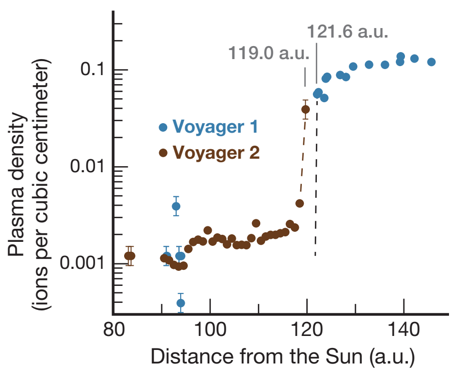
FOUR DECADES AFTER its launch into the outer solar system, Voyager 2 exited the *heliosphere*, the cavity around the Sun blown out by the solar wind. It crossed over on November 5, 2018, six years after that of the speedier Voyager 1 (*S&T:* Apr. 2019, p. 9).

Voyager 1 returned a surprisingly messy view of the outer boundary, known as the *heliopause*, that separates the Sun's domain from the interstellar medium. Voyager 2 promises a point of comparison. In the November *Nature Astronomy*, five teams of astronomers analyze the spacecraft's report from the frontier of the solar system.

Particles at the edge of the heliosphere are hot and sparse — a mere 0.002 electron per cubic centimeter, Donald Gurnett and William Kurth (both at University of Iowa) report in their study of Voyager 2 data. The gas and dust between the stars, on the other hand, are colder and denser. As Voyager 2 crossed over, its plasma instrument noted a 20-fold increase in plasma density.

A similar instrument on Voyager 1 failed in 1980, which made its crossing more difficult to recognize. However, its indirect measurements showed a similar jump in plasma density. Both Voyagers crossed the heliopause in under a day, corresponding to a boundary 0.005 astronomical unit (a.u.) thick.

The two spacecraft saw the density change at roughly the same distance from the Sun: 121.6 a.u. and 119 a.u., respectively. This was unexpected, since the heliopause's exact location ought to change with solar activity. Voyager 1 had crossed the boundary as the Sun was reaching a peak in its cycle of magnetic activity, but by the time Voyager 2 crossed, solar storms had quieted. "If we take our models at face value, we'd expect a difference," says Leonard Burlaga (NASA Goddard Space Flight Center), coinvestigator on the Voyagers' plasma and magnetic field experiments.



▲ As they traveled away from the Sun, the Voyagers encountered a surge in plasma density, thought to mark the boundary between the heliosphere and interstellar medium.

Another marker of the heliopause is a sudden change in the nature of the energetic particles measured by the spacecraft. As Voyager 2 crossed through the heliopause, it saw the low-energy ions of the solar wind largely drop away, replaced by higher-energy galactic cosmic rays produced in distant and long-ago supernovae.

However, even an astronomical unit beyond the heliopause, Voyager 2 continued to detect a few lower-energy particles from the solar wind. This leakage from the inside out was the opposite of what Voyager 1 saw, says Edward Stone (Caltech), the Voyagers' project scientist. "Even before [Voyager 1] left the heliosphere, we had two episodes where we were connected to the outside." How and how often particles leak in either direction across the heliopause remains an open question.

In addition, the Voyagers upended expectations when neither one saw a sudden shift in magnetic field at the heliopause. "We can dismiss this as a coincidence in one case, but we cannot do that twice," Burlaga says. "There must be some physical process that's coordinating the magnetic field across this region. That process is not understood."

Scientists will continue to study and compare Voyager data as the spacecraft zip along at 3 a.u. per year. They're heading toward the bow wave (or perhaps the bow shock) that forms in front of the heliosphere as it plows through the interstellar medium. But with only about five years or so of power left, neither one will reach this structure with working instruments. Instead, their main goal now is simply to measure the undisturbed interstellar medium — traveling as far from the heliosphere as they can in the time they have left.

■ MONICA YOUNG

Read more results from Voyager 2 at https://is.gd/voyager2.

VOYAGER 2: NASA / JPL; GRAPH: DON GURNETT / UNIVERSITY OF IOWA

MILKY WAY

Our Galactic Center's Raucous Youth

THE MILKY WAY'S CENTER is relatively quiet, but it wasn't always that way. Two new studies shed light on our galactic center's tempestuous past.

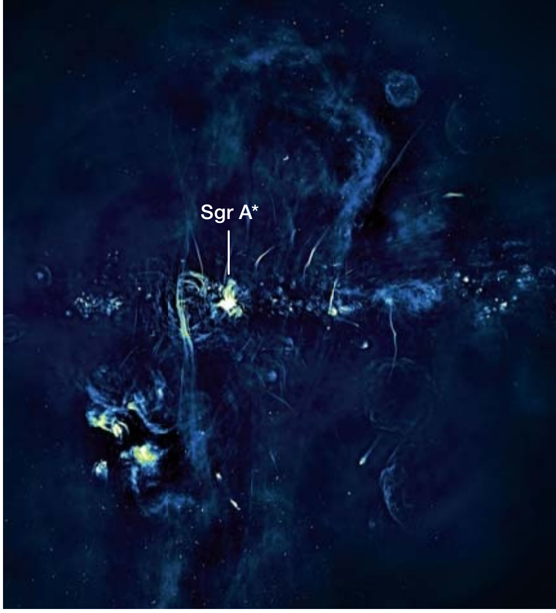
In the first study, Ian Heywood (University of Oxford, UK) and colleagues find a pair of outflows emanating from our galaxy's center using the MeerKAT radio telescope array in South Africa.

These radio lobes are reminiscent of the gigantic Fermi bubbles, but while those each span some 25,000 light-years above and below the disk (*S&T:* Apr. 2014, p. 26), the MeerKAT dumbbell is only 1,400 light-years long end to end. The researchers estimate that whatever blew up the MeerKAT bubbles, it happened a few million years ago. Perhaps, the authors speculate in the September 12th *Nature*, the MeerKAT event was a miniature version of whatever made the Fermi bubbles. Or, perhaps several events like the MeerKAT one combined to make the larger Fermi structure.

Heywood's team is circumspect when it comes to naming a culprit for the bubble structures. The astronomers maintain it could be star formation or black hole activity. But in another study, which will appear in the *Astrophysical Journal*, Joss Bland-Hawthorn (University of Sydney, Australia) and colleagues choose a side: They think gas dumped onto the doorstep of our galaxy's black hole, Sgr A*, fueled an outburst.

Bland-Hawthorn and others have been studying a ribbon of gas, called the Magellanic Stream, that winds itself around our galaxy. The team's ultraviolet measurements have revealed patches in the stream that contain ionized hydrogen, carbon, and silicon. These patches lie in what would be the direct path of a wide hourglass of radiation emanating from the galactic center.

By estimating how long the clouds have been cooling, the team rules out star formation as the cause of the patches and instead suggests that Sgr A* flared dramatically about 3½ million years ago. The ultraviolet radiation from the blaze then kicked electrons out of



▲ The MeerKAT radio bubbles extend vertically above and below the Milky Way's plane. The black hole, Sgr A*, is labeled.

the atoms in the Magellanic Stream some 250,000 light-years away.

Hsiang-Yi Karen Yang (University of Maryland) agrees that the new data strengthen the case for a prior flare. The bubbles and glowing patches in the Magellanic Stream may be relics of our black hole's rollicking past.

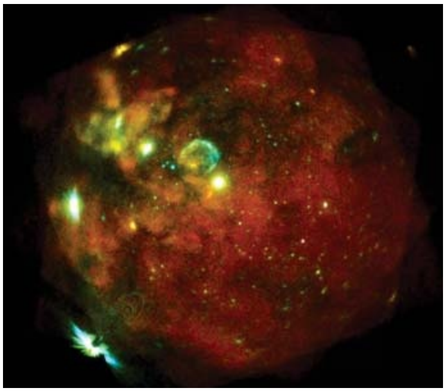
■ CAMILLE M. CARLISLE

SPACE OBSERVATORIES

German X-ray Telescope Sees First Light

IN MID-OCTOBER, the German-built EROSITA telescope used all seven of its X-ray-collecting modules to reveal the hot and violent star-formation processes in the galaxy next door.

Following its launch in July 2019, the telescope flew for three months aboard the Spektrum-Röntgen-Gamma (Spektr-RG) satellite before arriving at its destination: the Earth-Sun system's L_2 Lagrangian point, 1.5 million kilometers (930,000 miles) from Earth on the opposite side from the Sun. There, the telescopes aboard Spektr-RG underwent commissioning, as engineers turned on the instruments and worked out any kinks. Despite some hiccups during this phase, and after some extensive testing to show that everything was operating as expected, EROSITA is now seeing the universe near and far with X-ray vision.



The Large Magellanic Cloud (LMC) is the Milky Way's largest satellite galaxy and hosts prolific stellar nurseries, whose hot, X-ray-emitting gas is seen in the first-light image. The LMC is a close and well-studied target, so astronomers can compare EROSITA's image to ones taken by other X-ray observatories.

◀ EROSITA's first-light image reveals star formation in the Large Magellanic Cloud.

"We have obtained razor-sharp images," says EROSITA's project manager Thomas Mernik (German Aerospace Center). "These first impressions allow us to anticipate great things over the coming years."

EROSITA will soon begin its primary mission: a four-year program to map the entire X-ray sky eight times over, in the kind of detail normally reserved for zoomed-in views of selected objects. EROSITA is expected to detect millions of new X-ray sources, including 100,000 galaxy clusters. Ultimately, astronomers hope to use these clusters to shed light on the universe's evolution and the nature of dark energy.

The Spektr-RG space observatory also hosts the Russian ART-XC instrument, which observes X-rays at higher energies. The Russian space agency announced ART-XC's first light on July 30th, with images of the well-known X-ray pulsar Centaurus X-3.

■ MONICA YOUNG

GALACTIC CENTER: SARAO / ADAPTED FROM HEYWOOD ET AL. / *NATURE* 2019; FIRST LIGHT: F. HABERL / M. FREYBERG / C. MAITRA / MPE / IKI

EXOPLANETS

Observations Confirm Amateur-Discovered Exo-Neptune

FOLLOW-UP OBSERVATIONS of an amateur-discovered planetary system show that its planet has Neptune's mass and orbits its star in the region where ice giants are thought to form.

On October 25, 2017, Japanese amateur astronomer Tadashi Kojima was monitoring stars for the sudden brightening that might indicate a nova. Rescanning a field in Taurus he found one particular star that had brightened from magnitude 13.0 to 11.7. By Halloween, the star had brightened further to magnitude 10.8.

The star was faint in Kojima's observations, but calls for follow-up observations (via the Central Bureau for Astronomical Telegrams and the American Association of Variable Star Observers) soon showed that the brightening pattern he had observed was characteristic of *gravitational microlensing*.

When one star passes directly behind another from Earth's perspective, the foreground star's gravity bends the light from the background star so that it appears to brighten from Earth's perspective. If the foreground star has a planet, the planet's gravity adds a brief flash to the overall gleaming.

▲ Artist's concept of an exo-Neptune orbiting a red dwarf star

Astronomers have found several dozen exoplanets using this technique, but the event that Kojima discovered, named Kojima-1, is unique. For one, most microlensing events occur toward the galactic center, as there are more stars in that direction. Kojima's star is in the sparser region opposite the center. It's also relatively close, at 1,600 light-years away.

Because the foreground star is in an uncrowded region and closer to Earth than the typical microlensing star, it made for an easy target for follow-up observations. Multiple observing campaigns ensued, including one led by Akihiko Fukui (University of Tokyo). His team used 13 ground-based telescopes to repeatedly image the star and obtain its spectrum over 2½ months.

In the November issue of the *Astronomical Journal*, the team confirms the existence of this Neptune-mass planet in the outskirts of our galaxy. Designated Kojima-1Lb, the planet has 20 times Earth's mass and follows an orbit similar to Earth's, with an average distance from its star of 1.1 astronomical units. Because the star is less massive and less luminous than the Sun, that orbit puts the exo-Neptune near its system's *snow line*, beyond which water vapor and other gases condense into ice. The discovery hints that Neptune-mass planets might indeed be common outside this boundary.

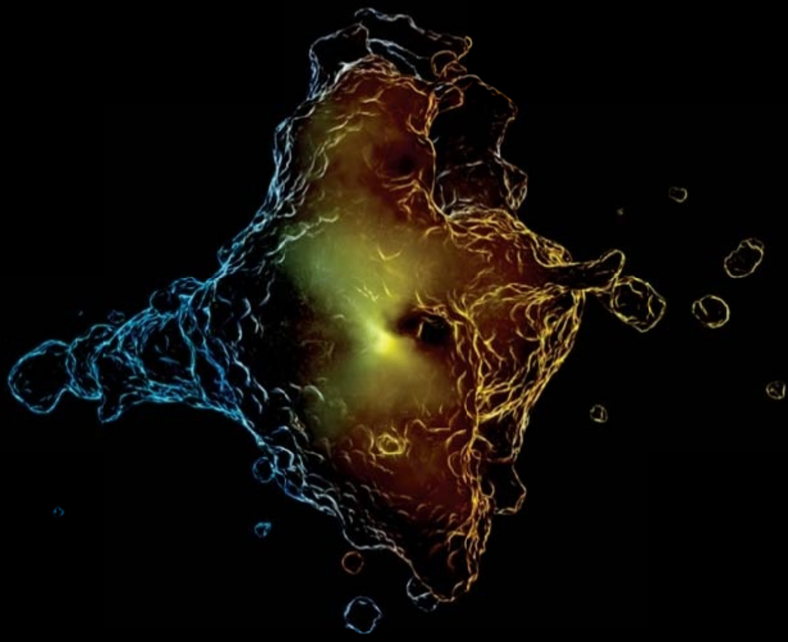
■ MONICA YOUNG

EXO-NEPTUNE: UNIVERSITY OF TOKYO; MAKANI GALAXY: JIM GEACH / DAVID TREE / PETER RICHARDSON / UNIVERSITY OF HERTFORDSHIRE

Refreshing Galactic Wind

Most "normal" or baryonic mass is contained not in stars but in gas that extends far beyond any galaxy. This gas is thought to fall onto galaxies over time, providing fuel for star formation. In turn, stars — or rather, the winds they produce as they're born and as they die — are thought to replenish that reservoir. For the first time, David Rupke (Rhodes College) and colleagues directly observed evidence of that replenishment using the Keck Observatory's Cosmic Web Imager, they report in the October 31st *Nature*. The KCWI, an integral field spectrograph, took simultaneous images and spectra of a giant wind flowing out of a galaxy into the sparser medium that surrounds it. The galaxy, named Makani ("wind" in Hawaiian), has probably driven this tempest via bursts of star formation ignited during a merger with another galaxy. Makani is currently forming 100 to 200 solar masses of stars every year. The wind from these stars fills a region 260,000 by 330,000 light-years with hot (10,000 K), ionized gas that's enriched with elements heavier than hydrogen and helium. Galactic winds have been observed before but not so far out from a galactic center.

■ MONICA YOUNG



EXOPLANETS

Monitoring a Planet-Scale Collision

OBSERVATIONS FROM the Stratospheric Observatory for Infrared Astronomy (SOFIA) confirm suspicions that dust around BD+20 307, a binary star system 390 light-years from Earth, came from a recent collision between planet-size bodies. The findings appear in the April 10th *Astrophysical Journal*.

The two stars of the BD+20 307 system are at least a billion years old, so any debris left over from their formation should have cooled down a long time ago. But when astronomers first imaged the system 15 years ago using ground-based telescopes and the Spitzer Space Telescope, they found an abundance of warm dust. The presence of this dust suggested a collision occurred tens of thousands of years ago between two large worlds in the system.

One decade later, astronomers used SOFIA, an infrared telescope that flies aboard a modified Boeing 747, to follow up on the system. Surprisingly, the observations revealed that the brightness of the dusty disk had increased by 10% over the past decade.

If leftover fragments had continued to collide with each other, gradually grinding themselves into dust in a process known as a *collisional cascade*, the total amount of dust would have increased. But a collisional cascade alone is not enough to explain the dramatic increase in infrared brightness.

One possibility is that the dust became warmer as it drifted inward toward the binary stars, explains project lead Alycia Weinberger (Carnegie Institution of Washington). Or, it could be the collisional cascade was more of a collisional avalanche, producing dust faster than expected.

▲ An artist's concept shows a planet-scale collision.

Scientists are still unsure which mechanism brightened the system over the past decade. Nevertheless, lead author Maggie Thompson (University of California, Santa Cruz) hopes that longer-wavelength data from future SOFIA observations will shed light on the system's evolution. Ultimately, the system might provide a window into our own solar system's violent early years.

■ JULIE FREYDLIN

COMMUNITY

Well-loved Astronomy Expo Comes to an End

AFTER 50 YEARS, the Riverside Telescope Makers Conference (RTMC) has ended its annual Astronomy Expo. Many factors contributed to the board's decision on October 6th to close off what was still one of the largest star parties and convocations on the West Coast. Even as it averaged 400 to 500 attendees (600 at its recent 50th anniversary), the event could no longer compete with its reputation.

The expo began in 1969 when Cliff Holmes, then president of the Riverside Astronomical Society, joined other telescope-makers for a conference at Riverside Community College (*S&T:* Feb. 2018, p. 64). For a while, their event was called "Riverside," and it pulled in some 135 attendants. But within a few years it outgrew the college, ending up in Camp Oakes in Big Bear to accommodate the attendees and their telescopes. The first digital setting circles made their debut at the 1978 expo. And while John Dobson may have begun his sidewalk astronomy movement on the streets of San Francisco, it wasn't until he brought those hippie-flowered tubes to RTMC that many others jumped on board.

By the conference's heyday in 1987, 2,340 people were coming to see the event. Attendance had expanded to the point that the show outgrew the Riverside Club that founded it and became its own corporation in the early 1990s.

Many other star parties have sprouted up in the area over the years; we will see if they can fill the Astronomy Expo's shoes.

■ ALEX MCCONAHAY

Reminisce about the Astronomy Expo's glory days: https://is.gd/RTMCExpo.

Stars trail over the 2009 RTMC

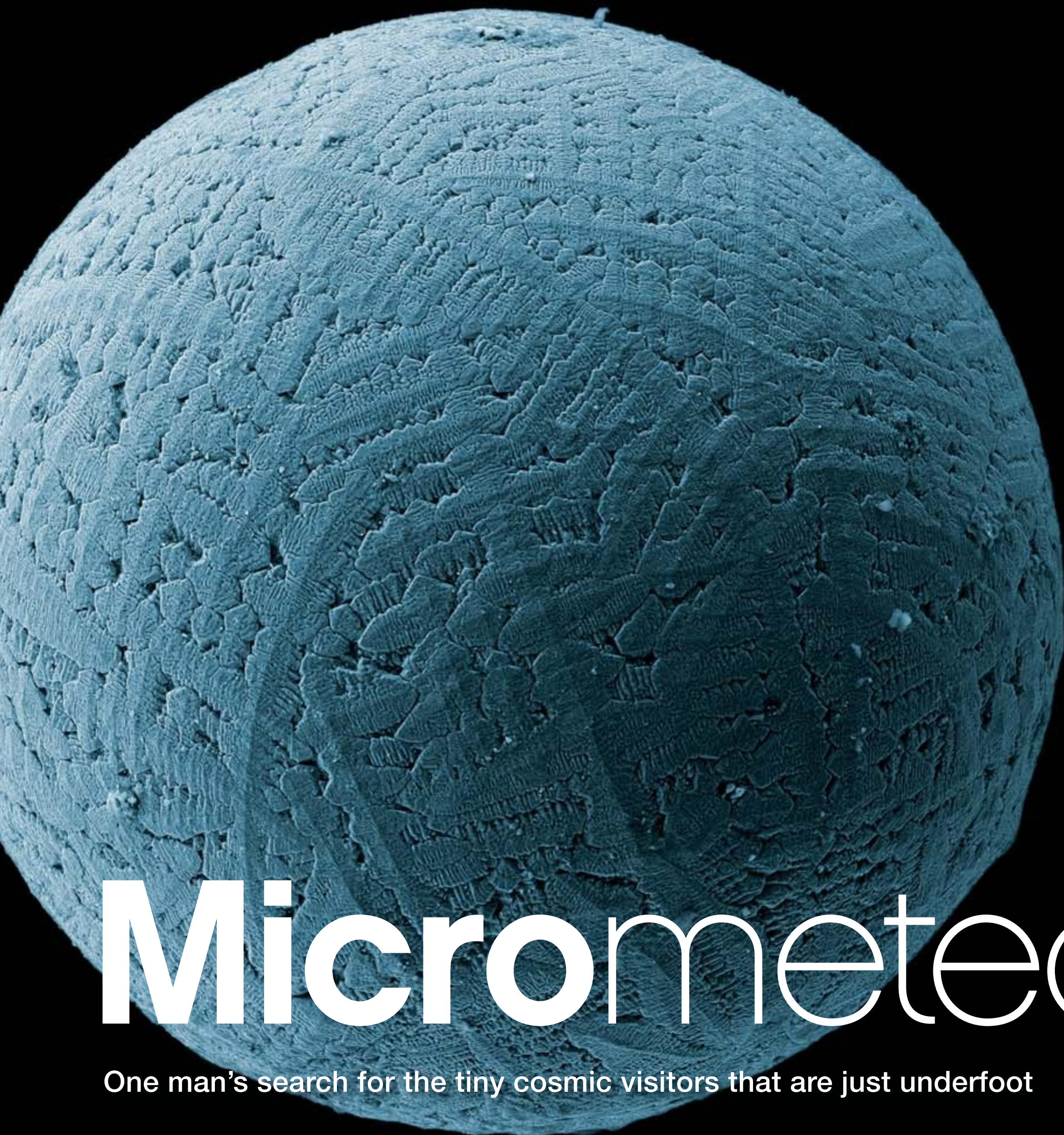
IN BRIEF

NASA Announces Lunar Rover for 2022

NASA has announced a robotic mission, named the Volatiles Investigating Polar Exploration Rover (VIPER), which will hunt for water ice at the lunar south pole and characterize the lunar regolith there. The rover will be about the size of a golf cart and is projected to cost $250 million. VIPER is scheduled for a late 2022 landing, which would put it on the lunar surface before NASA's ambitious "boots back on the Moon" goal for the Artemis program, currently set for late 2024. VIPER is expected to last about 100 days, so it will forgo nuclear power and operate strictly via solar panels and battery power. VIPER will carry a suite of science instruments, including a drill that will go 1 meter down into the lunar regolith and bring up samples for testing. It will also carry a spectrometer to detect potentially water ice–rich regions for drilling. The VIPER mission would be NASA's first soft landing on the Moon since Apollo 17 in 1972, and also the first soft landing in the Moon's polar regions.

■ DAVID DICKINSON

PLANET COLLISION: NASA / SOFIA / LYNETTE COOK; RTMC: ROBERT STEPHENS / RTMC



Micrometeorite

One man's search for the tiny cosmic visitors that are just underfoot

BLUE MARBLE The micrometeorite shown in this scanning electron microscope image is 300 microns across, about twice the width of a thick human hair. As the fragment entered Earth's atmosphere, it melted from the heat, and the surface tension of the molten metals brought it into a spherical shape. The author found this sample on the roof of his house, and he considers it to be the most beautiful micrometeorite he has ever found.

We are all familiar with the idea that meteorites fall to Earth, but most of us probably think our odds of finding one are rare. Yet tiny meteorites — those less than 1 mm wide, or about the size of the periods in this paragraph — are actually quite common. Micrometeorites make up the bulk of the stuff that Earth collects from outer space, and on average, one micrometeorite will land on every square meter of our planet's surface every year.

This cosmic dust is so common it can literally be found under our feet. One study even turned up several dozen micrometeorites via an exhaustive search of the rain gutters lining city rooftops (*S&T:* May 2017, p. 10). However, industrial contamination means that such rooftop studies are rare, as it takes a lot of sifting to remove possible imposters.

Instead, most bits of bona fide cosmic dust have been discovered in hard-to-reach places, such as deep-sea sediments, Antarctic ice, and the melt zone of the Greenland ice cap. For one of these studies, researchers at the South Pole even collected particles from the ice they had melted for drinking water. At such remote locations, industrial contamination is less likely. Researchers also use the size distribution and composition of the fragments they find to determine if they truly come from space.

For enthusiasts without the means to become collectors of large meteorites, micrometeorites offer an alternative — and finding them doesn't necessarily require a visit to remote locations. Although smaller meteorites are harder to study, they're in general more numerous. The smaller the meteorite you're looking for, the higher the probability you

Hunter

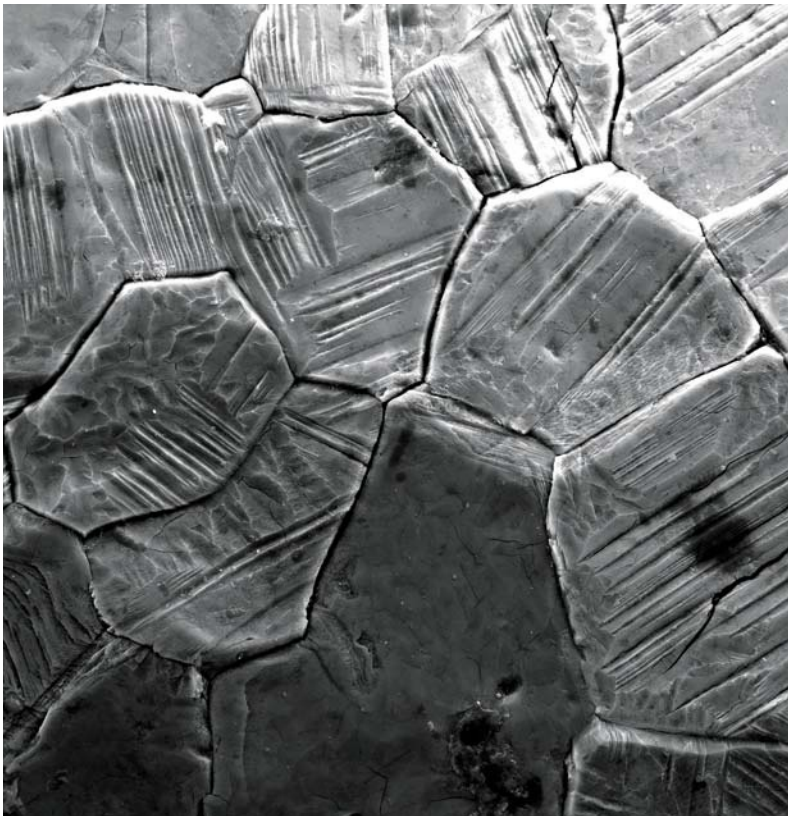
might find one. And because micrometeorites are relatively easy to find, their collection and study can be just as rewarding as the larger variety.

Collection

There are a number of ways to collect micrometeorites. I find that the magnetic ones — even though they are rare among meteorites in general — are the easiest to find and identify.

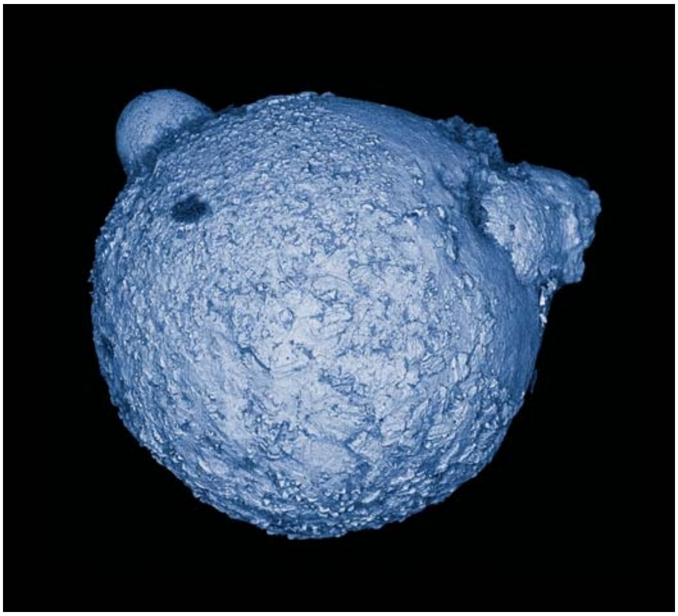
One method is to place magnets on the gutters of your home. In New England, I like to place magnets on the downspouts of churches that have slate roofs and lead downspouts. This ensures that the particles collected are not contaminated with asphalt roofing debris.

I've also picked up samples by dragging a strong magnet along the silty bottom of the shores of the Finger Lakes and

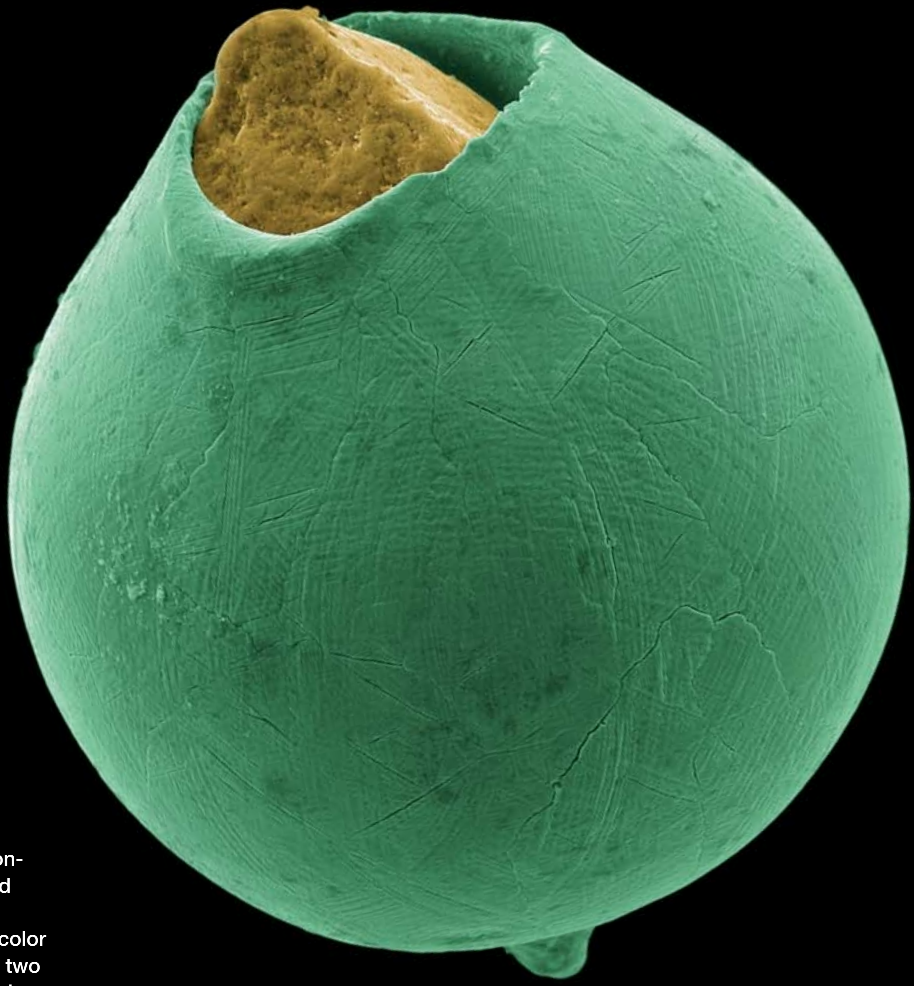


▲ **CRYSTAL SURFACE** This scanning electron microscope image, 80 microns to a side, shows the crystal structure on the surface of a micrometeorite. This meteorite is primarily made of iron, with small amounts of other elements. Iron micrometeorites are easy to find with the help of a strong magnet.

▼ **MICKEY MICROMETEORITE** The piece of cosmic dust in this false-color image is 600 microns wide. Its appearance has a distinct quality from that of the others because the author utilized a different imaging mode that uses back-scattered electrons.



ALL IMAGES COURTESY OF THE AUTHOR



NUT IN A SHELL This 320-micron-wide micrometeorite has iron and nickel melted around a grain of almost pure titanium. (The false color helps distinguish between these two components.) While other examples like this one exist in the literature, the author considers this to be one of the strangest samples he has collected.

the Great Lakes. These samples, though collected far from industrial centers, nevertheless probably carry some contaminants. To improve my chances of picking up a meteorite, I tend to search along cracks in the rocky river bottom. These older surfaces act as natural concentration mechanisms for cosmic dust.

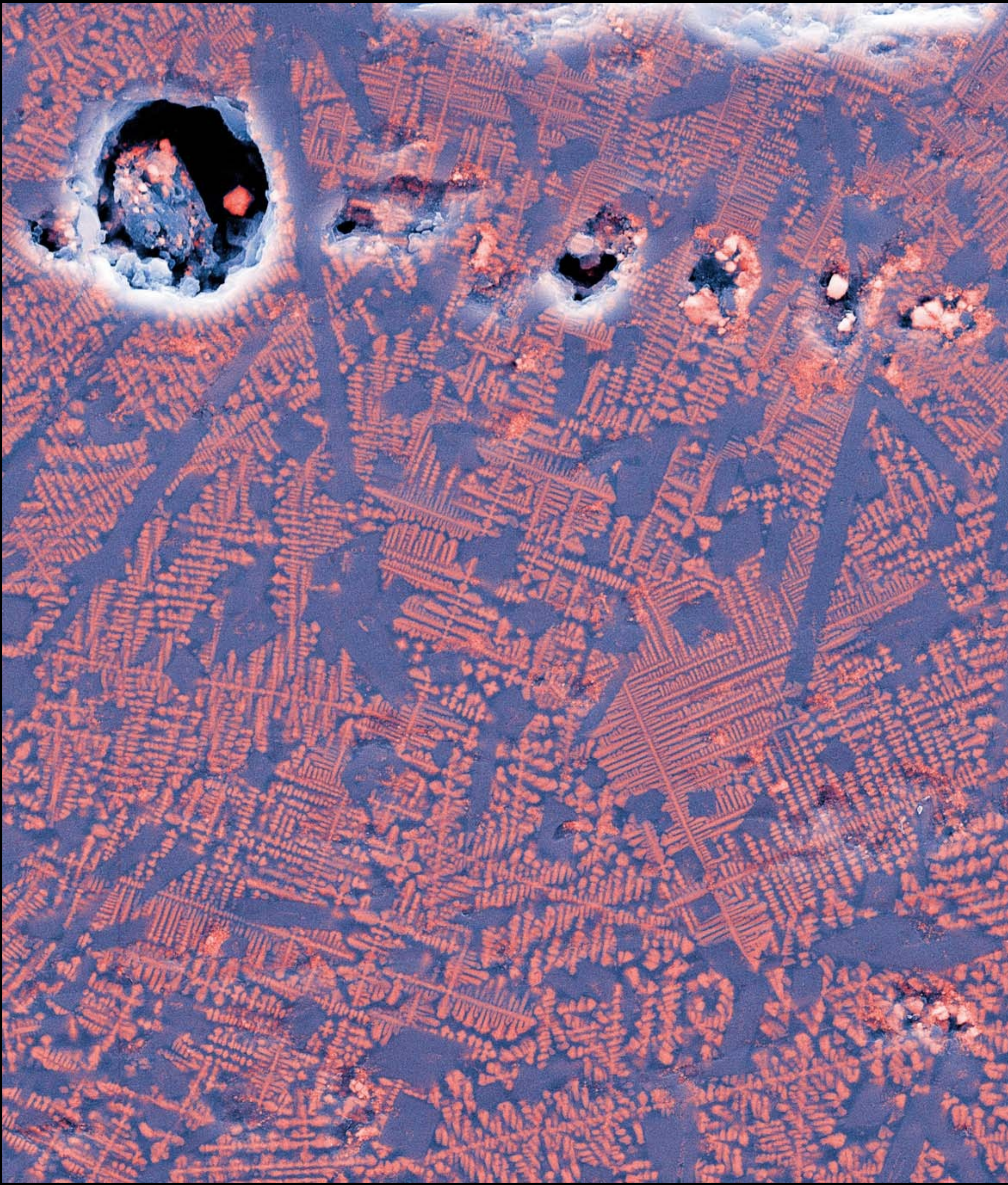
I have also used strong magnets to collect micrometeorites from the drainage of large parking lots. However, while these sites do contain tiny space rocks, they also contain numerous bits of metallic debris from cars. Several large parking lots at my university are even more complicated strewnfields because students often run metal chop saws there. Too much contamination fills the runoff for these sites to be useful.

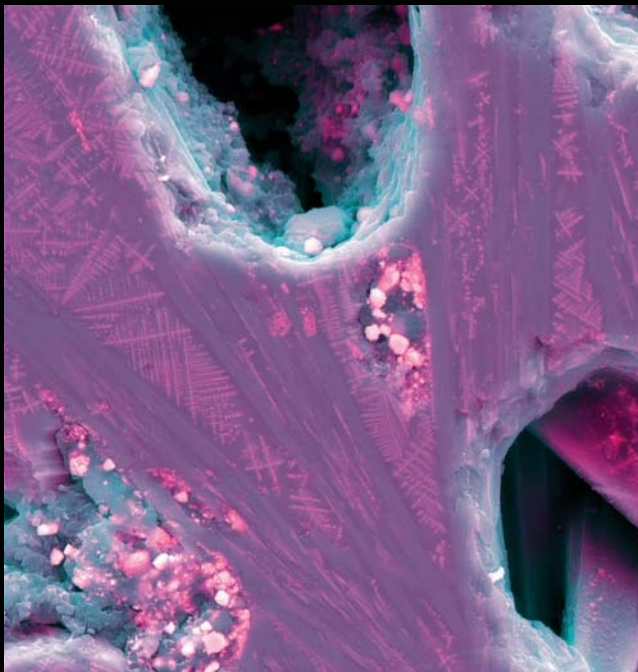
Analysis

I sort my samples by several criteria: A fragment has to be a magnetic sphere, have a surface melted by passage through the atmosphere, and be big enough for me to pick up with tweezers, so that I can place it under an optical microscope.

Since I teach scanning electron microscopy, I also have access to a number of these microscopes for imaging — which I admit makes me an unusual meteorite hunter. Under the microscope, magnetic micrometeorites are fairly easy to spot by their spherical shape and crystal patterns due to atmospheric wear. If a micrometeorite has sat in the environment for a while, though, a layer of rust may cover the surface, which complicates identification.

BLOWHOLES Many micrometeorites, made spherical due to atmospheric heating, have crater-like holes where hot gases or boiling liquid materials erupted from the center during reentry.





The specks may not look like much, but it's still rewarding to hold a little piece of the solar system on the tip of your finger.

Besides analyzing a micrometeorite's appearance, I also identify space dust by its elemental composition. To do this, I use a technique called *electron dispersive spectroscopy.* After placing a sample in the scanning electron microscope, I bombard it with electrons, which in turn generate X-rays. The wavelengths of the X-ray photons produced depend on which atoms the electrons hit, so this technique will tell me what elements are in a specimen. A sample containing iron, manganese, and aluminum, for example, is likely a micrometeorite. The micrometeorites I find are generally made of iron, with other elements such as manganese, silicon, or nickel mixed in.

Magnetic micrometeorites represent less than 5% of all the meteoritic debris raining down on Earth. But because they're also the easiest to collect and identify, I manage to accumulate a lot of them. Dealing with huge numbers of micrometeorites means I'm more likely to find relatively "large" specimens, with a diameter of at least 0.5 mm.

Even though you may not have access to the same equipment, you can still find micrometeorites with a fair degree of confidence as long as you look in the right places. The specks may not look like much to the eye, but it's still rewarding to hold a little piece of the solar system on the tip of your finger.

■ **TED KINSMAN** is a professor and high-speed photographer at Rochester Institute of Technology. He thanks Bryan McIntyre of the University of Rochester for his help in collecting X-ray spectra and for the use of his high-resolution scanning electron microscope.

◀▲ **MAGNETIC DENDRITES?** The circuit board-like texture that appears in these images could represent magnetic dendrites, if the fragments are from micrometeorites. However, this pattern can also be found in particles associated with industrial contamination. When scanning electron images do not tell the whole story, as is the case here, a spectrum can be helpful in determining the sample's composition.

▼ **SWEEPING FOR COSMIC DUST** The author searches along a crack in the rocky bottom of a riverbed (*left*), a surface that acts as a natural trap for micrometeorites. He uses a strong magnet (*right*) to aid his search.

Tracking Hubble's Variable Nebula

The author documents two decades of NGC 2261's variability through sketches.

March 10, 1999
20-inch f/5 at 413×

February 9, 2005
28-inch f/4 at 457×

▲ **HUBBLE'S VARIABLE NEBULA** Edwin would be proud of this image of his namesake nebula taken with the orbiting observatory that also carries his name!

▶ **CHANGING MORPHOLOGIES** The author's sketches are displayed in chronological order. Noted are the observation dates and telescope specs.

As you might expect, **Hubble's Variable Nebula** is named after Edwin Hubble, who, as a graduate student at Yerkes Observatory, first described the nebula's variability in a paper he wrote in 1916. Hubble went on to bigger things, of course: He established that spiral "nebulae" were in fact external galaxies; his name is attached to the law that describes the expanding universe and its associated constant; and the Hubble Space Telescope is named in his honor. But it's his work on NGC 2261, the variable nebula that would also carry his name, that came first.

William Herschel discovered the nebula in 1783, and Julius Schmidt noted in 1861 that R Monocerotis (R Mon), the star that illuminates NGC 2261, was variable. But Hubble was the first to document the nebula's changes in form (see the sidebar on page 24, though, for a curious historical twist). As it turns out, NGC 2261 is also the correct answer to "what was the first object photographed by the 5-meter Hale telescope at Palomar Observatory?" As a fitting tribute to his 1916 discovery, Hubble himself took that photo on January 26, 1949.

▲ **THE HALE CAPTURES HUBBLE'S NEBULA** When Edwin Hubble pointed the 200-inch Hale Telescope skyward for the first time, he snapped a shot of the nebula that bears his name.

Although Hubble's Variable Nebula is not the only one that varies in apparent brightness and shape, it's by far the brightest and most detailed member of the small class of variable nebulae. But are its variations obvious enough to be visible through an amateur-sized telescope? If so, how long does it take to see changes, and how big a scope does one need to see them? What causes the changes in the first place? The quick answers are yes, 24 hours or less, 8 inches or so, and shadows — but let's examine each in more detail.

Can You See the Changes Visually?

I've been tracking the apparent changes in Hubble's Variable Nebula on and off since 1999 and have accumulated 21 observations to date. NGC 2261's small and remarkable comet-like shape is quite striking, but the best part is that it has looked different every time I've observed it.

That's right, *every* time. My experience shows it's not only possible to see variations in NGC 2261 with your own eyes through a telescope, it's inevitable if you observe it more than once.

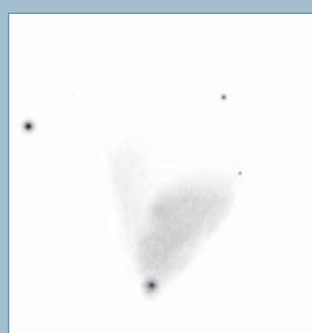
My first five observations were spread over several years (15, in fact), and even though they're fascinating snapshots showing dramatic changes, I couldn't help wondering just how short a time interval would show a change. During the winter of 2018–2019 I decided to find out and observed NGC 2261 every clear night I could — that meant most of my observations were from my home instead of a dark-sky site. These make up the remaining 16 of the 21 observations.

It quickly became evident that despite NGC 2261's small apparent size, its high surface brightness means changes can be seen under less-than-pristine skies. Sometimes the overall shape of the nebula looked different, and sometimes it was the details within the nebula that changed, which was when steady seeing and higher magnifications — 400× to 600× — were the most helpful. At other times it was the apparent brightness of R Mon that was the most striking difference, because it varies irregularly between 10th and 13th magnitude. In the end, every element of NGC 2261 looked different to some extent for each observation. However, it retained its basic form, which Hubble described well in his 1916 paper, even when the details of its appearance changed dramatically:

"A striking instance of actual change in form has been found in the case of the nebula N.G.C. 2261 . . . one of the few real examples of cometary form in the sky and easily the finest of

January 11, 2007
28-inch f/4 at 570×

February 17, 2010
28-inch f/4 at 408×



January 5, 2014
28-inch f/4 at 408×

November 19, 2018
28-inch f/4 at 408×

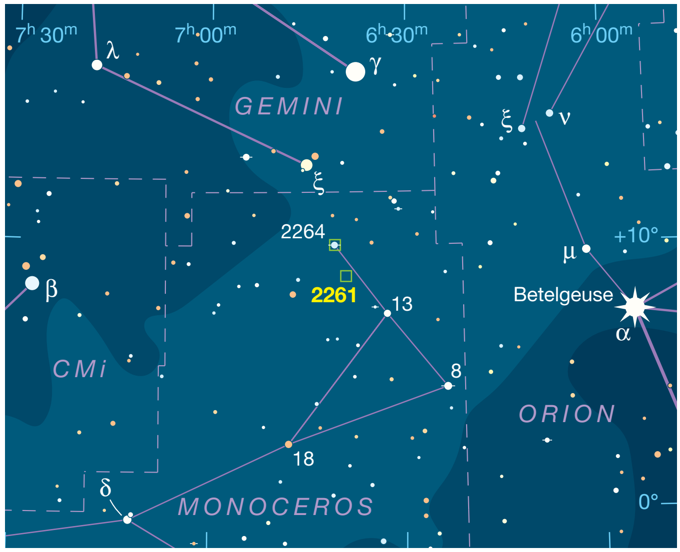
HST IMAGE: NASA / ESA / THE HUBBLE HERITAGE TEAM / AURA / STSCI; HALE IMAGE: COURTESY OF THE ARCHIVES, CALIFORNIA INSTITUTE OF TECHNOLOGY; ALL SKETCHES BY THE AUTHOR *them. Photographically it is well defined and has almost the form of an equilateral triangle with a sharp stellar nucleus at the extreme southern point. There are faint extensions from the northern portion of it. One long streamer which projects from the northern edge extends almost due north."*

During my 20 years of observations, I've seen obvious variations throughout the body of NGC 2261, but the most dramatic changes in form are associated with the north-curving streamer on the eastern edge of the nebula, which has brightened, dimmed, thickened, thinned, lengthened, shortened, and shown knots that come and go. It has also completely disappeared at times!

Because this streamer becomes increasingly fainter the farther it gets from R Mon, the quality of the sky affects how long it looks. An apparent change in its length may be partially due to observing conditions, and I'm sure that's been true at least a little in every one of my observations. The shortest I've seen it was on October 2, 2019, and the longest were on February 17, 2010, and March 3 and 4, 2019.

Another dramatic change is the constantly morphing shape of a dark area that takes a bite out of the western edge of the nebula immediately north of R Mon. I once saw that bite extend all the way to the eastern edge, seemingly cutting off R Mon from the rest of NGC 2261's nebulosity — take a close look at my sketch from February 17, 2010.

One of the more fascinating changes to look for is the variability of R Mon itself. When the star is near maximum brightness it looks like a star to me, but at its minimum it gives an impression of being a bright and very condensed nebulous patch. That happens to be exactly what we're seeing, because research has shown that R Mon is heavily obscured and truly encased within its nebulosity. We don't see R Mon itself, just the nebula that the star illuminates from within. This nonstellar appearance shows well in the image on page 20. Even though I've glimpsed the fuzzy look of this part of NGC 2261 during moments of steady seeing, I have yet to see it as the triangular patch that's so obvious in the Hubble Space Telescope image.



▲ **FINDER CHART** Hubble's Variable Nebula, also known as NGC 2261, lies in the northern reaches of Monoceros, just below Gemini and between Canis Minor to the east and Orion to the west.

Two Decades of Sketches

The series of sketches presented at the bottom of each page are my complete collection of Hubble's Variable Nebula drawings to date and clearly show the changes I've seen. Each caption lists the observation date, scope used, and magnification.

The sketches represent what I saw without the use of nebula filters. The unfiltered view was always the most detailed: Because NGC 2261 shines only by reflected starlight from R Mon, it doesn't respond to nebula filters. Most of my observations were made under skies that measured 19.4 to 20.4 with a Sky Quality Meter, with the darkest sky — on March 4, 2019 — measuring 21.49. That translates to limiting magnitudes of about 5.0 to 6.4.

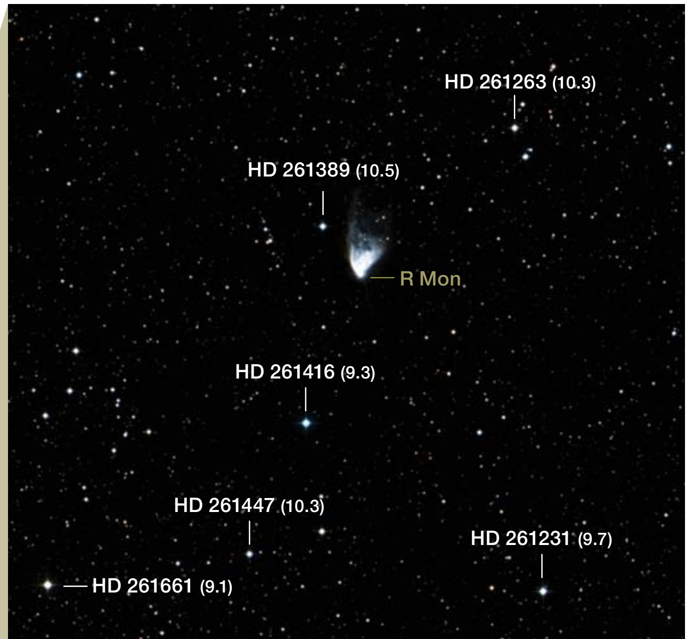
All but four of my observations were with my 28-inch scope. The very first observation on March 10, 1999, was with my old 20-inch Dob. I also observed NGC 2261 once in January 2019 with my wife's 8-inch f/3.3 Dob to see if I could detect enough detail to notice changes through a wide-field

Cold winter nights can certainly present a persuasive argument to stay inside, but NGC 2261 is one of the best reasons to get out there and observe anyway.

December 2, 2018
28-inch f/4 at 408×

December 4, 2018
28-inch f/4 at 408×

December 5, 2018
28-inch f/4 at 408×



◀ **IN NORTHERN MONOCEROS** Tiny NGC 2261 is below and right of the Cone Nebula and NGC 2264, the Christmas Tree Cluster — the star S Mon is the bright star at the base of the upside-down tree. By the way, the Cone Nebula is an extremely difficult visual target — have you snagged it?

▲ **ZOOMING IN** You don't need a monster of a scope to spot Hubble's Variable Nebula — its small apparent size and relatively bright magnitude yield a high surface brightness. Use the HD stars and their magnitudes (in parentheses) to estimate the brightness of R Mon. This image is 30′×30′.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY (2)

scope. As it turned out, I could. There are also two observations from October 2019 using my own 8-inch f/4 Dob.

One of the most valuable things I've learned from this observing project is that getting satisfying observations of Hubble's Variable Nebula doesn't require a huge telescope and freezing all night under the winter sky at a remote dark-sky site. Cold winter nights can certainly present a persuasive argument to stay inside, but NGC 2261 is one of the best reasons to get out there and observe anyway.

How Long?

After looking at an online animation of images taken over several months (see **https://is.gd/HVNanimation**), I had a hunch I'd be able to see changes over the course of a few nights. Although that turned out to be true, the shortest timescale during which I saw definite variations was only 24 hours. That was both unexpected and exciting, because I could see at a glance that the nebula had changed its appearance each time I observed it on consecutive nights. Observa-

December 6, 2018
28-inch f/4 at 408×

January 1, 2019
28-inch f/4 at 408×

January 14, 2019
28-inch f/4 at 408×

January 30, 2019
8-inch f/3.3 at 164×

tions with my 28-inch revealed obvious changes in the nebula and R Mon on the nights of December 5 and 6, 2018, March 3 and 4, 2019, and October 7, 2019, with respect to the preceding night's observations.

Observing conditions were different each night, of course — darkness, transparency, steadiness of the seeing all fluctuated — but the nightly variations of Hubble's Variable Nebula were obvious enough to transcend the ebb and flow of our turbulent atmosphere.

I now wonder if changes in NGC 2261 can be detected over the course of a single night by observing it as soon as the sky gets dark, and then again just before dawn. This would have to be attempted during the Northern Hemisphere winter, and if I ever get the chance I'll give it a shot.

How NGC 2261 Became Hubble's Variable Nebula

It may come as a surprise that Edwin Hubble didn't discover the variability of NGC 2261. Instead, John Mellish, an unpaid observer at Yerkes, originally mistook NGC 2261 for a comet. Based on Mellish's observations, Edwin Frost, the second director of the Yerkes Observatory, sent a telegram to Harvard College Observatory, as was customary, announcing the "comet" discovery. In its turn, Harvard promptly dispatched the usual telegram to observatories around the world informing them of this latest discovery, before it became apparent that Mellish had observed NGC 2261 instead of discovering a new comet. Oops. Mellish subsequently lost credibility with Frost. Hence, Frost assigned Hubble the task of substantiating Mellish's original 1915 visual observations of NGC 2261.

Shortly thereafter, Hubble confirmed the variations that Mellish had noted in NGC 2261 and wrote his first research paper on the subject in 1916 (**https://is.gd/HubbleNGC2261**). The rest is history.

How Big?

Although faintly visible in my 80-mm finderscope, the two 8-inch Dobs were the smallest instruments I used to observe NGC 2261. Because the nebula is rather small, I needed to boost magnification beyond what I'd normally use on nebulae to get enough image scale to see details well. Due to its high surface brightness, I think it's possible to track variations in NGC 2261 with a smaller scope under more pristine skies than I had, but the only way to find out is to give it a go. Be prepared to boost the magnification to around 300× to get a large enough image to more easily follow what's going on.

Why Does Its Appearance Change?

The driver of these apparent changes is a dusty accretion disc around the young (less than 300,000 years old), massive (approximately 10 solar masses), and still-forming star, R Mon. It's classified as a Herbig Ae/Be star with active accretion and has a small companion, R Mon B, which is probably a T Tauri star. Both stars are likely the same age and have a way to go before joining the main sequence.

A current working model for NGC 2261 invokes a dusty envelope surrounding R Mon and its circumstellar accretion disk. As the star and accretion disk rotate, they entrain matter from the dusty envelope, which is expelled along with disk material in the polar directions by a strong and fast (around 300 km/s) stellar wind. The ejected material takes the form of bipolar parabolic cones. Interestingly, what we see as NGC 2261 is only one half of the bipolar nebula: the outflow that is pointed in our direction (the accretion disk has an inclination angle of some 20°). The other component is pointed away from us and is hidden by the dust and gas of the envelope and the cone pointed toward us.

Some of the ejected material is thought to be in the form of long filaments that cast shadows inside the cones. These filaments appear to form some 2.2 astronomical units from R Mon and may rotate with the help of magnetic fields. It's

February 6, 2019
28-inch f/4 at 408×

March 2, 2019
28-inch f/4 at 408×

March 3, 2019
28-inch f/4 at 408×

March 4, 2019
28-inch f/4 at 547×

the shadows cast by these streamers as they spiral through the cone pointed toward us that are the likely source of NGC 2261's observed variations. Imagine what that might look like from inside the nebula!

HVN's Neighborhood

Hubble's Variable Nebula is in a fascinating part of the sky. It's located about 1° from the open cluster NGC 2264 and its associated H II nebulosity, Sh 2-273 (which is home to the infamously challenging visual object, the Cone Nebula), and, in fact, lies in the outer reaches of this H II region. But that doesn't mean it's in a less dense environment, only that the main illuminating star of Sh 2-273, S Mon, is too far away to efficiently energize Hubble's Variable Nebula's immediate environment.

See For Yourself

Hubble's Variable Nebula is about 2,500 light-years away and, including the northern streamer, spans about 1.5 light-years. It has an apparent size of 2′ — or about 2.5 times the apparent diameter of Jupiter at opposition — and fluctuates around 9th magnitude. This relatively bright magnitude and small apparent size together create a high surface brightness, so don't shy away from taking a look if you have a scope of 8 inches or less. Even though the great 18th- and 19th-century visual observers like the Herschels or Lord Rosse missed their opportunity to discover NGC 2261's variability, you can watch the unfolding action through a modest-size backyard telescope. You can't know what you'll see if you don't look, so *do* go look.

NGC 2261 is also a terrific astrophotography target. There are several animations online (my favorite is the one by Tom and Jennifer Polakis mentioned earlier), but at best they're composed of images taken months apart. An animation with images taken on as many consecutive nights as possible, or even more interesting, once every 30 minutes on the same long winter night, could be fabulous.

Hubble's Variable Nebula is well-placed in the northern sky from late fall to early spring, so when the cold tempts you to stay inside, bundle up anyway, grab your telescope, and watch night to night as this exceptional object hurtles through its extraordinary youth.

■ Contributing Editor **HOWARD BANICH** is enthralled by the shifting shadows of Hubble's Variable Nebula and hopes you get hooked on them, too.

OTHER VARIABLE NEBULAE: If Hubble's Variable Nebula inspires you to seek out further examples of this type of object, you can also visually follow NGC 1555 (Hind's Variable Nebula), NGC 6729, GM 1-29 (Gyulbudaghian's Nebula), and McNeil's Nebula. More information can also be found in Ted Forte's article in the February 2018 issue of *Sky & Telescope* (page 22) and at **https://is.gd/ReinerVogel**.

More About the Sketches

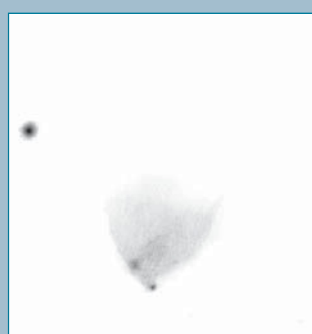
The 21 sketches presented here were redrawn from the originals in my observing notebook at the same scale so they could be directly compared to one another.

The sketches that show the most field stars represent the best observing conditions with the 28-inch scope, while the sketches with bloated stars represent the terrible seeing conditions of those nights.

Note that the two sketches of October 6, 2019, shown below, illustrate what I saw with 28-inch and 8-inch f/4 scopes within a few minutes of each other — and confirm that an 8-inch scope can indeed present a good view of Hubble's Variable Nebula at high power.

October 2, 2019
8-inch f/4 at 351×

October 6, 2019
28-inch f/4 at 457×



October 6, 2019
8-inch f/4 at 351×

October 7, 2019
28-inch f/4 at 605×

Shooting "Deepscapes"

Here's how to capture striking photographs of deep-sky objects above landscapes in a single exposure.

▲ Photographing deep-sky targets over terrestrial landscapes in a single exposure can be a worthy challenge. In this article, the author shares tips to capture deep images such as this shot of the Orion hourglass as it rises over mountains. The single, 35-second image was taken with a modified Canon EOS 6D DSLR and 85-mm lens at f/2.2, ISO 12800.

Picture an image of the constellation Orion rising above a distant mountain, with M42 and the Horsehead Nebula displaying vivid colors and wisps of faint gas and dust. The reddish crescent of Barnard's Loop cradles the central stars of the Hunter's belt, spanning from Bellatrix to Saiph and back to Rigel. The large glow of Sharpless 2-164, the Angelfish Nebula, surprises you with its visibility in the photograph. Surely this must be a composite — such deep images are only possible using complex processing techniques to blend the moving sky with a stationary foreground, right?

Not so! While in the past such an image would have required hours of *Photoshop* wizardry, today's digital sensors and fast, high-quality camera lenses make deep-sky nightscapes such as this possible in a single short exposure. With planning, processing the images takes almost no time at all.

While it's common practice for nightscape photographers to blend several exposures to create a smooth, picturesque composition or add a foreground to a deep-sky image, I prefer the challenge of capturing deep nightscapes in a single exposure by coupling old-school photography techniques with the latest digital cameras. The results give me the satisfaction and sense of accomplishment that just don't come from composites. Here are some tips on shooting your own single-exposure "deepscapes."

ALL IMAGES PROVIDED BY THE AUTHOR

A Good Plan

The first thing needed to capture deep images of nebulae, galaxies, and star clusters over an attractive foreground is a firm knowledge of the night sky. Sure, the Orion Nebula, Andromeda Galaxy, or Magellanic Clouds are obvious deepscape targets, but there are many other objects that can expand your subject matter and add variety to your work. Virtually every major constellation offers something to focus on.

Knowing where an object will rise above the horizon can help you plan a composition before it's ready to photograph. A planetarium app can help give you a general idea of where an object is going to rise, but placing the sky in context to the landscape you intend to shoot requires more specialized tools.

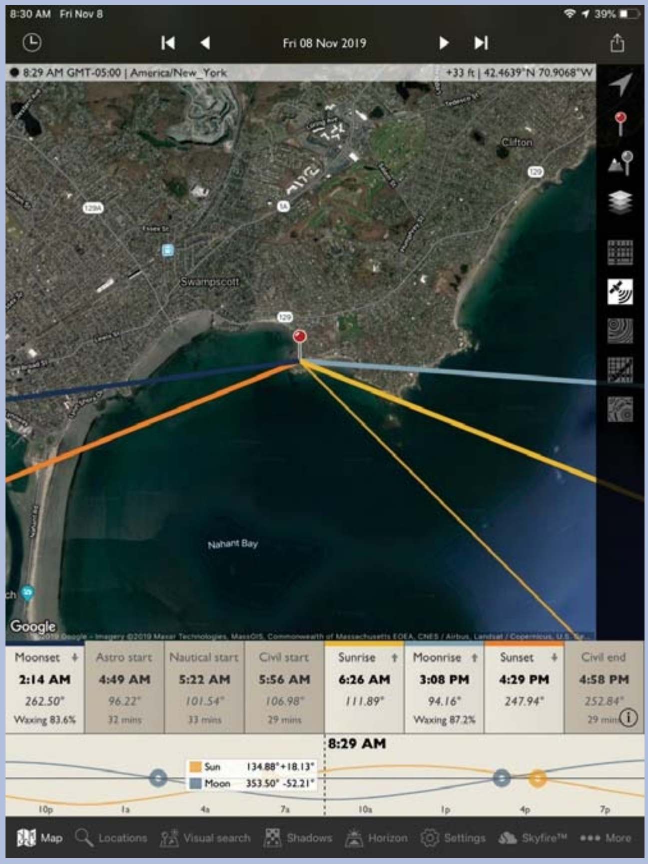
Several apps are available to aid in planning your composition. *The Photographer's Ephemeris* (**photoephemeris.com**), *PhotoPills* (**photopills.com**), and *PlanIt!* (**yingwentech.com**) are some of the powerful tools available online or downloadable as Apple and Android apps that can help you to plan exactly where to position yourself so that your subject rises *precisely* above the foreground as you envisioned it. Most of these apps use built-in planetariums that combine a night sky map and a Google Earth view of your chosen location.

Transient objects such as comets require you to monitor astronomy websites to get up-to-date information about where these moving targets will be in your sky as they brighten enough to photograph in a single exposure.

Choosing a Lens

Deepscape photography is more challenging than typical nightscapes in that you often use telephoto lenses with narrower fields of view. This means that you can only shoot for a short time before your subject becomes noticeably trailed. But a good choice for starters is a high-quality, fast prime-focus 35-mm or 50-mm f/1.4 lens that produces sharp star images when used at its widest aperture. I recommend that you stop the lens down to f/2 to reduce aberrations in the corners of the frame. Stopping down the lens also reduces vignetting to nearly imperceptible levels. Most recent full-frame DSLR and mirrorless cameras have decent noise characteristics. But the newest models tend to incorporate the latest sensors, which produce excellent images at the extremely high ISO speeds needed to "freeze" the motion of your target over a landscape in short exposures.

A handy rule of thumb for nightscape photography is known as "the rule of 500." This states that for a fixed (non-tracking) camera, 500 divided by the focal length of your lens in millimeters gives the length of an exposure in seconds before stars appear trailed in your image. (And that also applies to the appearance



▲ Apps such as *The Photographer's Ephemeris* help you plan your deepscape images by plotting the direction where specific targets will rise or set above the horizon based on your exact location.

▼ High-quality, fast lenses such as Sigma's Art lens series combined with the latest sensors will produce your best results.

of your foreground when the camera is tracking the sky.) For example, when shooting with a 35-mm lens, you can expose for about 14 (500/35 = 14.29) seconds before stars are visibly trailed in a photo. This is not an exact rule, as the trailing will depend somewhat on the pixel size in your camera, what part of the sky you are shooting, and whether you use a full-frame or crop-sensor camera. But it should be close enough that stars and deep-sky objects will appear relatively sharp and stationary.

▲ Longer exposures are possible when adding a tracking head to your camera and tripod. Models that include a ½ sidereal rate (0.5×) will double the exposure time you can achieve before stars appear trailed in a photo.

A lens with a large maximum aperture (small f/ratio) delivers more light to your sensor and reduces the needed exposure time, especially when using a telephoto lens to image deep-sky objects. Most zoom lenses aren't well-suited for extreme low-light photography, because they are often not as fast as a prime (fixed-focus) lens and often not as sharp at the ends of their zoom range.

With lens speed and the rule of 500 in mind, portrait lenses are excellent optics for capturing single-shot deepscapes. These lenses range from focal lengths of 85 to 135 mm. Canon, Nikon, and several other manufacturers produce excellent portrait lenses, and don't be afraid to shop for older, manual-focus lenses on the used market. I recommend Sigma's Art lens series as my most frequently used lenses for short deepscape images. They work quite well at full aperture.

Portrait lenses can reveal a surprising amount of detail in deep-sky targets. Nearby spiral galaxies start to display their spiral arms in exposures of as short as 20 seconds at high ISO. Many of the nebulae in Orion, including everything within Barnard's Loop, can be comfortably framed with a foreground object with a 135-mm lens on a full-frame camera.

For more resolution, you can step up to a 200-mm f2.8 lens or even longer. At this focal length, the Andromeda Galaxy (M31) shows its dust lanes, and larger globular clusters like Omega Centauri begin to resolve into individual stars.

Bending the Rule

As mentioned above, the 500 rule gives you the maximum exposure to avoid trailing stars. But this rule isn't set in stone. A silhouetted mountain peak against the sky won't look noticeably blurry in a short, tracked exposure, so you can track at full speed and go four to five times longer than the 500 rule recommends without losing foreground detail.

When shooting fields far from the celestial equator, you can increase the exposure because stars don't appear to move as much. For instance, midway between the celestial equator and poles, you can increase the exposure length by about 40% and still have acceptable stars. And you can expose areas near the celestial poles, such as the Big and Little Dipper asterisms, up to 70% longer.

Without tracking, you'll quickly realize the 500-rule exposure limit is too short with a telephoto lens to adequately record most deep-sky objects. Take the 85-mm lens, for example. The rule of 500 limit with this lens is only about 6 seconds. The obvious solution is to attach the camera to a tracking mount to follow the target as the landscape moves below. In normal deep-sky astrophotography, this allows you to expose as long as you can to improve an image's signal-to-noise ratio. However, our goal is to capture both the sky and objects here on Earth, so tracking for long periods blurs the foreground. The challenge is to reveal the celestial object in only a few seconds at extremely high ISO settings such as 6400 or more. One solution is to use a tracking mount that includes a ½ sidereal speed tracking rate. This trick splits image trailing between stars and the landscape. Using this tracking rate, you can effectively double the exposure limit. Our new rule of thumb for exposure then becomes 1,000 divided by the lens focal length.

Even so, this may be still too short to record dim objects, particularly when the foreground has interesting details to capture. One trick to overcome landscape blurring on nearby foreground objects is to illuminate them with a flashlight briefly at the start or end of the exposure. They only need to be lit for a moment or so and then remain dark for the rest of the exposure, freezing their motion in a tracked exposure.

One issue with shooting at full aperture on a fast lens is

◀ Balancing colorful deep-sky objects with lots of detail (such as the Carina Nebula, NGC 3372, seen here) with interesting foreground objects requires advanced planning. This shot was taken from the Atacama Desert in Chile using a 200-mm lens at f/3.5 paired with a Nikon D810a DSLR camera and tracked with the Vixen Polarie mount seen above. Total exposure was 25 seconds at ISO 12800.

a shallow depth of field — objects closer than the point at which a lens is set to focus will be noticeably blurred.

There's a great old-school technique you can use to overcome this issue. It works best with lenses that include a marked focal distance scale as well as a manual aperture ring. First, focus the lens on the foreground object of interest and illuminate it with a flashlight briefly at the beginning of the exposure. Then quickly but gently turn the focus ring of the lens manually to the marked infinity point on the lens, and let the exposure finish up. In the resulting image, both the stars and the illuminated foreground will appear sharp. If your camera is mounted on a sturdy tripod, you can experiment with stopping down the aperture of the lens at the start of the exposure to ensure the nearby subject is as sharp as possible, briefly light it up, then open the aperture and move the focus to infinity.

▶ "Painting" in foreground objects at the start of an exposure using a flashlight will help balance your composition, as was done with the ALMA radio telescopes seen beneath the Large Magellanic Cloud in this photo.

▼ This group of ALMA radio telescopes below the Coal Sack and Southern Cross was taken by first focusing on the telescopes, quickly illuminating them with a flashlight, then changing the focus to infinity to record the stars and constellations all in the same exposure.

This focus-ramping technique is tricky to perform, particularly in the dark, so you'll need to practice it few times to ensure you get it right.

Camera and ISO Speed

This type of complex nightscape photography requires a detector suitable for low-light imaging regardless of the ISO setting used. Changing the ISO setting in your camera amplifies the signal recorded, increasing noise as well as the signal recorded, and is not a replacement for a high-sensitivity detector. The true sensitivity of a CMOS sensor is directly related to the size of its individual pixels. These tiny wells collect photons like buckets collect raindrops — larger pixels collect more photons before filling up (saturating) than small pixels do. Cameras using APS-sized detectors with more than 30 megapixels sound astounding but use tiny pixels that saturate quickly, which translates into white, colorless stars after post-processing. Full-frame cameras are better suited for deepscape imaging because they incorporate larger pixels in a bigger detector, and thus saturate at a much higher threshold.

Recent camera models designed for astrophotography such as the Nikon D810A and the Canon EOS Ra both utilize 30+ megapixel full-frame sensors with about 5-micron pixels. Although 5-micron pixels are a bit small, they are paired with powerful internal processors that finely control noise in images taken at high ISO speeds.

The benefit of these Canon and Nikon cameras is their spectrally enhanced internal filters which, compared to standard cameras, pass a larger percentage of the hydrogen-alpha (Hα) light that most nebulae emit. Since most deepscape targets include a lot of Hα, a spectrally enhanced camera will produce your best results. You can shop for one of these newer cameras, though several companies offer services to modify older DSLR and mirrorless cameras to pass more of this astronomically important wavelength.

Challenging Skyglow

Deepscape photography by its very nature often requires shooting your subject close to the horizon where distant skyglow is more evident. Even in a totally dark sky, an atmospheric phenomenon known as *airglow* may visibly brighten the background sky, imparting an orange or greenish glow that obscures your intended subject. Skyglow or light-pollution filters can suppress the sky brightness and increase nebulae contrast, but keep in mind the image will need more exposure to overcome the reduced signal. Skyglow filters are more impactful with modified cameras.

Using additional filters can also impart a color cast to your photos that is best corrected by setting a custom white balance in your camera. This is accomplished by setting your camera color setting to auto (AWB) and photographing a gray

◀ Some foreground subjects will not detract from your final image even if they are blurred. The cloud deck below the peaks on the Canary Islands adds a mystical quality to this tracked photo of nebulosity in Sagittarius and Scorpius.

▲ Depending on the subject you are shooting, the stars don't always need to be in focus. In this case, these nightscape photographers are the focus of the composition.

card or a piece of white paper in daylight with your intended filter in place. Make sure the card or paper completely fills the frame. Then simply change the color setting to Custom White Balance and select this photo as the calibration image. Be sure to keep this photo on your memory card when shooting deepscapes, and to use the custom white balance setting.

Processing the Results

Once you've shot your images, a little post-processing is necessary to achieve the best results. It's important that you shoot in RAW mode to get the most out of your night's work. I prefer to use *Adobe Lightroom* and *Adobe Camera Raw* (ACR), though Nikon and Canon offer their own processing programs that can accomplish much of the same enhancements.

My first step is to reduce noise in the image by opening it in ACR and first lowering the Texture slider by around 20. I select the Detail tab in the right column. Rather than adjusting the Luminance slider in the Noise Reduction area, I prefer to lower the Sharpening setting. Masks can also be applied to target certain areas for additional noise reduction after applying ACR, adding a layer mask over the areas you'd like to target and repeating the ACR process. Next I change the color profile in the Basic tab to Adobe Standard, which slightly increases contrast and saturation. If necessary, I'll increase the Contrast and Vibrance sliders.

If I shot my deepscape at maximum aperture, I'll select the Lens tab and find the lens I used from the extensive pulldown menu, which corrects for vignetting and chromatic aberration in many lens designs. Other settings that can improve an image are the Shadow and Highlight sliders, which help to bring out faint nebulosity or suppress bright areas in a picture if necessary. The Dehaze slider is very powerful in increasing contrast in an image but requires restraint so as to not "overcook" the result.

If you shot under light-polluted conditions, you can correct the white balance in the Basic tab. Keep in mind that shifting the color slider to low temperatures in order to remove the orangish cast of light pollution from the sky background will also shift the colors of the stars, Milky Way, and other celestial objects.

Using these tips, you too can shoot captivating deepscapes that bring your favorite deep-sky objects down to Earth.

■ Contributing Photographer **BABAK A. TAFRESHI** captures the beauty of the Earth and sky from exotic locations worldwide. See more of his work at **babaktafreshi.com**.

▼ *Left:* Unilluminated foregrounds like the mountains seen here below nebulosity in Scorpius won't display much blurring in longer exposures, so you can expose a deepscape for roughly four times as long. This image was captured with a Nikon D810a camera and a 105-mm lens, and tracked for 25 seconds at ISO 12800. *Right:* Slight illumination on the arc limited this exposure to 15 seconds at ISO 6400 with a 50-mm lens at f/2.8.

Two Simple Spectrographs

Homebrew science for a sunny day

▲ David Britz's spectrograph uses a polished metal rod in place of the more traditional slit. Light enters on the left, bounces off the rod in back, and illuminates the diffraction grating in front right. The camera (not mounted here) slides left and right to capture the entire spectrum. Different diameter rods, visible on the right, provide different resolutions.

▲ Joseph Gerencher's spectrograph uses a traditional slit but a decidedly non-traditional CD or DVD for a diffraction grating. Light enters on the left, bounces off the grating at the junction on the right, and goes through a lens at the white coupling partway up. The resulting spectrum reaches the camera body (without lens) on top.

▲ The slitless spectrograph produces a sharp, detailed solar spectrum.

▲ A CD or DVD produces a curved spectrum due to the spiral lines that create the diffraction.

JUST ABOUT EVERYTHING we know about stars comes from observing the light they emit. For centuries, our observations were limited to examining the brightness and color of those distant suns, but that changed in 1814 when Joseph von Fraunhofer split the incoming light into a wide spectrum and noticed dark gaps within it. Later, Gustav Kirchhoff and Robert Bunsen realized that those lines corresponded to the emission/absorption spectrum of specific chemical elements, and with that discovery we were able to determine the chemical composition of stars. A new element, helium, was even discovered spectroscopically in the Sun before it was found here on Earth.

Later still, we learned how to measure a star's velocity by studying the Doppler shift of those elemental lines. The thickness of the lines can tell us things about the strength of the star's magnetic field and its rotational speed. We know the age of the universe and its rate of expansion largely through spectrographic studies. And so on.

Because this column is about amateur telescope making, you probably already suspect where this is going: Yes, you can indeed build your own spectrograph and measure your own stellar spectra. Here are two different designs for you to consider.

First a word on nomenclature: A *spectroscope* is something you look through or which projects an image on a screen that you observe by eye. A *spectrograph* is a device that allows you to record the spectrum. We'll be looking at spectrographs here, in part because the easiest star to obtain a spectrum of is the Sun. It's bright enough that you don't need a long exposure, so you don't need to worry about tracking, but you really don't want to be looking directly into it without a specially designed spectroscope that's beyond the purview of this column. So these spectro-gadgets use cameras — hence they're spectrographs.

A spectrograph consists of three

SLITLESS SPECTROGRAPH AND SPECTRUM: DAVID BRITZ; CD/DVD SPECTROGRAPH AND SPECTRUM: JOSEPH GERENCHER simple parts: something to split the incoming light into a spectrum, something to narrow the light source enough to prevent blurring of that spectrum, and something to record that spectrum with. Let's look at each element in turn.

Splitting light into its component colors was first done with a prism. When light passes through a wedge-shaped piece of glass, the shorter wavelengths (blue) bend more than the longer wavelengths (red), and the light beam disperses. You can still use a prism and get a decent spectrum, but a simpler, lighter, and often better choice is a diffraction grating. Diffraction gratings have thousands of fine lines etched into them, which causes light that passes through or bounces off them to interfere with itself in such a way that it spreads out just as if it had passed through a prism. Diffraction gratings used to be very difficult to make, but nowadays they're everywhere. You know them as CDs and DVDs.

That's right, a simple CD or DVD has enough lines etched into it, at close enough spacing, to act as a diffraction grating. And that's exactly what Joseph Gerencher (Moravian College professor of Earth Science, emeritus) uses in his spectrograph. David Britz (research consultant for AT&T Labs), on the other hand, uses a commercially available diffraction grating. The CD/DVD version is called a *reflection grating*, producing spectra by reflecting light, while the more traditional one is a *transmission grating*, which light passes through. Both do the job admirably.

When you're pointing your spectrograph at an extended object like the Sun, which is ½° across, the spectrum that the diffraction grating produces is smeared out. Each spot on the Sun produces its own spectrum, and those multiple spectra blend together to produce a wide smear. Your spectrograph needs something to narrow down the width of the incoming light beam so the sample size is thin enough to not blur the absorption lines. The usual way to do this is by making the sunlight pass through a slit before reaching the diffraction grating, and that's what Joe has done, using two razor blades to create a sharp-edged, narrow opening.

▶ Joe's CD diffraction grating can be tilted to sweep the full spectrum across the camera's sensor. At right you can see the slit made from two opposing razor blades.

Dave came up with another solution. Recognizing that a shiny ball bearing reflects the Sun as a tiny point, he reasoned that a shiny cylinder would reflect sunlight as a long, slender line. He uses a highly polished metal rod instead of a slit, and its cylindrical shape produces a perfectly straight and narrow reflection line. And there's an advantage to this method: The thin reflection samples the entire face of the Sun, compressing it down into a line, rather than simply selecting a slice of the Sun. That makes for a brighter image. And you can use different diameter rods to get wider or narrower reflections, which in turn affects the resolution of the final image. (Dave says, "I will never look at chrome stripping the same way again.")

The difference between a CD and a DVD is much the same. A DVD has much finer line spacing so produces a much more detailed spectrum . . . at the cost of spreading it out about 3× as far (requiring more overlapping photos to assemble a full spectrum).

▲ The glint of sunlight off a polished rod is squeezed down to a line. Just as with a traditional slit, that line is only as long as the Sun's angular diameter — about half a degree.

So the incoming sunlight passes through the slit or bounces off the rod, hits the diffraction grating/CD/DVD, and scatters into a spectrum. If the light goes through the grating, then you place your sensor (a digital camera) behind that grating; if it bounces forward, then you place your sensor in front of it. Tilting the CD or DVD will sweep different sections of the spectrum across your sensor, but tilting a transmissive diffraction grating doesn't do that. You need to move the camera's aim instead.

Joe took the lens off his camera and uses one part of an inexpensive close-up lens set mounted inside the spectrograph to focus the image directly onto the camera's sensor, but you can still use the camera's normal lens and focusing system if you want. Dave's system does just that.

Both of these spectrographs are set up for solar observing. To photograph stellar spectra, you don't need a slit or a polished rod, since stars are already effectively point sources. You do need tracking, however, and a very sensitive astronomical camera. There's also some question of whether a CD or a DVD would provide enough signal for distant stars. But for solar work, these two designs work beautifully!

For more information on these two spectrographs, and on a star spectrograph that Joe also built, visit Joe's website at **https://is.gd/CDspectro**, and contact Dave at **briswold@gmail.com**.

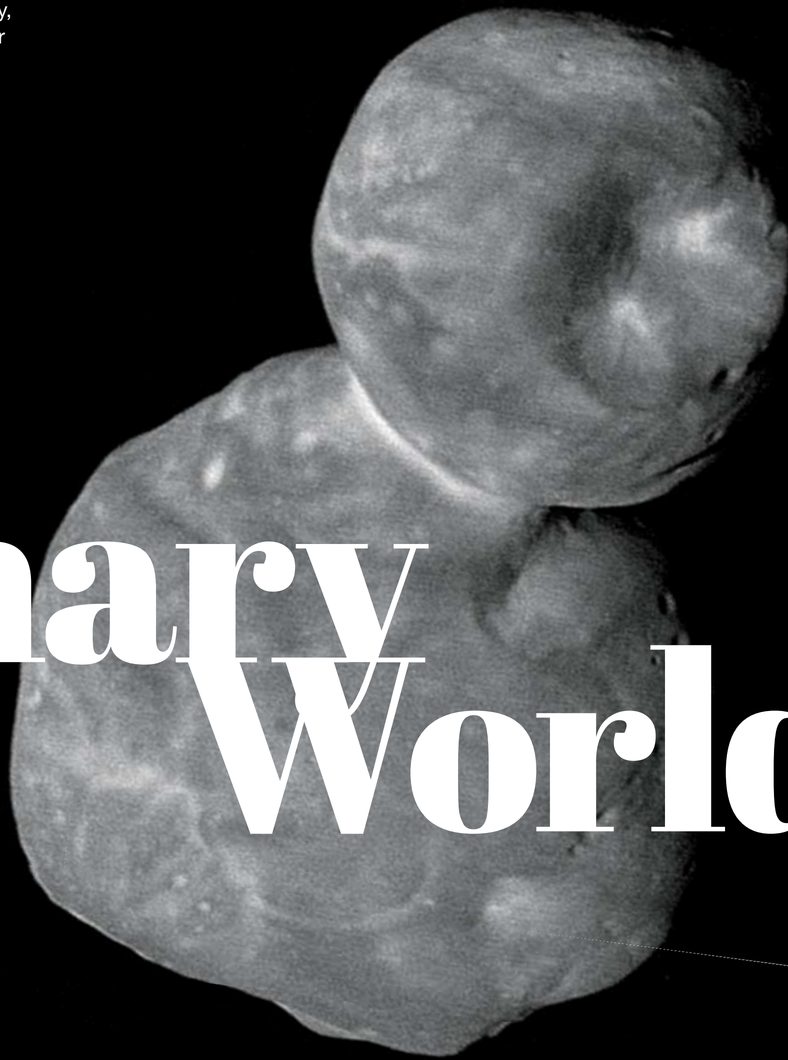
■ Contributing Editor **JERRY OLTION** keeps a diffraction grating in his eyepiece case to examine bright stars with, and another to play soft music with while he observes.

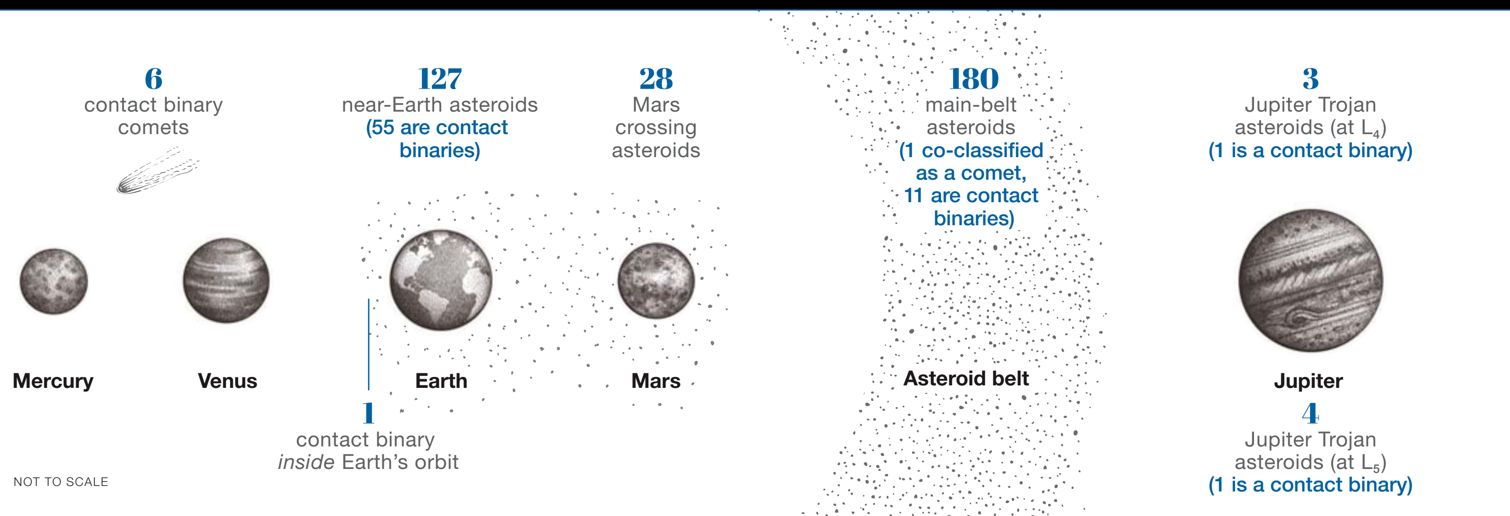
POLISHED ROD: DAVID BRITZ; CD HOLDER: JOSEPH GERENCHER

SEEING DOUBLE by Jeff Hecht

Binary Worlds

PRIMITIVE WORLD The Kuiper Belt object 2014 MU_{69} (now officially named Arrokoth) is a contact binary, each lobe a hodgepodge of smaller regions. Scientists think this is the most unchanged object from the solar system's formation that a spacecraft has so far encountered.





The wide variety of binary objects in the solar system not only surprised astronomers but is now also helping us understand the birth of planetary systems.

Astronomers had hoped to see something interesting when they steered the New Horizons spacecraft on course to visit a Kuiper Belt object soon after it flew past Pluto. They chose the object 2014 MU_{69} because its nearly circular orbit beyond Neptune marked it as among the most primordial objects known in the solar system, and its path put it within reach for New Horizons. They nicknamed it Ultima Thule, "beyond the known world." On November 8, 2019, its official name became Arrokoth, meaning "sky" in the Powhatan Algonquian language.

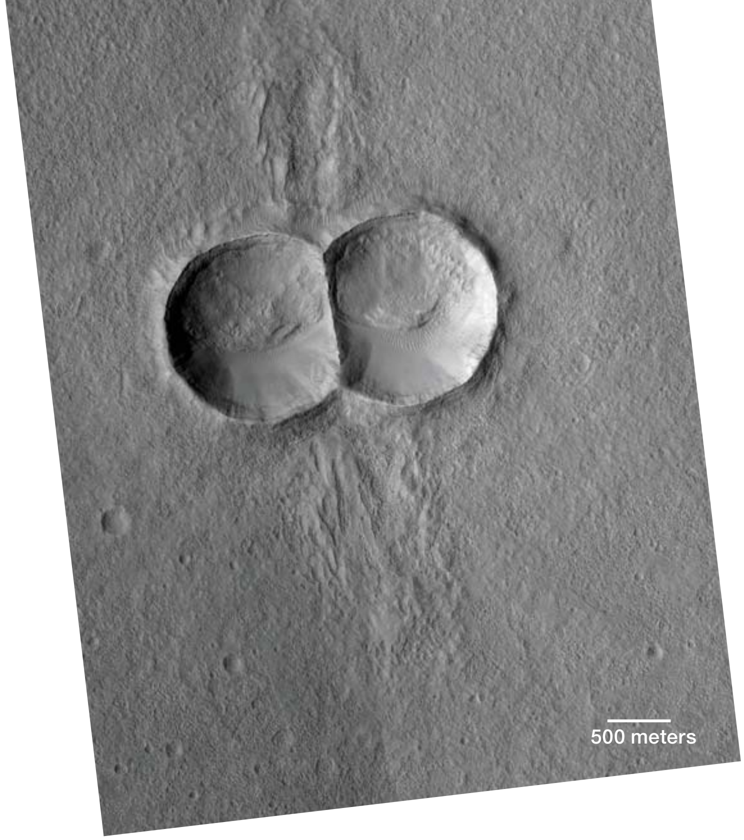
All Hubble recorded was a tiny spot in the sky, but when astronomers watched Arrokoth occult a distant star, the little world's silhouette hinted at a pair of objects orbiting close to, or even touching, each other. So controllers were both hopeful and anxious as the spacecraft bore down on Arrokoth for its close encounter early on New Year's Day 2019.

Our first close-up view of Arrokoth bore out those hints: It showed a contact binary shaped like a giant snowman. The two lobes seem to have bumped very slowly into each other sometime early in their history and stuck together. Subsequent images revealed that the two reddish lobes are fairly oblong, joined on their long ends, with brighter stuff spread around the junction almost like glue.

Arrokoth is not alone in its strange shape. Observers have found many binaries in the solar system, both contact binaries like Arrokoth and ones in which the members don't touch but orbit each other. They appear in the Kuiper Belt, the main asteroid belt, and even among comets and the objects that come near Earth. Some scientists wonder if binaries might have been a standard stage of planet formation.

Yet just 30 years ago, most astronomers doubted these binary worlds existed.

ARROKOTH: NASA / JHU APL / SWRI / NOAO; INFOGRAPHIC: TERRI DUBÉ / *S&T*; SOURCE: JOHNSTONSARCHIVE.NET; PLANETS: MARINAT197 / SHUTTERSTOCK.COM; DOUBLET CRATER: NASA / JPL / UNIVERSITY OF ARIZONA

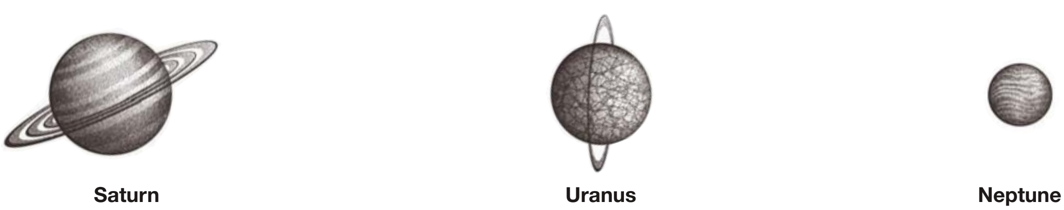


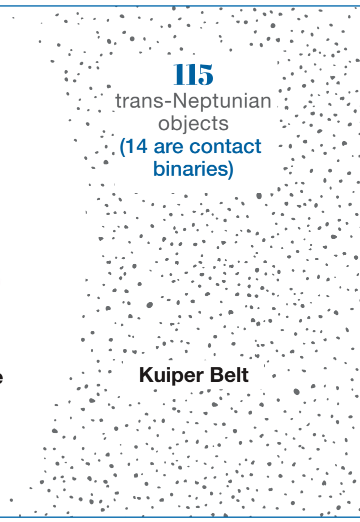
▲ **DOUBLE CRATER** The shared rim and plume-like ejecta of this Martian double crater formed when two objects hit simultaneously. The impactor may have consisted of two loosely connected objects of the same mass.

Discovering Binaries

The first hints came in the 1970s, when observers recording the light curves of stars occulted by asteroids saw unexpected variations before or after the asteroid passed in front of the star. Geologists found a few terrestrial craters that appeared to have formed in pairs. And in August 1989, Steven Ostro (Jet Propulsion Laboratory) and colleagues used the 305-meter (1,000-foot) Arecibo radio telescope to reveal the peanut shape of the potentially hazardous near-Earth asteroid 4769 Castalia (1989 PB). His team suspected the 1.4-kilometer asteroid might be a contact binary rotating every four hours.

Binaries are everywhere and come in varied forms. Some pairs are touching; others have widely separated orbits. Some pairs are equal size; others differ widely in size.



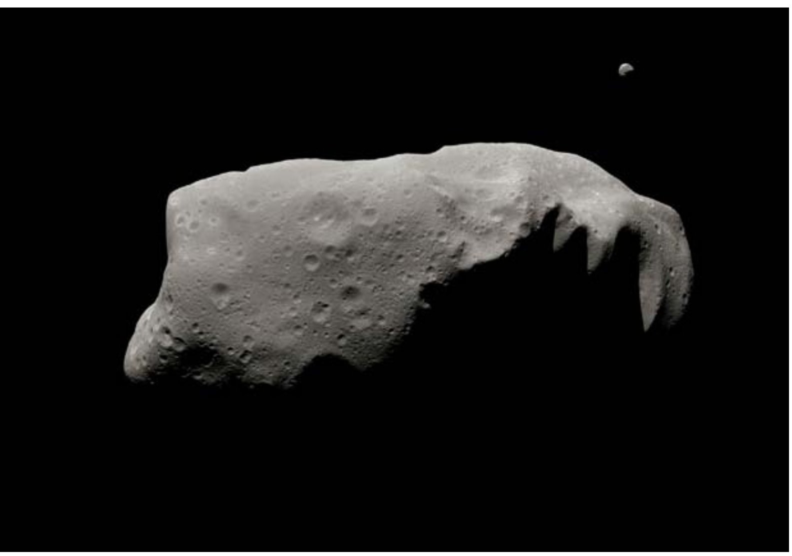


The first convincing evidence of a pair of asteroids orbiting each other, however, was a byproduct of NASA's Galileo mission to Jupiter. The spacecraft had to pass through the main asteroid belt, so planners arranged flybys of two asteroids. The second, on August 28, 1993, revealed that the 60-km oblong asteroid 243 Ida was orbited by a 1.5-km moon, later dubbed Dactyl. The images of little Dactyl moving along with the much larger Ida were finally enough to convince Brian Marsden, the long-time director of the Minor Planet Center at the Harvard-Smithsonian Center for Astrophysics, that binary asteroids existed.

More discoveries followed. Some have involved radar, others were made using ground-based telescopes with adaptive optics or the Hubble Space Telescope, which can resolve separate bodies if their orbits take them far enough from each other. Often the best data come from spacecraft exploring objects up close, like Galileo's visit to Ida and New Horizons' flybys of Pluto and Arrokoth. The Rosetta mission to famous "rubber duck" Comet 67P/Churyumov-Gerasimenko, for example, showed us spectacular close-ups of a contact binary nucleus (*S&T:* May 2017, p. 14). But extremely precise measurements from far away of how an object's brightness changes over time have identified more than half of known binaries.

As of November 2019, astronomers had identified 375 asteroids and trans-Neptunian objects with at least one companion: 359 have one, 15 have two, and the record holder, Pluto, has five. These objects are spread throughout the solar system: 72 near-Earth asteroids, 28 Mars crossers, 169 objects in the main asteroid belt (one of them a comet), five Jupiter Trojans, and 101 beyond Neptune. An additional 67 inner solar system and main-belt asteroids, two Jupiter Trojans, 14 trans-Neptunian objects, and six comets are contact binaries, including Arrokoth.

▼ **IDA AND DACTYL** This mosaic shows asteroid 243 Ida and its moon, Dactyl, as seen by the Galileo spacecraft en route to Jupiter. The moon's discovery shocked much of the planetary science community when announced in 1994.



NASA / JPL / DANIEL MACHÁČEK / CC BY-SA 3.0

The YORP effect can spin up a rubble-pile asteroid enough for the centrifugal force at its equator to exceed the body's gravitational attraction, and pieces can drift away.

That adds up to quite a diverse bestiary. Binaries are everywhere and come in varied forms. Some pairs are touching; others have widely separated orbits. Some pairs are equal size; others differ widely in size. Some rubble piles spin off chunks that orbit the main body for a while, then slowly return to merge with it. Astronomers think their differences reflect where they formed and where they have wandered since.

To sort through the bestiary, we will start with near-Earth binaries and move outward through the solar system to Arrokoth and other objects in icy orbits beyond Neptune.

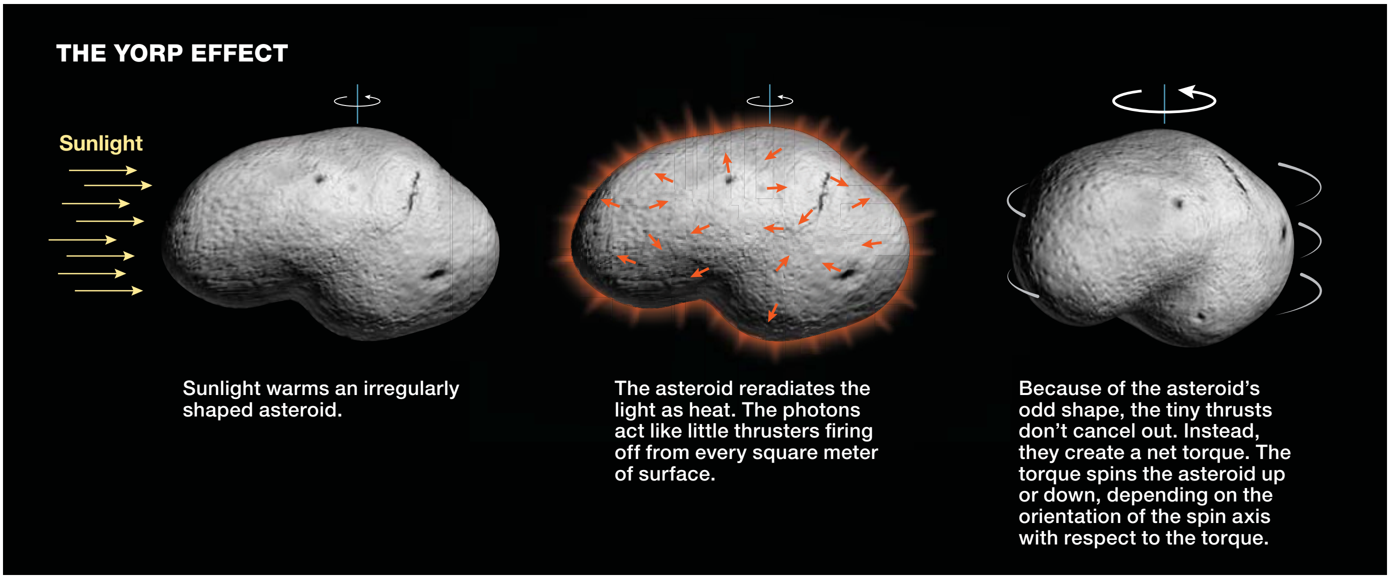
Near-Earth Binaries and the YORP Effect

Radar has discovered about three-quarters of the multi-member near-Earth asteroids, says Patrick Taylor (Lunar and Planetary Institute). Maximum size is a few kilometers. He says that one-sixth of near-Earth asteroids wider than 200 meters are binaries; another one-sixth are contact binaries like Castalia and Arrokoth, with two similar-size lobes touching each other and rotating jointly.

The separate members of near-Earth binaries generally orbit only a few kilometers from each other, or a few times the size of the primary. The bigger objects tend to spin fast, with "days" lasting only 2.2 to 4.5 hours. The smaller components typically are 4% to 58% the sizes of the primaries.

Near-Earth orbits are chaotic, and objects normally stay in them for only around 10 million years before colliding with a planet or the Sun or being ejected out of the region. Most near-Earth objects are "rubble piles," accumulations of material held together loosely by gravity, which makes them vulnerable to three processes that can break them apart before they are lost. Collisions can knock pieces out of the rubble pile, which then drift back to form binaries with their parent bodies. Close gravitational encounters with planets can tear apart both asteroids and comets, as happened when Comet D/Shoemaker-Levy 9 passed near Jupiter on July 7, 1992.

The third process relies on far weaker forces, but over time it is far more effective because it is powered by sunlight. Light carries momentum that it can transfer to objects when reflected or absorbed and reradiated, and the induced torque can change the spin of an irregularly shaped object. The process is called the *YORP effect*, and depending on the object's rotational orientation it can either speed up or slow down its rotation. "It's very weak, a measurable force but not a huge force," says Daniel Scheeres (University of Colorado,



Boulder). Over long periods, the YORP effect can spin up a rubble-pile asteroid enough for the centrifugal force at its equator to exceed the body's gravitational attraction, and pieces can drift away.

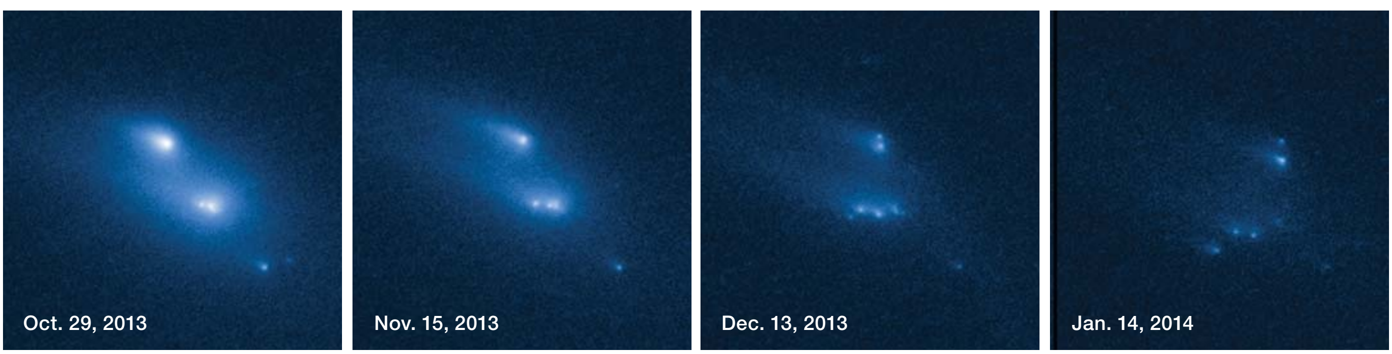
The strength of the effect depends on the intensity of the incident light. It's stronger for near-Earth objects and much weaker in the main belt, which lies farther from the Sun. Also, the smaller the object, the more a given amount of sunlight can increase its spin. "This means that these effects are only active on small bodies," Scheeres says. His students have measured the YORP effect as it spun up small defunct artificial satellites in geostationary orbit within months to years. Asteroids are more massive, so it takes hundreds of thousands to hundreds of millions of years to spin them up. But the Sun shines relentlessly. Many single near-Earth asteroids are spinning nearly fast enough to start shedding material, and all the near-Earth binaries have close orbits, both outcomes expected from the YORP effect.

Asteroid rubble that has spun off may drift away, but it generally does not escape permanently. Instead, it goes into orbit around the asteroid, where in theory escaped pieces might accrete to form a smaller, stable companion for the original asteroid. Details are unclear, including how much material would escape, how much would stay to form the resulting binary companion, and how large it would be. However, Scheeres says, formation of a new object in orbit could in theory trigger the related "binary YORP effect," which can cause the pair to either spiral in or out depending on details. If the two spiraled out, they could become separate objects. But if they spiraled in, they could merge with each other to re-form a single object, even though some mass would be lost.

Main Belt and Comets

The YORP effect is much weaker farther out in the main asteroid belt, so other effects are likely responsible for most of its 169 orbital binary asteroids. Estimates of the fraction of binaries in the main belt vary widely because few have been observed closely enough to detect whether these are multiple objects. Main-belt binaries include a wide variety of relative sizes and orbital spacings, and many are much larger and more widely spaced than objects with orbits near Earth's.

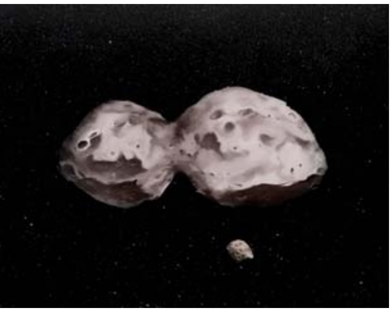
▼ **ASTEROID BREAKUP** Main belt object P/2013 R3 disintegrated unexpectedly in 2013. Each piece has its own comet-like dust tail. Researchers suspect the YORP effect might have spun the asteroid up until it flew apart.



YORP EFFECT: GREGG DINDERMAN / S&T; ASTEROID BREAKUP: NASA / ESA / D. JEWITT (UCLA)

Collisions are known to happen in the main belt, a region of space that is much more stable and densely populated than the region of near-Earth orbits. Collisions could form widely separated pairs with a large primary and a very small secondary, like Ida and Dactyl.

Only about 10 contact binaries have been spotted in the main belt, most detected by radar. That number includes a peculiar object among the Trojan asteroids that share Jupiter's orbit, 624 Hektor. It's a large contact binary orbited by a smaller moon. Ground-based adaptive optics show the larger body is a peanut-like contact binary measuring about 400 by 200 km, orbited by a 12-km moon. That makes Hektor both a contact binary and an orbital binary. In 2014 Franck Marchis (SETI Institute) and colleagues calculated that the moon's orbit is stable. They proposed that two 200-km components had collided, forming a contact binary and ejecting a fragment that became the moon.



▲ **624 HEKTOR** Artist's concept of the Trojan contact binary Hektor and its 12-km moon. The primary body is about 400 km long and may be a porous mixture of rock and ices.

Although we think of asteroids as rocky objects, some two dozen objects originally designated main-belt asteroids have been reclassified as comets after they began spouting comas or tails. One, P/2013 R3, broke up into several pieces that went their separate ways in 2013. Another, initially designated asteroid 2006 VW_{139} and later numbered 300163, has now been recognized as the first orbital binary comet. In 2017, a team led by Jessica Agarwal (Max Planck Institute for Solar System Research, Germany) published Hubble images showing two roughly kilometer-size objects in an elongated orbit around each other that spanned 100 kilometers. No binary asteroid has the same combination of wide separation, similar-size members, high orbital eccentricity, and cometary emissions. Agarwal says the binary may have formed either when the two pieces split from a single collision fragment, or when two fragments from a collision hooked up gravitationally in the aftermath. Intriguingly, it is one of 11 objects in main-belt orbits traced to the breakup of a 10-km object 7.5 million years ago. Yet none of the others has shown similar cometary emissions.

▶ **BINARY COMET** This series of Hubble images reveals that the nucleus of 2006 VW_{139} is made of two objects revolving around each other. Astronomers think that the main-belt object has only been a binary for about 5,000 years. (The tail's changing orientation is due to the change in the Sun-Earth-object alignment between observations.)

Contact binaries are common in comets. Four of the six comets imaged by spacecraft have two distinct lobes. The most impressive images are from Comet Churyumov-Gerasimenko, which show that ices began eroding from both lobes of the rubber duck after the incoming comet passed Jupiter's orbit. Close-ups near the "neck" show networks of cracks where the two lobes meet, a sign of weakening that might be linked to stress or ice sublimation.

How such an object forms remains a big question. Comets are thought to have formed 20 to 30 astronomical units from the Sun, then to have been pushed far beyond Neptune's orbit dur-

Contact binaries are common in comets. Four of the six comets imaged by spacecraft have two distinct lobes.

UP CLOSE Spacecraft have imaged six comet nuclei up close. Four of these have a bilobe shape, including Comet Churyumov-Gerasimenko *(above right)*.

ing the time of planetary migration. They stay there until perturbations send them inward to the planetary region, where encounters with the giant planets make them the periodic comets we see in the inner solar system. Comet Churyumov-Gerasimenko, for example, now has a 6.44-year orbit that takes it just beyond Jupiter.

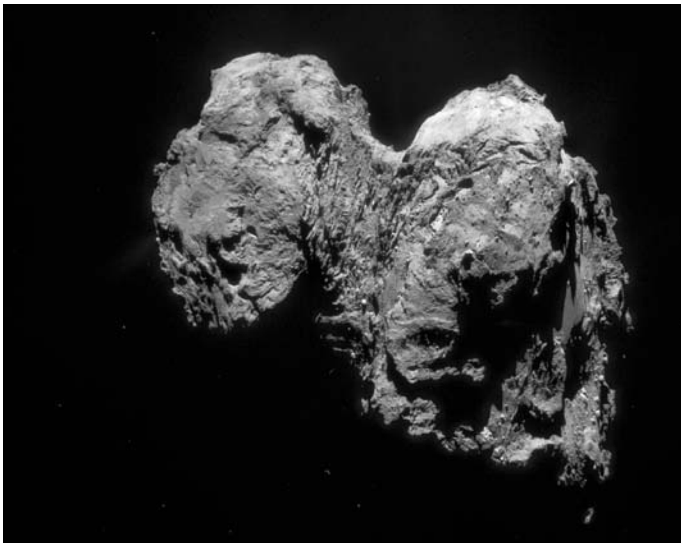
David Nesvorný (Southwest Research Institute) says mergers like those that produced Arrokoth in the Kuiper Belt might produce an object shaped like Comet Churyumov-Gerasimenko. But he doubts that the process could occur often enough to explain why two-thirds of the nuclei imaged so far are contact binaries.

Primordial Planetesimals on Ice

The New Horizons spacecraft launched in January 2006 to explore Pluto and the other objects in the Kuiper Belt that stretches beyond the orbit of Neptune. So far it has delivered spectacular close-up images of two Kuiper Belt binaries: Pluto with its five moons and the contact binary Arrokoth. The two share many features that come from having spent billions of years in the icy fringes of the solar system. However, even before New Horizons reached Arrokoth, we had learned that the Kuiper Belt is a refuge for a diverse range of objects that differ in their orbits, origins, and early histories.

Discovered 90 years ago this month, Pluto is the exemplar of a class of objects called *plutinos* that formed closer to the Sun, were scattered when Neptune migrated outward, and became locked into an orbital resonance with Neptune. Pluto's largest moon, Charon, was discovered in 1978 and is so large that the duo's center of mass lies outside Pluto entirely — the two bodies orbit a common center. The system likely formed when a giant impact on proto-Pluto blasted debris into orbit that accreted to form Charon.

Hubble spotted two small new moons in the spring of 2005, soon before the New Horizons launch. The discovery of two more followed in 2011 and 2012. The four small moons are neatly spaced with orbital periods about three, four, five,

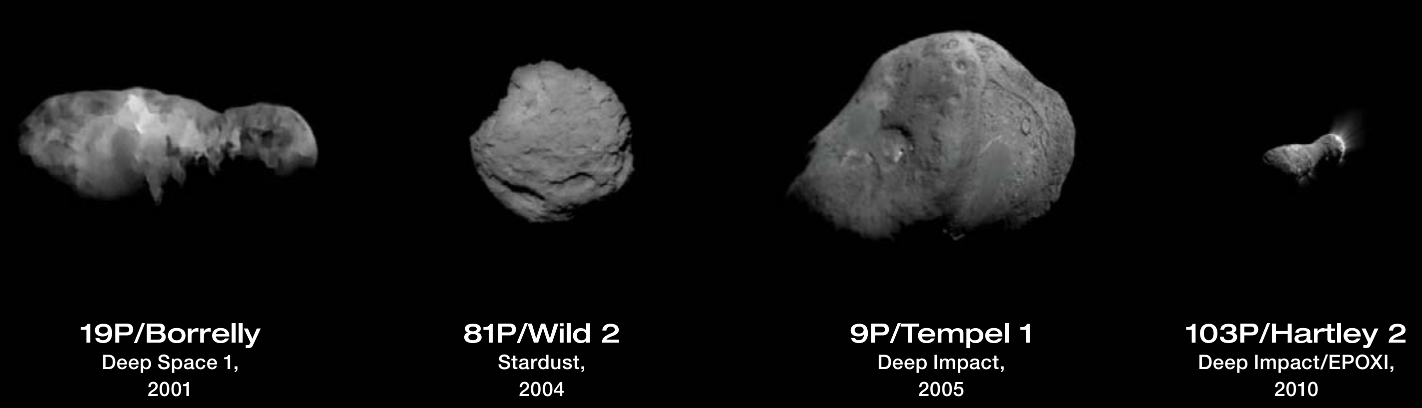


▲ **COMET CHURYUMOV-GERASIMENKO** This post-perihelion Rosetta image reveals the linear, rugged terrain of the southern neck region, called Sobek. Cracks in this region might be due to the two lobes straining against each other. The nucleus is a couple of kilometers wide.

and six times Charon's. Nesvorný says how they formed remains "a big puzzle."

David Jewitt (then University of Hawai'i) and Jane Luu (then University of California, Berkeley) discovered the second of more than 2,000 known Kuiper Belt objects in 1992. Initially called 1992 QB_1 — and recently renamed 15760 Albion — it is smaller and fainter than Pluto. Albion's orbit is also more circular and lies almost flat in the plane of the solar system. Many more such bodies have been found in similar orbits and are called *cold classical objects* because their orbits are more planet-like than Pluto's.

Cold classical objects are thought to have formed directly from the outer part of the protoplanetary disk and remained unaltered for the past 4.6 billion years. That makes them the most pristine planetesimals we've found. Astronomers wanted



New Horizons to visit one, but Albion was out of its path so they searched for another and found Arrokoth in 2014. The images showed their choice was right. Arrokoth "is as primordial as it gets," says William McKinnon (Washington University in St. Louis). "It has not been disturbed and was not part of any large-scale rearrangement or orbital scattering."

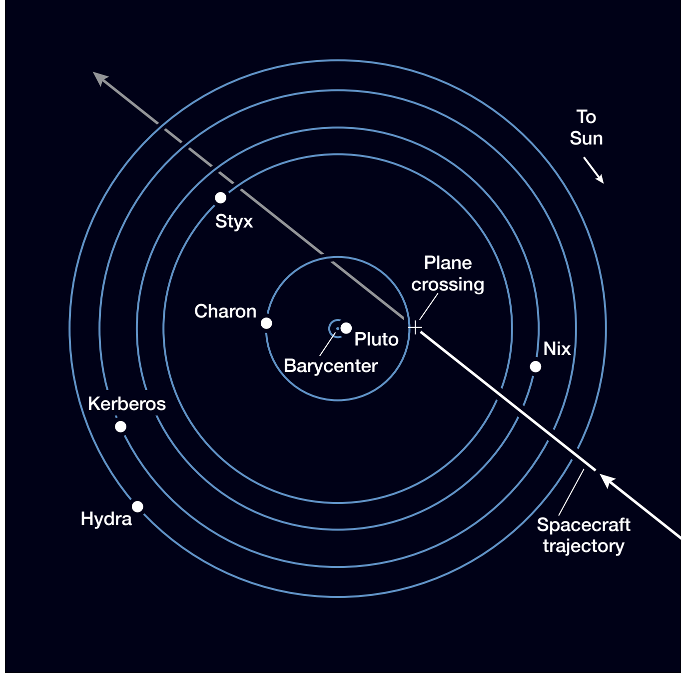
When initial images revealed Arrokoth was a contact binary, observers first assumed the two lobes were round. As more photos gave better perspective, Audrey Thirouin (Lowell Observatory) recalls, the squashed shapes "kind of surprised all of us." Two flattened oblong disks, 22 kilometers and 14 kilometers long, respectively, had collided end to end with no obvious deformation. They're spinning around an axis that passes through the larger one, close to the contact point. They also show several distinct topographic regions, which may be remnants of smaller pieces that accreted to form each lobe. Astronomers saw similar units on comets Churyumov-Gerasimenko and 9P/Tempel 1.

Scientists had predicted that about a third of all trans-Neptunian objects should be contact binaries. By studying light curves, Thirouin and Scott Sheppard (Carnegie Institution for Science) found that 10% to 25% of cold classical objects may be contact binaries made of equal-size members, lower than the 40% to 50% they found for *plutinos*. But we are still in the early days; observations are difficult and uncertainties are large.

The fraction of objects with companions in this region is high. Most of the largest objects found have at least one moon. "Binaries are much more common in the Kuiper Belt than anyone had appreciated," says McKinnon.

Curiously, more binaries have been found among 100-kilometer cold classical objects than had been expected. "We are talking about the majority of 100-kilometer objects being binaries," says Nesvorný. "That's really interesting."

The result shows intriguing similarities to computer models of the solar system's formation, which predict building blocks of the same size range. The models show that, as gas and dust collapse under their own gravitation into 100-kilometer-class bodies, an effect called the *streaming instability* mixes the stuff in a way that helps it stick together. Conditions in the collapsing cloud cause the clumps to form binaries with similar-size components.



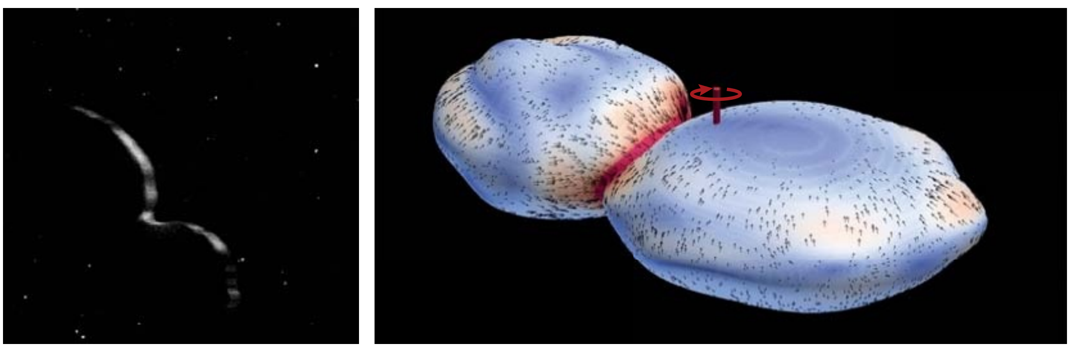
▲ **SEXTUPLE SYSTEM** Pluto and its five moons orbit the *barycenter* (center of gravity) of the Pluto-Charon binary. The outer four moons' shapes suggest they assembled from smaller fragments.

In both the model and for real trans-Neptunian binaries, 80% of the time the two bodies circle each other in the same direction as the pair revolves around the Sun. Nesvorný says the theory applies over a wide range of conditions, so the streaming instability could seed planetesimal formation around other stars, too.

More painstaking measurements and analysis are needed to identify binaries and to extract information on their orbits. Theoretical models need further analysis and more computer power. And more is on the way from New Horizons, which will not finish sending its Arrokoth data until September 2020 and may yet fly by a third Kuiper Belt object. Yet the dramatic close-ups of Arrokoth in the Kuiper Belt and Comet Churyumov-Gerasimenko closer to us have already shown us the richness of the minor planets that not too long ago were just faint dots in even our best telescopes.

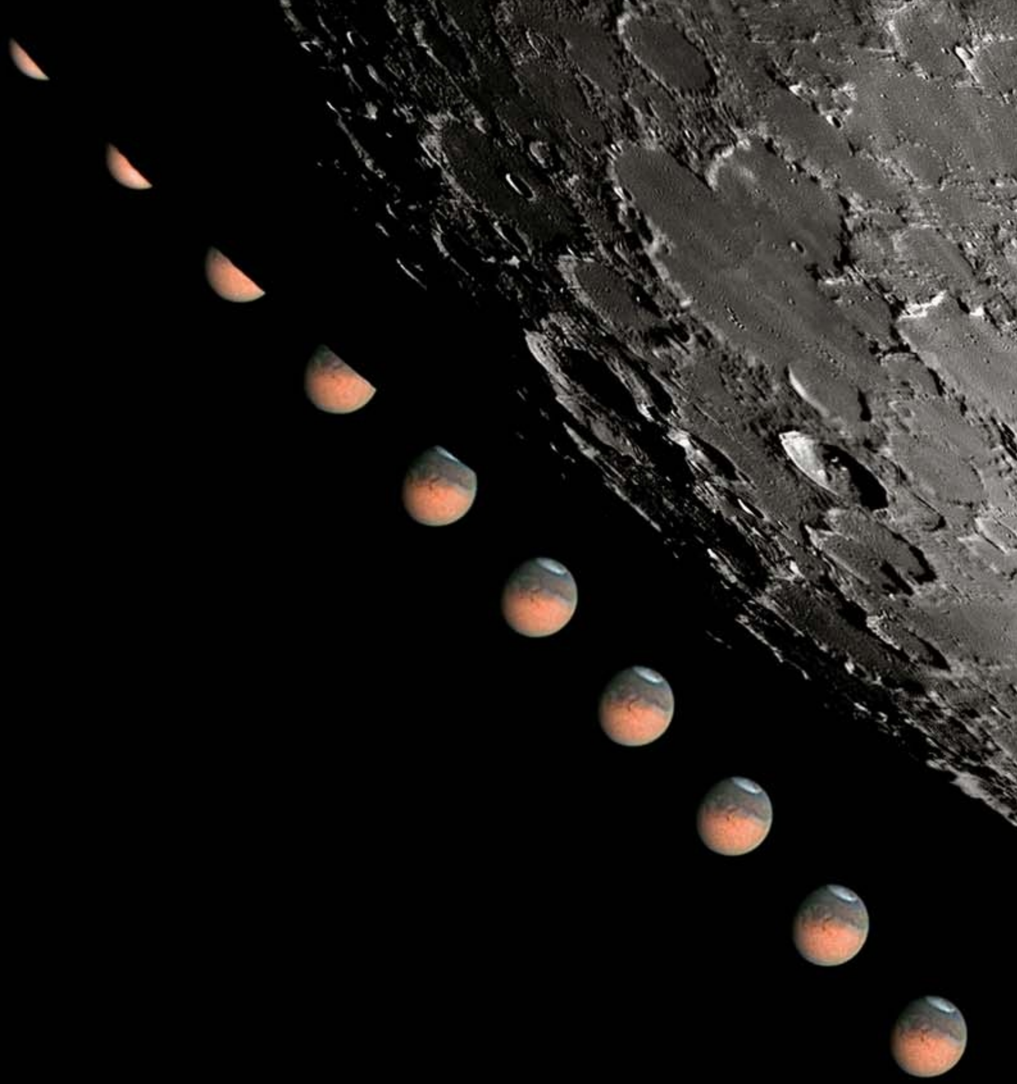
■ **JEFF HECHT** writes about science and technology and is a fellow of the Optical Society. His most recent books are *Understanding Lasers* and *Lasers, Death Rays, and the Long, Strange Quest for the Ultimate Weapon*.

▶ **STRANGELY FLAT** Backlit views of Arrokoth *(left)* provided an outline of the part hidden in shadow during New Horizons' flyby. The profile helped scientists estimate the contact binary's shape *(right)*. Redder colors indicate steeper slopes, with the steepest at the neck. Black arrows show which direction is downslope — basically, which way a ball set on the surface would roll.



PLUTO SYSTEM: LEAH TISCIONE / *S&T*, SOURCE: SIMON PORTER ET AL.; BACKLIT VIEW OF ARROKOTH: NASA / JHU APL / SWRI / NOAO; SHAPE: NASA / JHU APL / SWRI

OBSERVING
February 2020



1 DUSK: The month opens with Venus blazing above the southwestern horizon. Watch throughout the month as the Evening Star climbs higher along the ecliptic. Can you spot Mercury far lower right of Venus? It's best visible between the 6th and the 14th.

5 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:21 p.m. PST (see page 50).

8 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:10 p.m. EST.

10 DUSK: Mercury reaches greatest eastern elongation from the Sun, and half an hour after sunset it's still more than 10° above the west-southwestern horizon. Catch the tiny world before it sets.

16 DAWN: The Moon is in Scorpius, a mere degree or so from Beta (β) Sco, also known as Graffias.

18 DAWN: The waning crescent Moon occults Mars for most viewers in North and Central America (see pages 47 and 50).

19 DAWN: The thinning Moon and Jupiter sit some 3° to 4° apart left of the Teapot in Sagittarius.

20 DAWN: An even more slender lunar crescent lies some 2° lower right of Saturn. Catch the pair in the southeast before the Sun rises.

27 DUSK: Watch as the waxing lunar crescent and Venus, 5° or more apart, sink toward the western horizon.

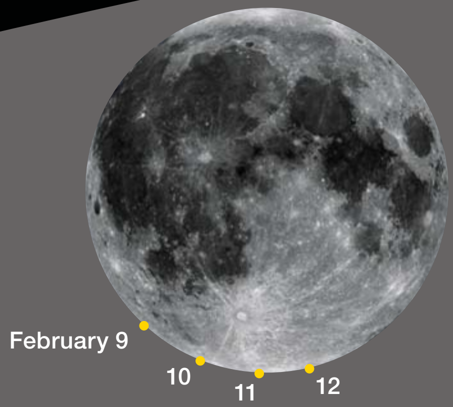
28 EVENING: Algol shines at minimum brightness for roughly two hours centered at 7:55 p.m. PST (10:55 p.m. EST).
— DIANA HANNIKAINEN

▲ Provided skies are clear this month, most of North America will see Mars gradually disappear behind the Moon's limb, then reappear. This time-lapse image is from the 2003 Mars occultation (south is down).
RON DANTOWITZ

FEBRUARY 2020 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart



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

NASA / LRO

MOON PHASES

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

FIRST QUARTER
February 2
01:42 UT

FULL MOON
February 9
07:33 UT

LAST QUARTER
February 15
22:17 UT

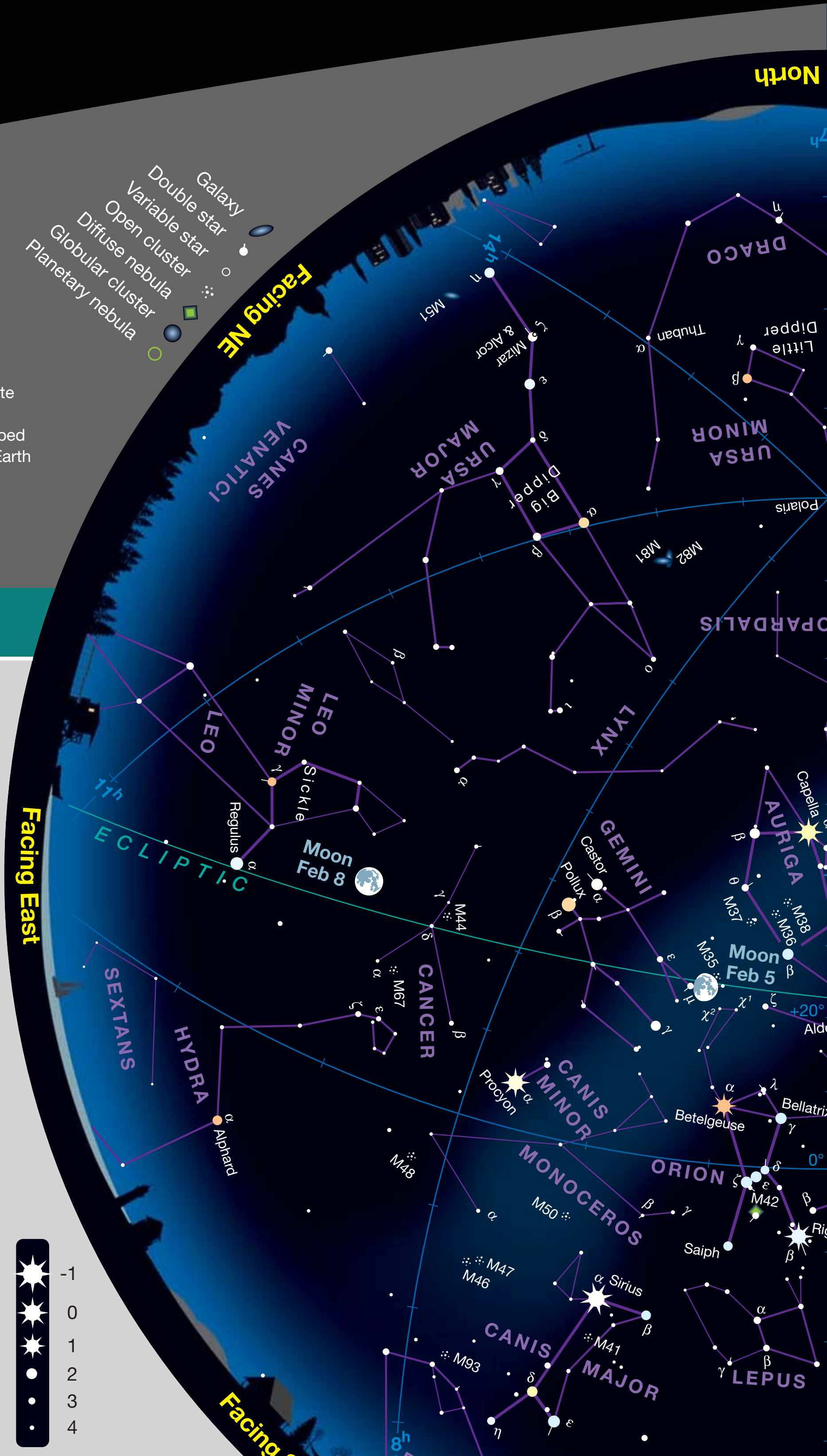
NEW MOON
February 23
15:32 UT

DISTANCES

Perigee	February 10, 20^h UT
360,461 km	Diameter 33′ 09″
Apogee	February 26, 12^h UT
406,278 km	Diameter 29′ 25″

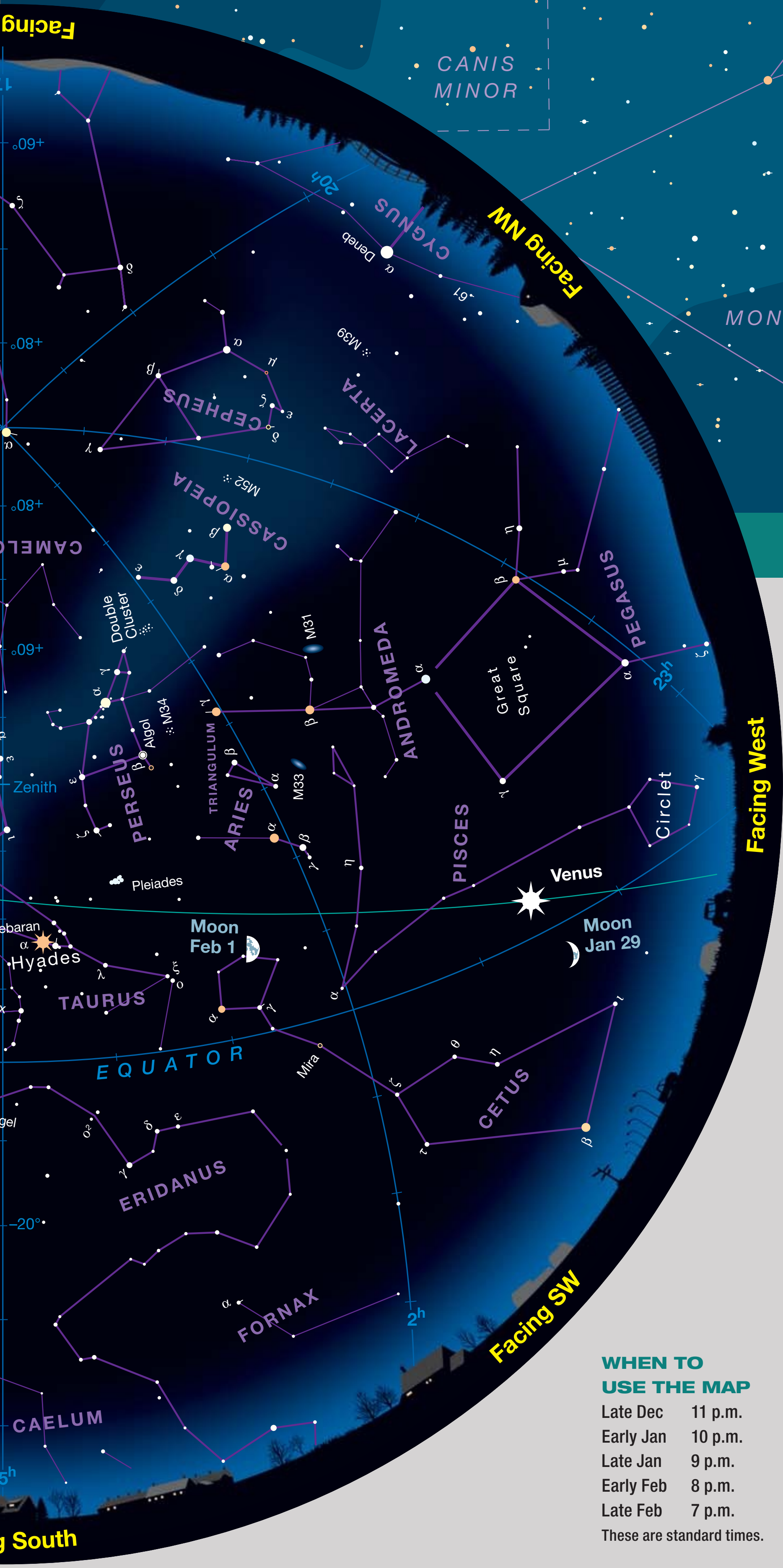
FAVORABLE LIBRATIONS

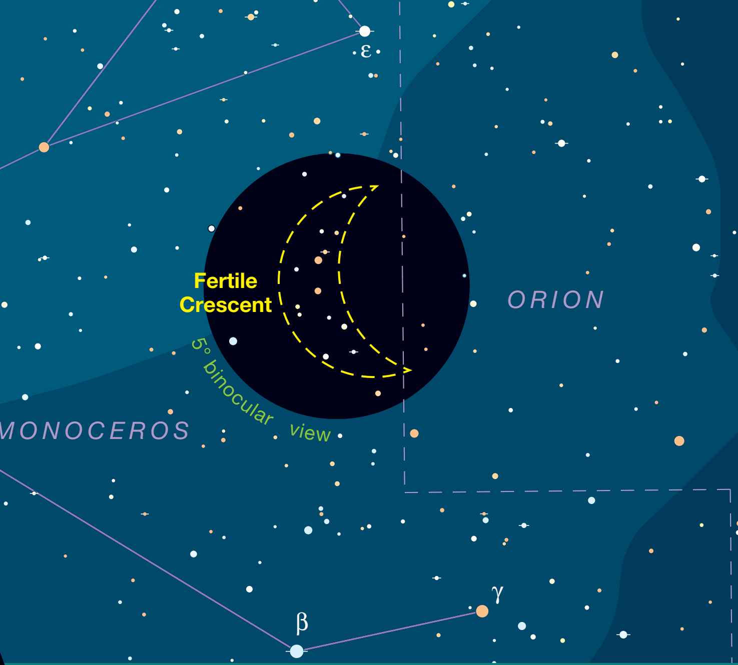
- Baade Crater — February 9
- Hausen Crater — February 10
- Drygalski Crater — February 11
- Schomberger Crater — February 12



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

Cornucopia in Monoceros

I'm sure I'm not the only stargazer who is frequently arrested by the sight of the constellation Orion striding across the night sky. In fact, the celestial Hunter ensnared my attention so successfully that it took me years to discover the riches of the nearby constellation Monoceros, the Unicorn. Monoceros has few bright stars, but since it lies squarely in the winter Milky Way it contains an almost unbelievable density of star clusters and nebulae.

On one of my first "unicorn hunts," I stumbled across something remarkable. Right on the celestial equator and about halfway between Beta (β) and Epsilon (ε) Monocerotis (the latter is also known as 8 Mon), I found a field so rich that I assumed it must have a name. The group is anchored by a double arc of bright stars that curves to the west like a pair of open parentheses. Many dimmer lights pad out the field, filling almost 4° of sky with more stars than you can shake a stick at.

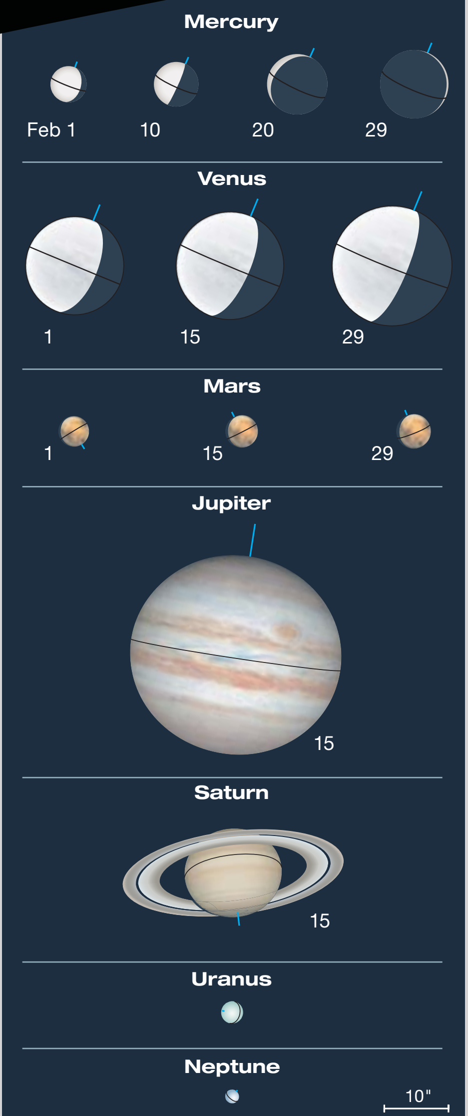
I didn't find a name for this wonderfully rich field in any of the atlases I had at the time, so I called it the **Fertile Crescent**. Years later, I learned that I hadn't been the first to catch this particular unicorn. Brazilian astronomer Bruno Alessi got there first, and at least the central portion of my Fertile Crescent is Alessi 48 in his catalogue of asterisms and possible star clusters. I strongly suspect that Al-48 will turn out to be an asterism rather than a cluster, since the bright stars seem to be scattered at many different distances. Whatever it turns out to be and whatever we call it, it's worth tracking down. And if you end up off the beaten path in the hinterlands of Monoceros, I recommend that you stop and have a look around.

■ **MATT WEDEL** likes bright, easy targets on cold winter evenings, so that's what he's serving.

WHEN TO USE THE MAP

Late Dec	11 p.m.
Early Jan	10 p.m.
Late Jan	9 p.m.
Early Feb	8 p.m.
Late Feb	7 p.m.

These are standard times.



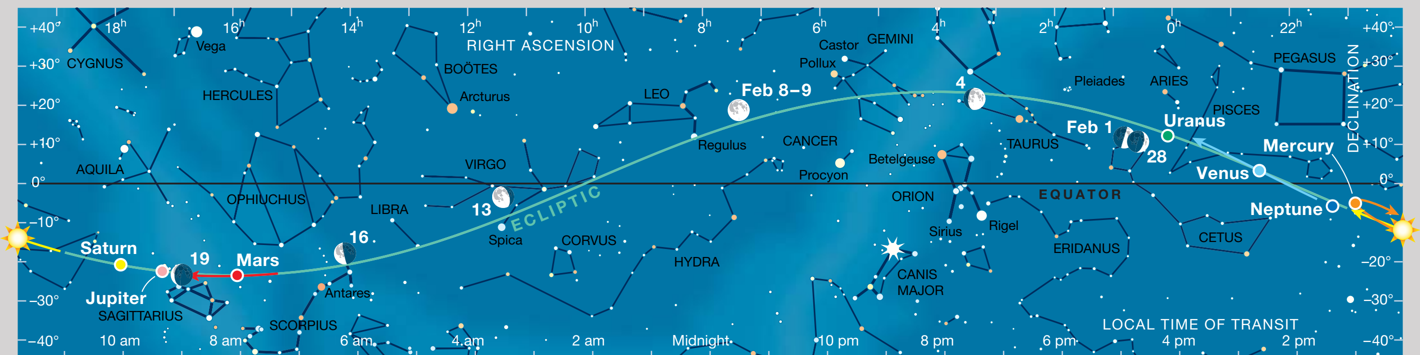
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY **Mercury:** low in the west-southwest at dusk through the 17th • **Venus:** high at dusk, sets mid-evening • **Mars:** rises around 4 a.m., reasonably high in the south-southeast by dawn • **Jupiter:** low at dawn • **Saturn:** very low at dawn starting on the 7th

February Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	20^h 55.0^m	–17° 23′	—	–26.8	32′ 28″	—	0.985
	29	22^h 44.6^m	–7° 58′	—	–26.8	32′ 18″	—	0.991
Mercury	1	21^h 53.6^m	–14° 05′	14° Ev	–1.0	5.6″	85%	1.192
	10	22^h 40.0^m	–7° 48′	18° Ev	–0.7	7.0″	55%	0.965
	20	22^h 48.4^m	–4° 14′	12° Ev	+2.1	9.4″	11%	0.712
	29	22^h 16.6^m	–6° 55′	7° Mo	+4.2	10.7″	3%	0.630
Venus	1	23^h 30.7^m	–4° 07′	40° Ev	–4.1	15.3″	73%	1.090
	10	0^h 08.9^m	+0° 35′	42° Ev	–4.2	16.2″	70%	1.030
	20	0^h 50.5^m	+5° 47′	43° Ev	–4.2	17.4″	67%	0.960
	29	1^h 27.5^m	+10° 17′	44° Ev	–4.3	18.6″	63%	0.896
Mars	1	17^h 12.7^m	–22° 59′	52° Mo	+1.4	4.8″	93%	1.948
	15	17^h 54.4^m	–23° 37′	57° Mo	+1.3	5.1″	92%	1.835
	29	18^h 36.5^m	–23° 34′	61° Mo	+1.1	5.4″	91%	1.721
Jupiter	1	18^h 58.2^m	–22° 43′	28° Mo	–1.9	32.5″	100%	6.067
	29	19^h 22.7^m	–22° 05′	51° Mo	–2.0	34.1″	99%	5.780
Saturn	1	19^h 46.8^m	–21° 09′	17° Mo	+0.6	15.1″	100%	10.972
	29	19^h 59.5^m	–20° 37′	42° Mo	+0.7	15.5″	100%	10.745
Uranus	15	2^h 03.4^m	+12° 02′	67° Ev	+5.8	3.5″	100%	20.171
Neptune	15	23^h 14.8^m	–5° 57′	22° Ev	+8.0	2.2″	100%	30.847

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-February; 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.

A Month for Open Clusters

February's night sky is awash with sparkling targets.

There are tens of thousands of them in the Milky Way Galaxy. Given a good, dark night sky you can see some of them — with your telescope, your binoculars, even your unaided eyes — in any season. Yet we shouldn't take these objects for granted. And there's a season, even a particular month, that's arguably the best for viewing them.

The month I'm talking about is February. The objects I'm talking about are open star clusters.

Open season on open clusters. The entire February evening Milky Way — from the last peek of Cygnus in the northwest to Puppis low in the southeast — is splashed with open star clusters.

If we count the Double Cluster of Perseus as a single attraction, the number of open clusters marked on our all-sky map for February is 18. This includes two pairs of clusters that are a little bit outside the gently luminous band of the Winter Milky Way: the Pleiades (M45) and the Hyades in Taurus, and M44 and M67 in Cancer. The other 14 clusters are closer to the *galactic equator*, the central line in the equatorial plane of the Milky Way. In order, from low in the northwest across the celestial vault to low in the southeast at the hour indicated on the chart, they are: M39 in Cygnus; M52 in Cassiopeia; the Double Cluster and M34 in Perseus; M38, M36, and M37 in Auriga; M35 in Gemini; M50 in Monoceros; M48 in Hydra; M41 in Canis Major; and M47, M46, and M93 in Puppis.

February's Messier open clusters by number. Let's now say a thing or two about each of the abovementioned Messier open clusters in order of increasing Messier number.

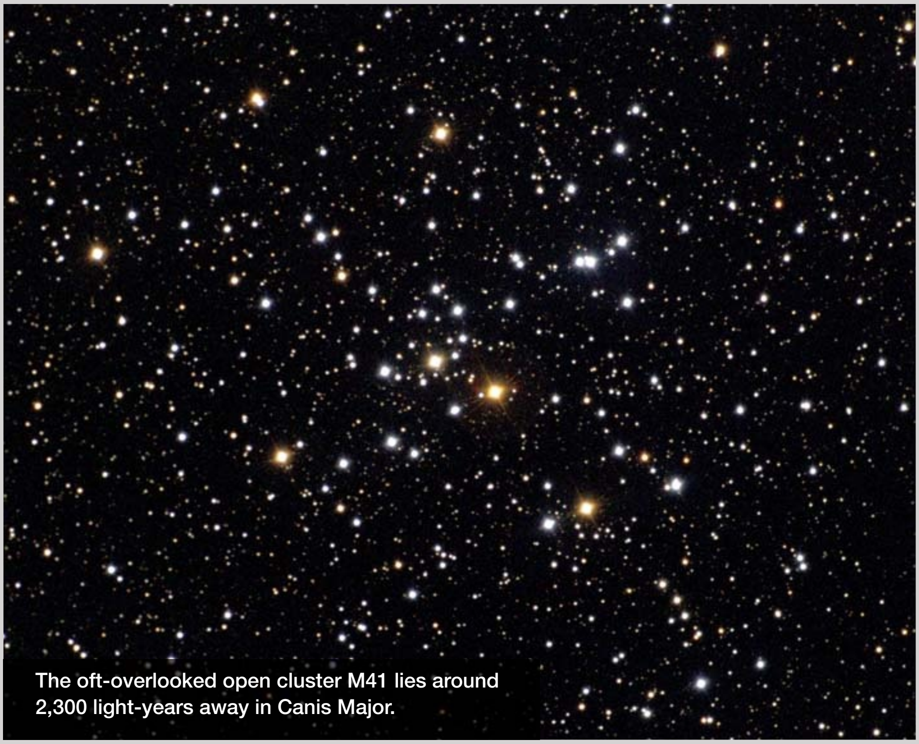
We begin our numbered tour with M34, a good low-magnitude telescopic sight and intriguing naked-eye fuzzy spot of light near Algol, or Beta (β) Persei. M35 in the feet of Gemini is huge, easy for the unaided eye in a dark sky, and also so near the ecliptic that it's a prime target for the Moon and planets. M36, M37, and M38 in Auriga are all wonderful yet all different. While M36 and M38 are within Auriga's pentagon, the brightest of the three, M37, is just outside the lines of that pattern. M39, one of the last outliers of summer in Cygnus, was likely observed by Aristotle around 325 BC. M41 is a really bright (magnitude 4.5) and handsome cluster about 4° south of Sirius — why don't people observe it more? It's certainly plainly visible to the naked eye on a dark, transparent night.

M44 and M45, the Beehive Cluster and the Pleiades, respectively, are already so renowned we'll skip over them here (*don't* skip over them in the sky, though!). M46 and M47 are a delightful odd couple a little more than 1° apart. M47 is brighter but with stars of very different brightnesses irregularly distributed. M46, on the other hand, comprises faint stars of similar brightness arranged in a spherical gathering (a gathering that has a planetary nebula shining through from behind it!). M48 was a "missing Messier" until it was identified with the fine open cluster NGC 2548 in Hydra near Monoceros. M50 is in Moncoceros and is a bright cluster with ill-defined edges. M52 is a beautiful open cluster in Cassiopeia.

Then the Messier catalogue almost runs out of open clusters. The last by number on our map are rich M67 near Alpha (α) Cancri (Acubens) and M93 in Puppis. M103 in Cassiopeia is apparently a bit too faint for the map.

Globulars, anyone? This month's central sky chart in *Sky & Telescope* is the only one of the year that doesn't display even a single *globular* star cluster. If you feel compelled to see one at the hour of our map, you can check out the rather dim M79 in Lepus. But wait a few hours and one bright globular after another will start coming up. The first will be the great M3 in Canes Venatici.

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



The oft-overlooked open cluster M41 lies around 2,300 light-years away in Canis Major.

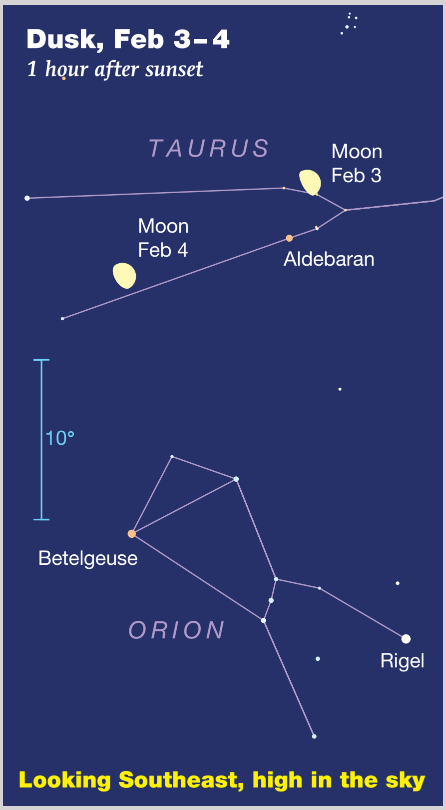
NOAO / AURA / NSF

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

Five Ecliptic Crossings

All five bright planets arrive at either ascending or descending node this month, but the highlight for some lucky viewers might be the Moon's occultation of Mars.

At nightfalls this month, Venus keeps appearing higher in the west-southwest, while Mercury peaks far lower than Venus in the same direction at dusk during the first part of the month. Before and during dawn, there's a parade of three planets — Mars, then Jupiter, and finally Saturn — rising and getting farther away from the Sun as the month progresses. The Moon occults one of these planets — Mars — for most of North America on the morning of February 18th (though after sunrise for some observers). Interestingly, all five bright planets cross the ecliptic this month.

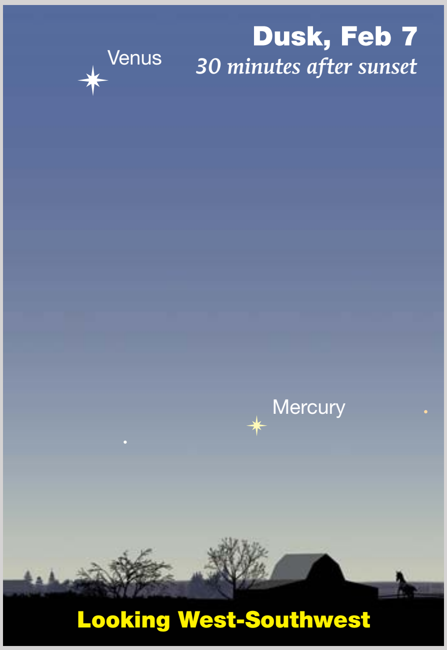


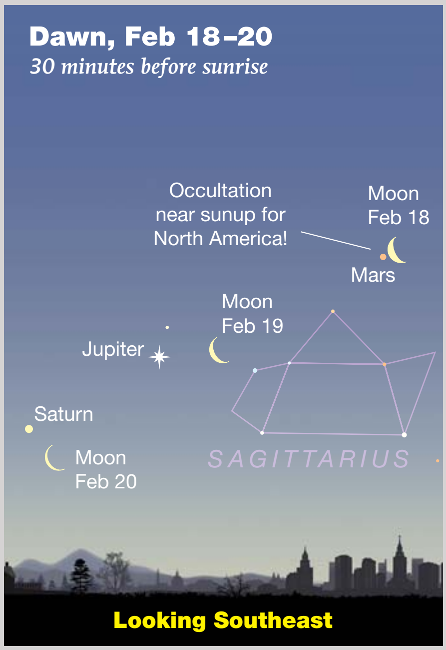
DUSK AND EVENING

Venus continues to appear higher at each sunset, climbing from almost 35° to a bit more than 41° in sunset altitude during February as seen from around latitude 40° north. At sunset, or even earlier, is the best time to get a sharp telescopic view of Venus, for its illuminated part begins to dazzle against the darker sky later in dusk. The angular diameter of Venus increases from about 15″ to 19″ in February, while its illuminated percentage decreases from about 73% to 63%. If you want to admire the naked-eye spectacle of Venus in a darker sky, you can find its beacon brightening from magnitude –4.1 to –4.3 in February and, at mid-twilight, hanging 30° high as the month begins and about 35° as the month ends. Venus doesn't set until about 3⅓ hours after the Sun on February 1st and about 3¾ hours after on February 29th.

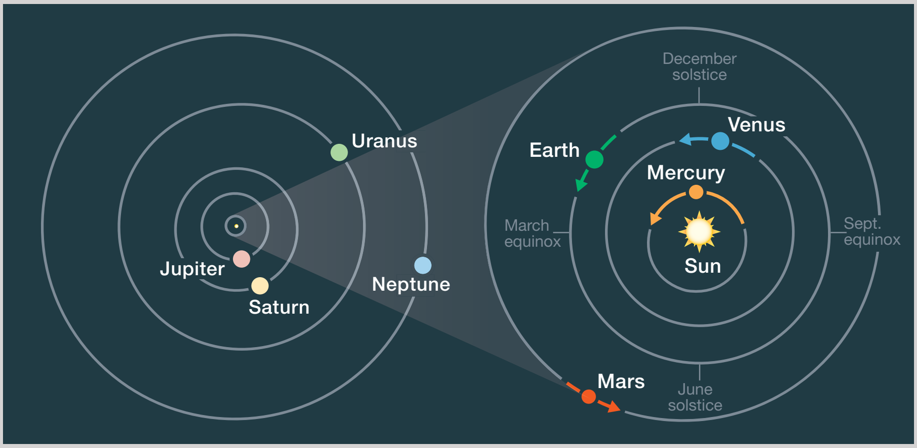
Even better days are ahead for viewers of Venus, for next month it reaches the highest it ever does in its 8-year cycle of recurring appearances. Then in the first few days of April the bright planet skims along the southern edge of the lovely Pleiades.

Mercury appears far lower than Venus at nightfall in the first two weeks of February yet stands a satisfying 10° above the west-southwestern horizon shortly after sunset. From February 1st to 14th, Mercury dims from magnitude –1.0 to +0.2. The highlight of this fine evening apparition of Mercury comes on the 10th when the little planet reaches a greatest eastern elongation of 18.2° from the Sun, and its 7″-wide disk is almost exactly half-lit.





Between February 14th and 17th, Mercury fades from magnitude +0.2 to 1.6. It's lost soon after as it dims by about one magnitude or more every two days on its way to inferior conjunction with the Sun on the American evening of February 25th. On the American evening of the 15th, **Neptune** is a minimum of 5.8° east of Mercury before the latter starts moving away from it. Neptune becomes lost in the Sun's afterglow on its way to conjunction with the Sun on March 8th. **Uranus** is much higher for observation at dusk (and right after dusk) than Neptune is this month. Detailed finder charts for Uranus and Neptune are in the September 2019 issue and can also be accessed at **https://is.gd/urnep**.

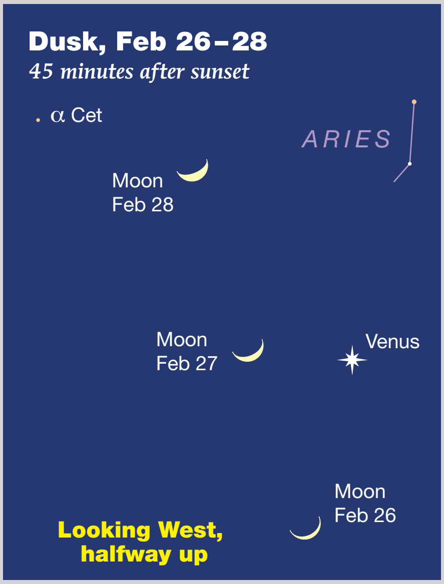


ORBITS OF THE PLANETS

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

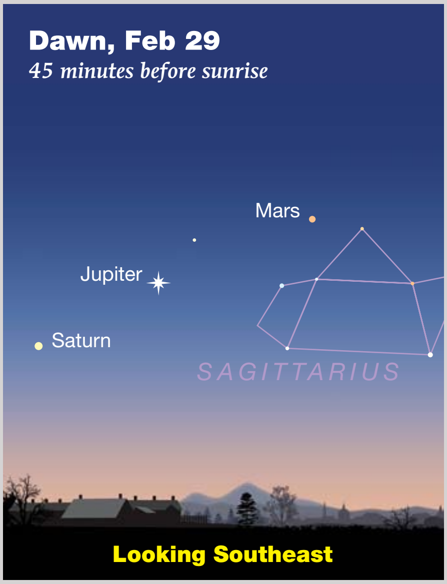
PRE-DAWN AND DAWN

Mars rises about three hours before the Sun in February, its brightness improving from magnitude 1.4 to 1.1. Watch the orange-gold planet as it marches above the Teapot of Sagittarius in the second half of February. The greatest morning is that of the 18th when viewers in most of North America get a rare opportunity to see an occultation of Mars by the Moon. Will the event be before or after sunrise from your location? See page 50 for more information on this occultation. The angular diameter of Mars increases from 4.8″ to 5.5″ this month, still very small for detecting any telescopic detail.



Jupiter starts the month rising more than 1½ hours before the Sun and ends the month coming up about 2½ hours before the Sun. **Saturn**'s lead on the Sun increases from less than one hour to about two hours during February. Jupiter shines east of the Teapot of Sagittarius and is slowly gaining ground on Saturn, which in turn is nearing the borderline of Sagittarius and Capricornus. Follow as the two gas giants trek eastward relative to the background stars. Mars is gaining ground much more swiftly on Jupiter and Saturn, and next month will pass close to the pair.

During February, Jupiter brightens from –1.9 to –2.0, while Saturn dims from +0.6 to +0.7. The globe of Jupiter grows ever so slightly, from 32″ to 34″, the globe of Saturn even less so, from a bit wider than 15″ to 15½″. These usually well-defined worlds are unlikely to appear sharp in the telescope because they're still quite low in the southeast as dawn brightens.



By the way, Saturn is at its descending node (crossing the *ecliptic*, the plane of Earth's orbit) on the 13th, just two days before Venus is at ascending node and only 13 days before Jupiter itself reaches descending node. The last two classic planets also pass through the ecliptic this month: Mars is at descending node on February 1st and Mercury is at ascending node on February 7th.

MOON PASSAGES

The Moon, waxing gibbous, is in the Hyades at dusk on February 3rd. The next evening, it's some degrees right or upper right of Zeta (ζ) Tau. The waning crescent Moon occults Mars above the Teapot of Sagittarius for many observers before or at sunrise on February 18th. At dawn on the 19th, the thinning lunar crescent has moved to a few degrees right of Jupiter, while on the 20th viewers will see the crescent some 2° to 3° lower right of Saturn. The waxing lunar crescent is well to the left, some 5° or more, of Venus at dusk on February 27th.

■ **FRED SCHAAF** lives on the edge of the New Jersey Pinelands Reserve, with no lights for about 10 miles to his east.

A Comet on the Move

Viewers in the Northern Hemisphere have ample opportunities to spot a comet high in the northwestern sky.

Comet PanSTARRS (C/2017 T2) hurtled past M36 in Auriga on October 28, 2019. It's now on course to swing by the Double Cluster in Perseus at the end of January, then rush through Cassiopeia on its way to perihelion.

Mobile, mutable, and subject to surprise fluctuations. These are some of the reasons amateurs so enjoy observing comets. I've nothing against the "fixed" stars and deep-sky treasures but give me a comet and I'll follow it anywhere. While many look like blurry glows, once a comet grows a tail it can become one of the most singularly beautiful objects in the night sky.

Enter Comet PanSTARRS (C/2017 T2), discovered by the PanSTARRS 1 telescope in Hawaiʻi on October 2, 2017. It knocked around for months — no, years — as a faint blip visible in only the largest amateur telescopes. Not anymore. Assuming the comet follows its predicted brightening trend, it should be an easy target for small instruments this month.

Comet T2 starts the month off as a creamy, 9.5-magnitude fuzzy patch with a well-condensed inner coma. It's fresh off a close conjunction with the iconic Double Cluster in Perseus that occurred on January 26–28. Owners of 6-inch or larger telescopes should have little difficulty spotting it just 1° northwest of the glittery duo on February 1st.

From Perseus it creeps westward into Cassiopeia and steadily brightens to around magnitude 8.8 by month's end. Northern Hemisphere observers have a corner on Comet T2 because it's cir-

Earn Loyalty Points

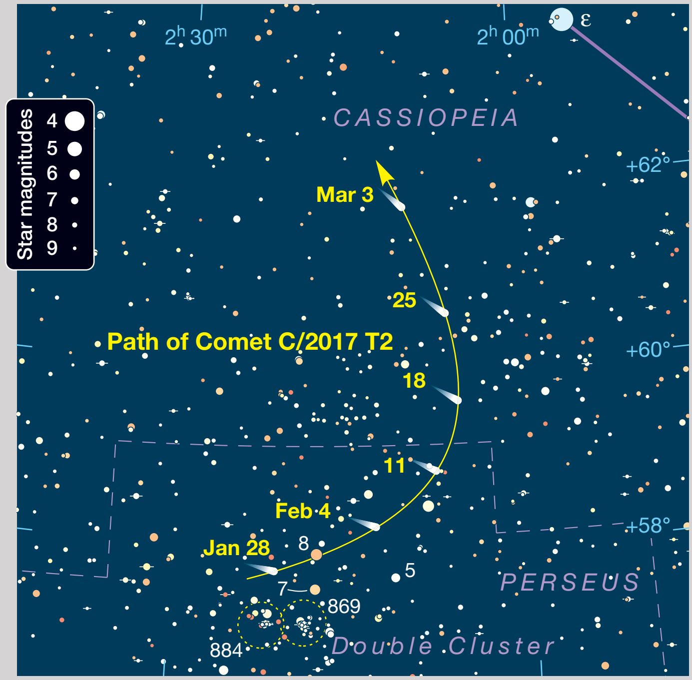
ASTEROID 37 FIDES, named for the Roman goddess of loyalty, will be plying the star-poor byways of eastern Cancer this month. Fides is a large S-type, or stony, asteroid 108 kilometers across that spins once every 7.33 hours. Based on its unusual light curve, which displays three minima and three maxima, some astronomers think it might be a binary object.

At opposition on February 2nd and brightest at magnitude 10.1, Fides will slowly fade thereafter as it moves west in retrograde, almost reaching the Beehive Star Cluster (M44) by the end of the month.

▲ Asteroid 37 Fides, indicated by short lines, traveled between Atlas and Pleione in the Pleiades on the night of November 7–8, 1967.

▶ The ticks (every five days) on Fides's path are plotted for 0^h UT (late afternoon or evening of the previous date in the Americas).

COMET: MARTIN MOBBERLEY; FIDES: SKY PUBLISHING CORPORATION

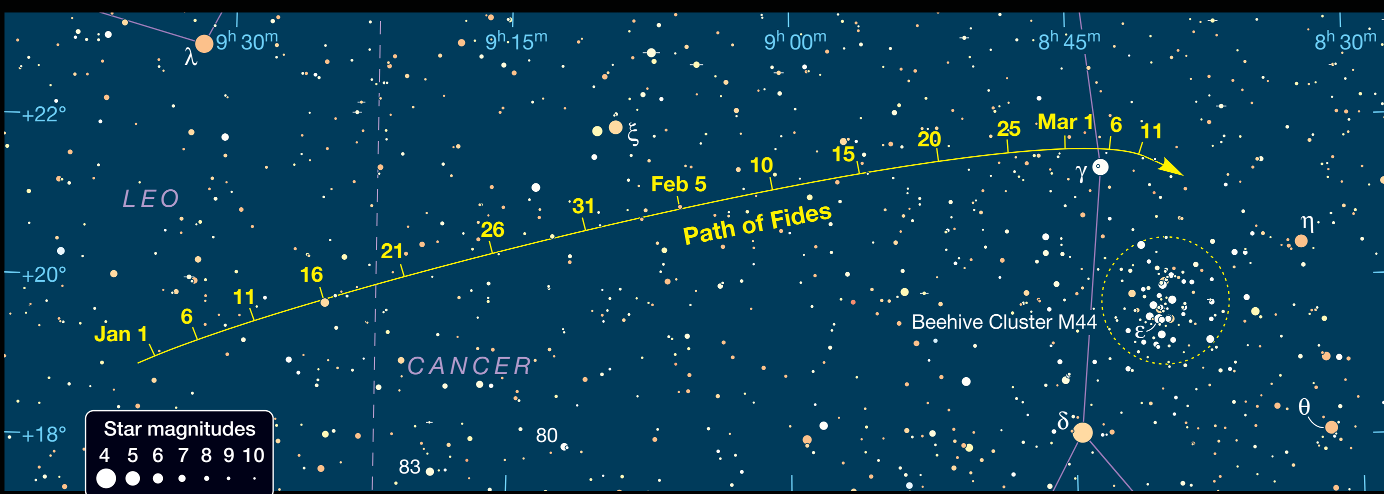


▲ Comet T2 brightens from magnitude 9.5 at the beginning of the month to magnitude 8.8 by month's end. In the chart at right, Comet T2's position is marked with a tick at 0^h UT every seven days. For North America, this time falls in the early evening (or late afternoon) of the previous date.

cumpolar all month from many locales and ideally placed high in the northwestern sky at nightfall. Moonlight will compromise the view through February 10th, but the remainder of the month will be open for business.

As the comet plunges toward a May 4th perihelion, it will continue to brighten and attract attention throughout the winter and spring. Depending on the source, Comet T2 could reach 5th magnitude during the first half of May, bright enough to discern with the naked eye from the countryside. Or it might only manage 8th magnitude, which would still make it a fine target for binoculars and smaller scopes from suburban or better skies.

As the comet sails across the far northern constellations over the next several months, moving from Perseus to the Big Dipper's Bowl by June, it will pass several prominent deep-sky objects, including the bright galaxy pair of M81 and M82 on May 21–23, and the rich Coma Cluster of galaxies (Abell 1656) on July 16–19. Interestingly, Comet T2 drew closest to Earth last December 28th (when it was 1.5 astronomical units away) but stood 2.3 a.u. from the Sun at the time, or 105 million kilometers more distant than it will when it's at perihelion.



Mars and Moon Meet

◀ The Moon will occult Mars (*just* seen here) for most viewers in North America on February 18th.

MOVING ON TO MARS, the waning crescent moon will occult the planet for much of the continental United States, Canada, and parts of Central America during the pre-dawn hours on February 18th. For the East Coast the occultation will take place after sunrise with the Moon well-placed in the southern sky. Because Mars will shine at magnitude 1.2 at the time, it should be visible in a small telescope hovering along the Moon's eastern (celestial direction) edge. Locations farther west will see the Moon cover the planet in twilight or darkness and reappear along the dark limb about 90 minutes later.

Unlike most stellar occultations, in which a star suddenly disappears at immersion and reappears at emersion, Mars will *gradually* disappear and reappear due to its much larger apparent size of 5.2″. If the seeing allows it, use high magnification to best appreciate Mars-set during immersion and the especially dramatic Mars-rise along the opposite lunar limb at emersion. Skywatchers in some parts of Central America will be able to watch a grazing occultation with the Red Planet fading and rebrightening as it slides behind mountain peaks protruding from the Moon's southern limb.

Neptune Flies By Phi

THAT'S PHI as in Phi (φ) Aquarii, a 4th-magnitude star that sits squarely in Neptune's path as the planet treks eastward across Aquarius this month. On February 10th the 8th-magnitude planet practically brushes up against the star, passing 2.3′ to its north with the duo about 10° high in the southwestern sky in late evening twilight. Steadily held 10× binoculars will show the two as a temporary, unequal double star. A modest 6-inch scope will highlight the strong color difference between blue Neptune and its stellar companion, an *M*-type red giant with a distinctively warm hue.

Minima of Algol

Jan.	UT	Feb.	UT
2	19:29	3	8:31
5	16:18	6	5:21
8	13:08	9	2:10
11	9:57	11	22:59
14	6:46	14	19:49
17	3:36	17	16:38
20	0:25	20	13:27
22	21:14	23	10:17
25	18:03	26	7:06
28	14:53	29	3:55
31	11:42		

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

Action at Jupiter

JUPITER REEMERGED from behind the Sun in January, and it's readily observable at or before dawn in February. Although it rises while the sky is still fully dark, you're likely to get the best telescopic views when it's highest, just before sunrise.

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

All the February interactions between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed shortly before sunrise in your time zone, when Jupiter is at its highest.

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

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

February 1: 1:56, 11:52, 21:48; **2:** 7:43, 17:39; **3:** 3:35, 13:31, 23:27; **4:** 9:22, 19:18; **5:** 5:14, 15:10; **6:** 1:06, 11:01, 20:57; **7:** 6:53, 16:49; **8:** 2:45, 12:40, 22:36; **9:** 8:32, 18:28; **10:** 4:24,

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14:19; **11:** 0:15, 10:11, 20:07; **12:** 6:02, 15:58; **13:** 1:54, 11:50, 21:46; **14:** 7:41, 17:37; **15:** 3:33, 13:29, 23:24; **16:** 9:20, 19:16; **17:** 5:12, 15:08; **18:** 1:03, 10:59, 20:55; **19:** 6:51, 16:46; **20:** 2:42, 12:38, 22:34; **21:** 8:30, 18:25; **22:** 4:21, 14:17; **23:** 0:13, 10:08, 20:04; **24:** 6:00, 15:56; **25:** 1:52, 11:47, 21:43; **26:** 7:39, 17:35; **27:** 3:30, 13:26, 23:22; **28:** 9:18, 19:13; **29:** 5:09, 15:05

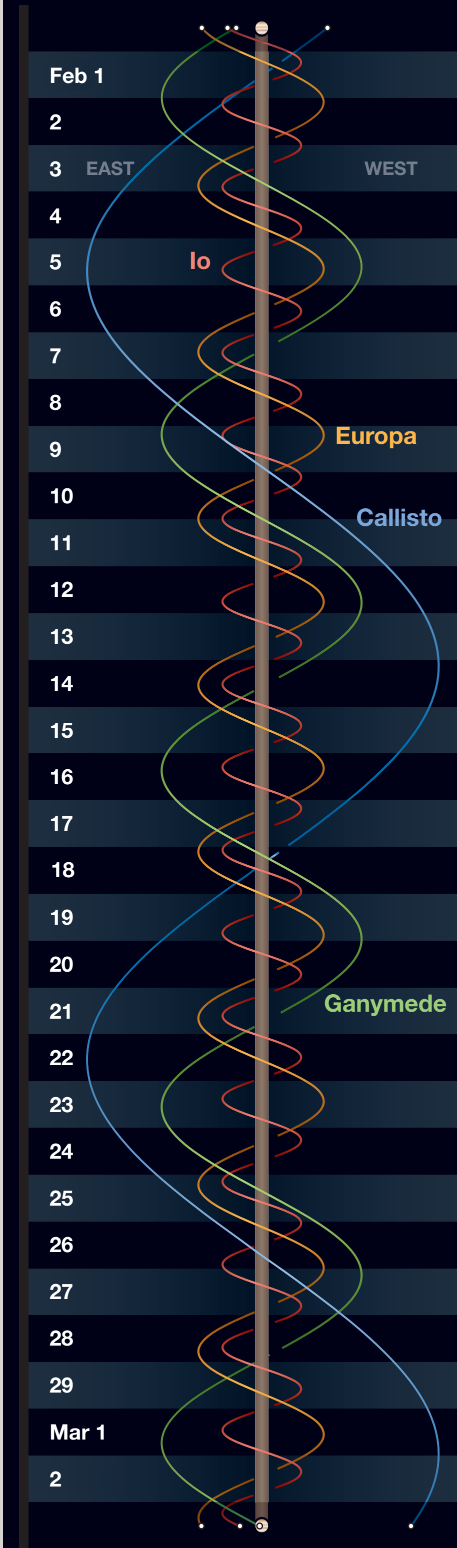
These times assume that the spot will be centered at System II longitude 324°. If the Red Spot has moved elsewhere, it will transit 1²/₃ minutes earlier for each degree less than 324° and 1²/₃ minutes later for each degree more than 324°.

Phenomena of Jupiter's Moons, February 2020

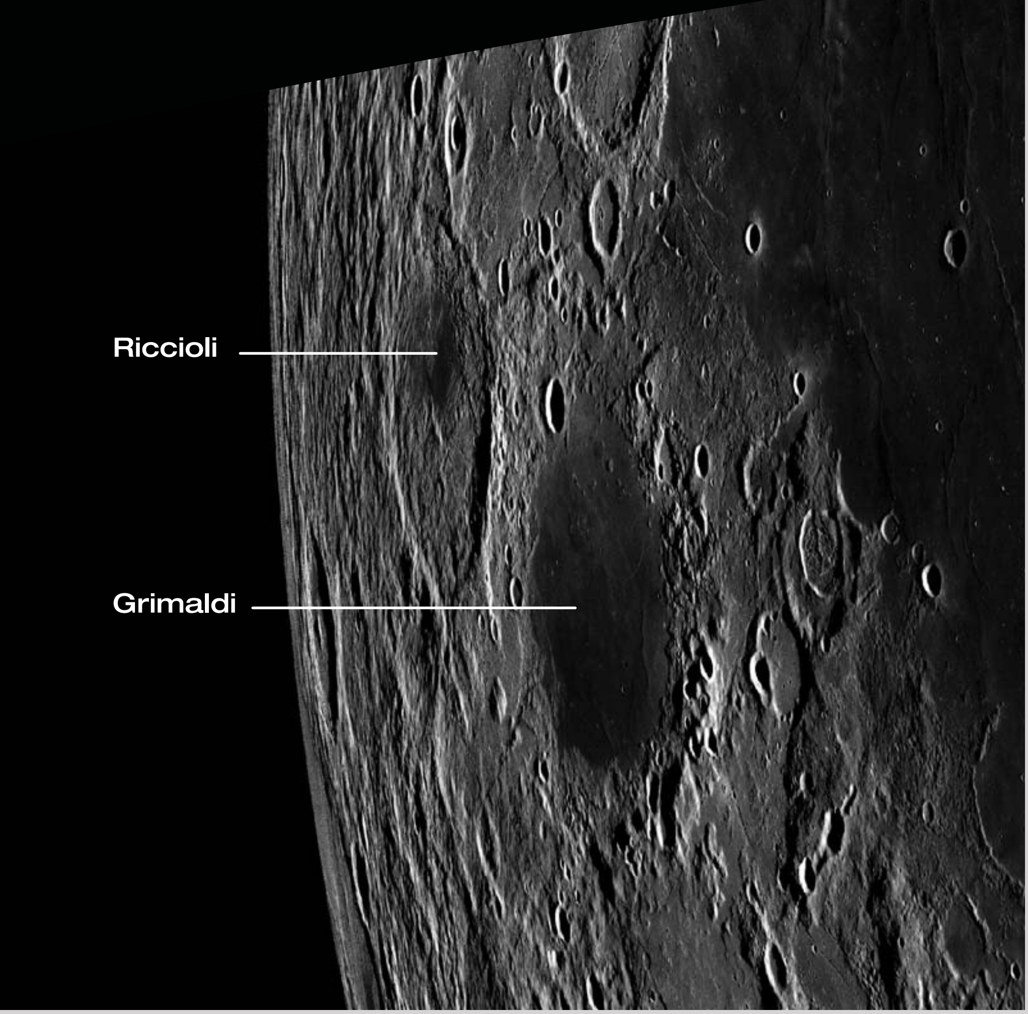
Date	Time	Event
Feb. 1	2:26	II.Sh.I
	3:37	II.Tr.I
	5:06	II.Sh.E
	5:29	IV.Ec.D
	6:20	II.Tr.E
	8:05	IV.Ec.R
	11:02	IV.Oc.D
	14:01	IV.Oc.R
	14:44	I.Ec.D
	17:36	I.Oc.R
Feb. 2	11:52	I.Sh.I
	12:29	I.Tr.I
	14:06	I.Sh.E
	14:44	I.Tr.E
	20:36	II.Ec.D
Feb. 3	0:33	II.Oc.R
	9:12	I.Ec.D
	12:06	I.Oc.R
	15:01	III.Sh.I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

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

Jupiter's Moons



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



◀ Located on the western limb, Riccioli and Grimaldi are both mare-flooded craters visible after full Moon.

NASA / GSFC / ARIZONA STATE UNIVERSITY

Prospecting and Landing

The Moon may hold the fuel for future energy production.

For thousands of years we've relied on coal and more recently on oil for civilization's energy needs. Other power sources such as solar, wind, and nuclear fission have entered the energy market in recent decades. An additional potential energy source is nuclear fusion, which has the advantage that it produces no radioactive byproducts, though estimates have continually put fusion "about 20 years in the future" for the past half century.

The goal of fusion is to merge deuterium (^2H) with tritium (^3H) to create helium-4 (^4He) and one neutron, while releasing prodigious amounts of energy. This process powers the Sun and other stars. Two problems we've yet to surmount are the technical requirements to build a reactor able to contain the immense heat and pressure that fusion reactions produce and the extremely limited availability of helium-3 (^3He), the ideal fuel. After hydrogen, helium is the most abundant element in the universe, but nearly all helium found on Earth is ^4He, with ^3He being only about one-millionth as abundant.

However, the Moon is a veritable ^3He goldmine. Billions of years of solar wind has deposited ^3He in the lunar regolith. On the Moon, ^3He is available in the order of parts per billion, compared to the parts-per-trillion paucity here on Earth. Thus, the lunar-exploration programs of China, Korea, and other nations are partially focused on finding safe landing sites that have mineable concentrations of ^3He. Kyeong Kim (Korea Institute of Geoscience and Mineral Resources) and colleagues have created a global map of lunar ^3He abundances to determine potential landing-site locations that maximize mining opportunities and minimize landing danger. The most favorable of these sites are visible in backyard telescopes.

Soil samples brought back during NASA's Apollo missions show that the abundance of lunar ^3He is related to titanium dioxide (TiO^2) content, soil maturity, and solar wind flux. The element is found in the iron-rich mineral ilmenite, which efficiently traps ^3He carried by solar wind. Lunar lavas are classified as having high, medium, or low concentrations of TiO^2, with the high titanium lavas having greater-than-average ^3He concentrations. Since ^3He occurs in the regolith or lunar soil, those maria peppered with recent small impact craters have churned the soil more, reducing the concentration of ^3He. The third variable, solar wind flux, or the amount of solar wind that hits a particular area of the Moon, corrects for the fact that the Earth's magnetic field shields various areas of the Moon from solar wind and hence ^3He deposition.

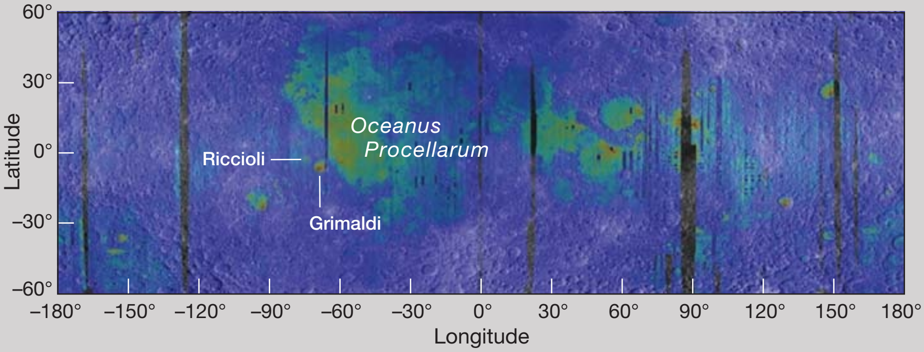
Kim and colleagues used data from the Clementine, Lunar Prospector, and Chandrayaan-1 lunar orbiters to construct high-resolution maps of TiO^2, and to correct for soil maturity as well as solar wind variations to create their ^3He map. They found that the highest abundances occur in the mare patches inside **Grimaldi** and **Riccioli** craters, as well as part of **Oceanus Procellarum**. Similar abundances were detected in Mare Moscoviense, but that lunar farside location would make control of mining operations difficult.

One additional parameter is needed to identify which area of high ^3He

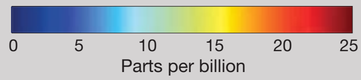
abundance is best for safe landings (as is necessary for commercial use), and that is a site's topographic slope. This was estimated by determining the average slope of the surface at each potential target location using the 2-meter-resolution images from NASA's Lunar Reconnaissance Orbiter narrow-angle cameras. Surfaces sloping less than 10° are considered level enough for safe landing. One final factor affects the site selection. The high ^{3}He abundance must occur over a wide enough area so that landing errors of up to 10-15 km still result in getting the miner into a rich ^{3}He zone. Considering all these requirements, and the fact that crater interior geology is more interesting than mare geology, Kim and coworkers state that Grimaldi and Riccioli are the most promising sites for a future mining operation.

From the point of view of the backyard observer, these two depressions are relatively easy to find. When the Sun is high over this area, dark patches of mare lavas on the crater floors are quite visible against the bright background of surrounding highlands material. More details can be seen just after sunrise, when the grazing illumination reveals Grimaldi's dark floor to be relatively smooth, unbroken by detectable craters, with a flattish dome near the north end of the 145-km-wide mare patch. The highest ^{3}He region is near the southern edge of the dark mare.

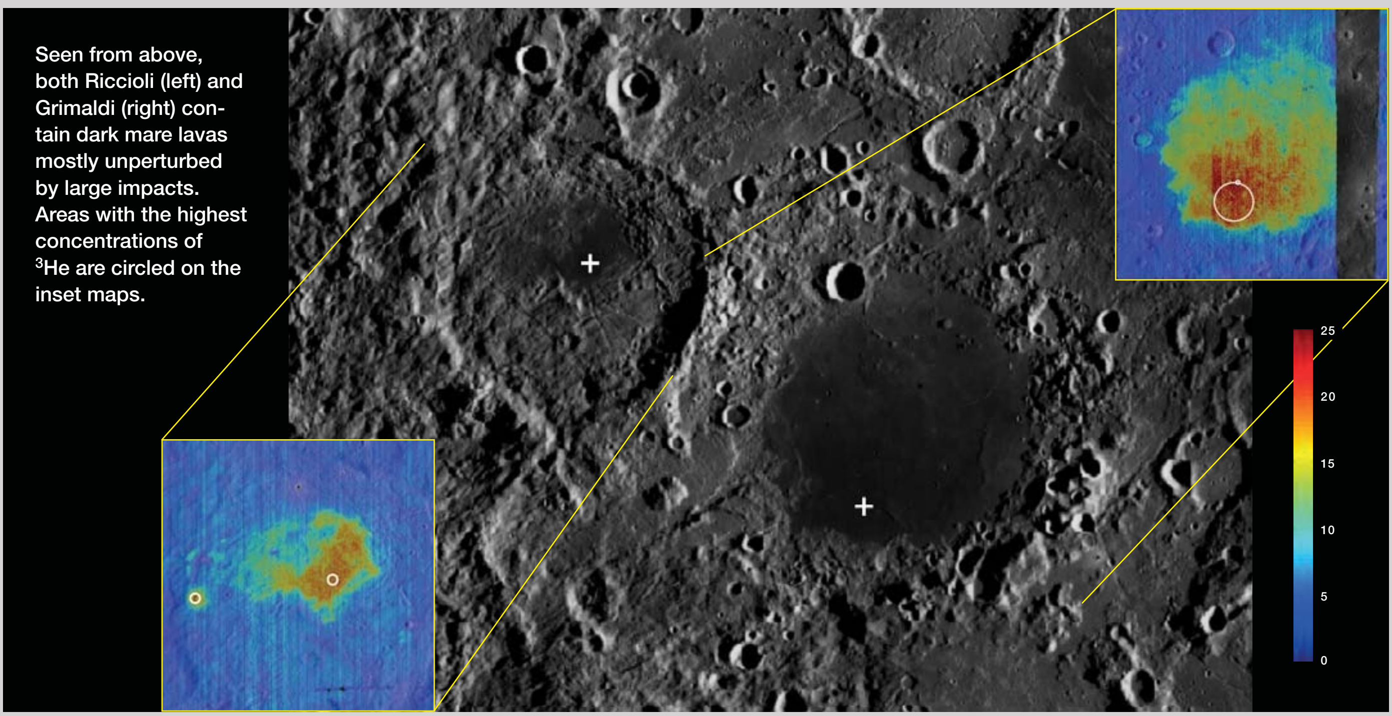
Riccioli crater's rim is about the same diameter as the mare material covering most of Grimaldi's floor. But unlike that smooth surface, the majority of Riccioli's floor is covered by ejecta emplaced during the impact formation of the Orientale Basin to the south-southwest. Only a 40-km-long "pond" of dark lava fills a low area in the northern half of Riccioli's floor — the greatest concentration of ^{3}He is at the southern end of this small mare patch. The fact that the dark lavas in these two craters are not defaced by ejecta demonstrates that they were volcanically emplaced after that basin's formation about 3.85 billion years ago. The dark floors of Riccioli and Grimaldi show no surface manifestation of the great isotopic wealth that we may someday harvest from those lavas.



▲The global map of ^{3}He shows the element to be concentrated in several locations mostly on the lunar nearside.



■ Contributing Editor **CHUCK WOOD** has shared his lunar insights with *S&T* readers for more than 20 years.

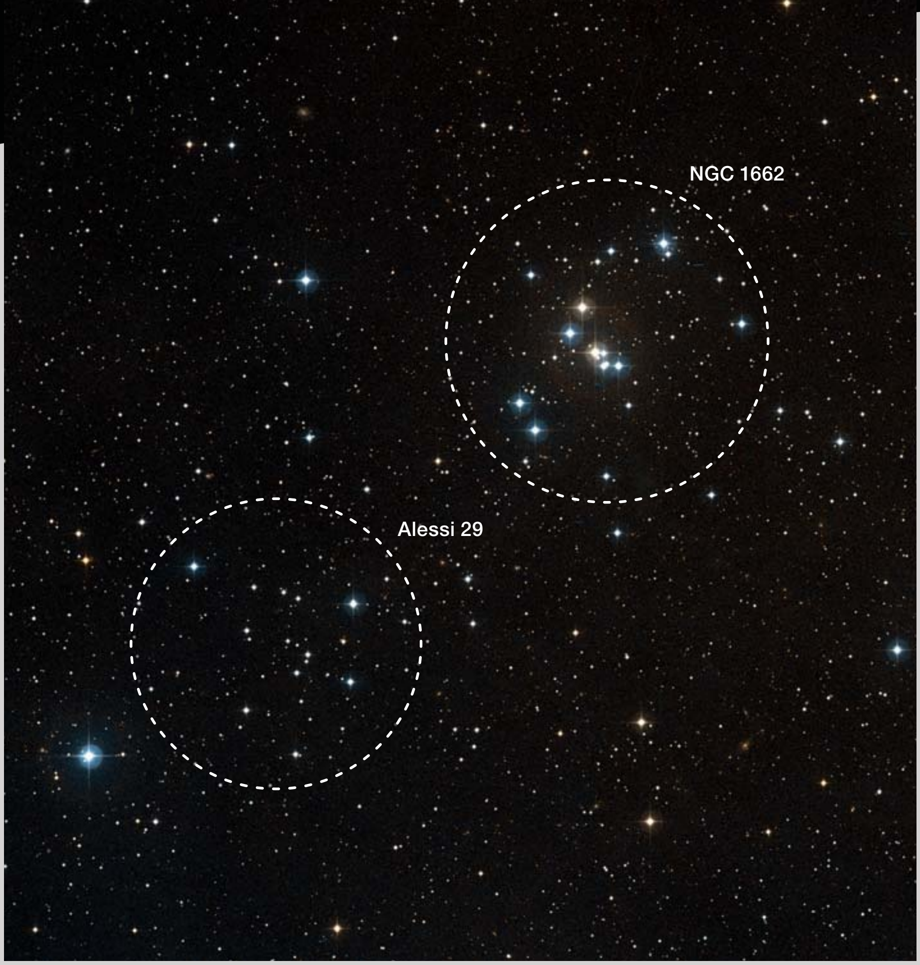


Seen from above, both Riccioli (left) and Grimaldi (right) contain dark mare lavas mostly unperturbed by large impacts. Areas with the highest concentrations of ^{3}He are circled on the inset maps.

GLOBAL MAP: NASA / GSFC / ARIZONA STATE UNIVERSITY; RICCIOLI & GRIMALDI MAP: LRO MOON: NASA / GSFC / ARIZONA STATE UNIVERSITY; 3HE DETAILS: K. J. KIM ET AL. / *PLANETARY AND SPACE SCIENCE* 2019

Orion's Golden Shield

Remarkable clusters and nebulae encircle the giant's torso.



POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

His sword hung gleaming by his side,
And, on his arm, the lion's hide
Scattered across the midnight air
The golden radiance of its hair.
— Henry Wadsworth Longfellow,
The Occultation of Orion

In this column, we've explored some of the amazing deep-sky wonders in the environs of Orion's gleaming sword. Now let's set our sights a bit farther north, starting in the mighty Hunter's shield, which is often portrayed as a golden lion pelt draped over Orion's outstretched arm.

We find an aptly seasonal Valentine's Day treat 1.8° west-northwest of Pi^1 (π^1) Orionis, atop Orion's shield. The open cluster **NGC 1662** is a heart-shaped beauty you could share with someone special.

My 130-mm (5.1-inch) refractor at 23× shows 22 stars in NGC 1662, all but four outlining a stylized heart with a loop where the lobes meet. The cluster's two brightest stars have a yellow hue; one ornaments the loop and the other shines at the top of the heart. The four loop stars belong to the multiple star h684, and a dimmer, fifth component becomes visible at high powers.

The light from this Valentine heart has traveled about 1,400 years to reach your eyes, starting approximately two centuries after the feast of St. Valentine was established.

Just southeast of NGC 1662, we find the possible open-cluster remnant **Alessi 29**, discovered by Brazilian amateur Bruno Sampaio Alessi. Open-cluster remnants are the residue of clusters that lost their gravitational grip on most of their original members and have been pared down to more stable multiple systems. Such remnants are difficult to identify unless they have enough members to show a telltale spectral sequence indicating their former glory as part of a larger group.

Visually through my 130-mm scope at 63×, Alessi 29 is a teardrop of 13 stars magnitude 9.7 and fainter. The glistening teardrop is 9½′ long and appears to be falling from the northeast.

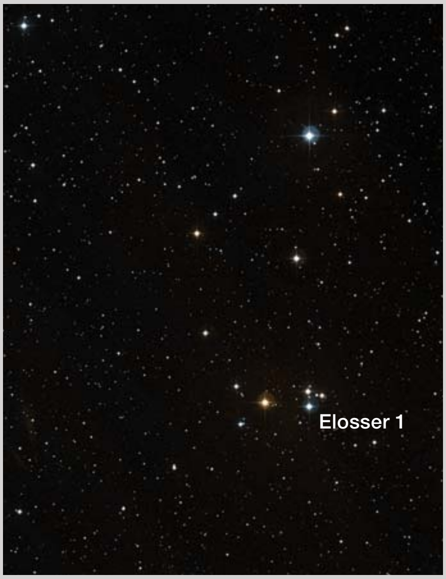
The bright, eye-catching asterism **Elosser 1** sits halfway between Pi^2 and Pi^3 Orionis and just east of an imaginary line connecting them. In the mirror-reversed view of my 130-mm refractor, Elosser 1 is a J of 13 stars hooked around a golden 9th-magnitude star. The brightest stars in the top and bottom of the J glow yellow and orange, respectively. At 63×, 15 faint stars are visible within the J, filling it out into an egg shape 21′ long.

North Carolina amateur David Elosser chanced upon this group while observing with his 4-inch refractor. It's now listed in the Deep Sky Hunters' asterism catalog at **https://is.gd/deep-skyhunters**. Elosser points out that the two star-triangles at the southern end of the group seem to form "an old-fashioned rocket ship."

Let's work our way away from the shield to the pretty double star **Rho (ρ) Orionis**. My 105-mm refractor at 87× shows a bright, golden primary with a much dimmer companion 6.9″ to the east-northeast.

The more equal and tighter pair **32 Orionis** is pinned to Orion's western

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.



shoulder. Both stars look white through my 130-mm refractor, the attendant watching its 4.4-magnitude primary from the northeast. Separated by only 1.3″, the components are split by a hair at 164× and nicely split at 234×.

The position of Orion's head is marked by Lambda (λ) Orionis and the other bright stars of the loose cluster **Collinder 69**. Lambda is a double star with blue-white, 3.5- and 5.5-magnitude components separated by 4.9″ and split in my 105-mm refractor at 87×. At low power, Collinder 69 covers about 1° and shows about 45 bright to faint stars in the 105-mm scope and 55 in the 130-mm scope.

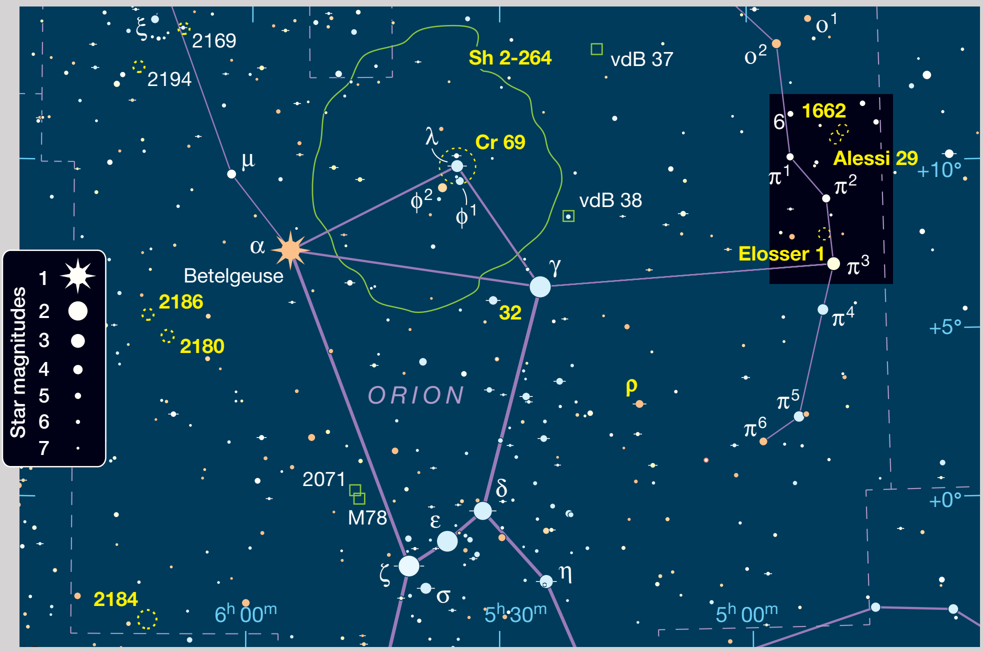
If you visualize Collinder 69 as Orion's head, then the giant is a pinhead. But **Sharpless 2-264**, the 6½°-wide emission nebula surrounding the cluster, gives him a swelled head. Although Sh 2-264 is quite faint, Lowell Observatory's Brian Skiff found it "straightforward" with the unaided eye, and California amateur Robert Ayers has spotted it through 7×42 binoculars. Also in California, Kevin Ritschel observed the nebula with filter-aided eyes. Ritschel mounted a pair of 2-inch hydrogen-beta filters in holes cut into a shallow box, and he held the box up to his face like a mask. This not only helped him combat light pollution, but also kept stray light from reflecting off the back of the filters.

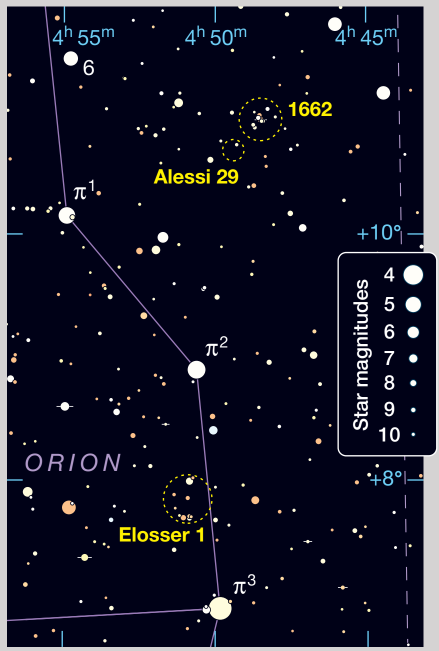
Sh 2-264 is too big to fit in the field of my refractors, even at lowest power. But I've been able to detect the nebula by sweeping a telescope across it and watching for edge effects, where the brightness of the nebula ends and gives way to a darker, nebula-free background. This works best with a hydrogen-beta filter, but a narrowband nebula filter can also help.

Collinder 69 is an extremely youthful cluster — only 5 million years old — and just 1,400 light-years distant. The cluster and its surrounding nebula are part of the Orion Complex, a vast array of nebulae and youthful stars that engulfs most of the constellation.

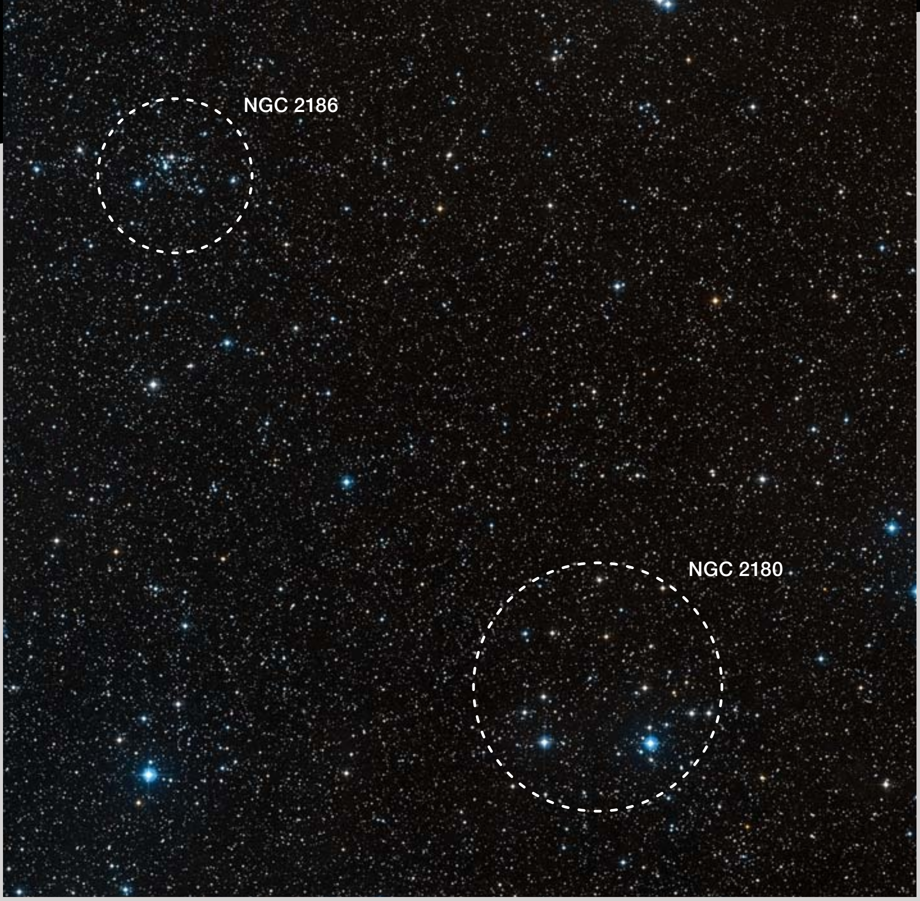
▲ The bright stars of Collinder 69 make up the head of Orion and lie at the center of the huge nebula Sharpless 2-264. Note also the nebulosity around Betelgeuse in the lower-left corner and the small, bright nebula van den Bergh 38 near the right margin.

Now we'll leap over to a few open clusters in eastern Orion. The first is **NGC 2186**, found two-fifths of the way from 8 Monocerotis to Betelgeuse. My 130-mm refractor at 37× displays a small hazy patch flecked with two stars. At 117× the southern star becomes a close pair, the northern one gleams yellow, and a half-dozen faint





ASTERISM: POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY;
NEBULA: SEAN WALKER / S&T



POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

stars emerge. NGC 2186 is an attractive cluster in my 10-inch reflector. At 70× the brighter stars are crowded by many sparkly pinpoints of light. At 118× the yellow star closely guards a distinctive line of stars trailing northward from the pair. Together they dominate the northeastern region of a 20-star wedge tapering southwest for 4½′. The yellow star is thought to be a giant of spectral type G0 and a true member of the cluster.

At low power, NGC 2186 shares the field of view with the open cluster **NGC 2180**. Through the 130-mm refractor at 23×, I see an 8th-magnitude star surrounded by a bunch of faint suns in a starry field. At 63× the faint stars seem to form a hook wrapped around the bright one, as though they were trying to yank it offstage to the east. The hook is about 8½′ long and 4½′ wide, but it's only the south-southwestern part of a splashier group of 55 stars spanning 20′.

The split personality of NGC 2180 is reflected in the various catalogs and atlases that include it. Some show the cluster as a small group centered on the 8th-magnitude star, while others have it as a much larger group centered farther northeast. Our table reflects the size and position from the 2005 *Catalog of Open Cluster Data* (Kharchenko et al.).

Our final target, **NGC 2184**, is larger and showier than its neighbors to the north. It lies 8.4° south of NGC 2180 and 34′ west-northwest of a deep-yellow, 5.8-magnitude star. The 130-mm scope at 23× shows a loose collection of 30 stars, magnitude 7.8 and fainter, splashed across 32′. A lopsided pie wedge of four bright stars dominates the southeastern side of the cluster, all but the faintest one in shades of yellow. The middle star in the arc of the pie crust is the lovely double Struve 874 (Σ874), its 8th-magnitude primary closely attended on the north-northwest by a 9th-magnitude companion. Some of the cluster's lesser gems also glitter with yellowish hues.

In the 1973 *Revised New General Catalog* (Sulentic et al.), NGC 2184 was deemed nonexistent because Jack Sulentic couldn't verify it on the 1950s National Geographic Society – Palomar Observatory Sky Survey prints. However, clusters are sometimes overwhelmed by field stars on deep images, while our eyes do a better job of sorting them out.

■ Contributing Editor **SUE FRENCH** wrote this column for the February 2012 issue of *Sky & Telescope*.

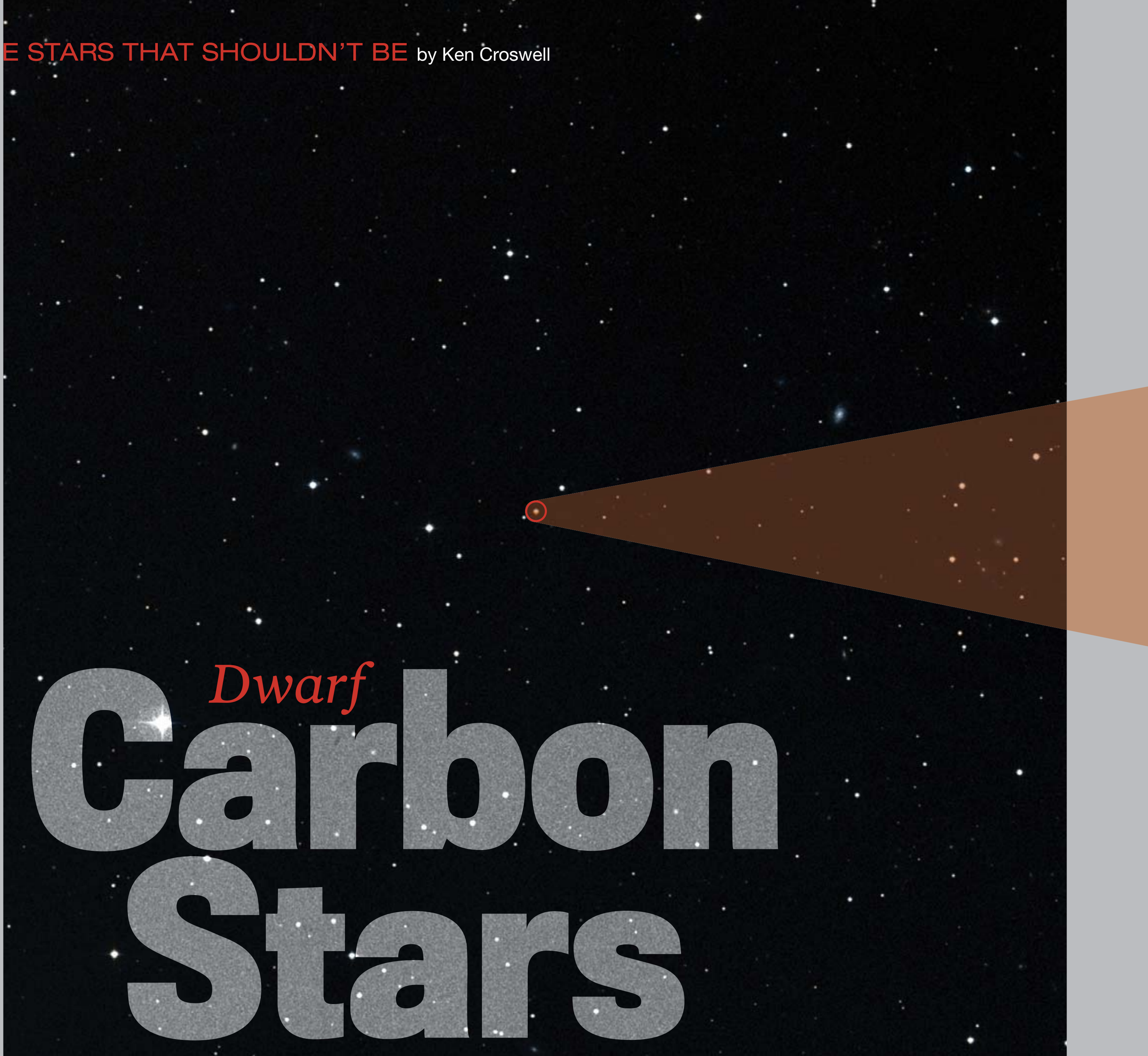
Clusters, Doubles, and a Nebula in Northern Orion

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 1662	Open cluster	6.4	20′	4^h 48.5^m	+10° 56′
Alessi 29	Cluster remnant?	—	10′	4^h 49.4^m	+10° 41′
Elosser 1	Asterism	—	21′	4^h 50.9^m	+7° 51′
Rho Ori	Double star	4.6, 8.5	6.9″	5^h 13.3^m	+2° 52′
32 Ori	Double star	4.4, 5.8	1.3″	5^h 30.8^m	+5° 57′
Cr 69	Open cluster	2.8	70′	5^h 35.0^m	+9° 56′
Sh 2-264	Emission nebula	4.0	6.5°	5^h 36.3^m	+9° 58′
NGC 2186	Open cluster	8.7	5.0′	6^h 12.1^m	+5° 28′
NGC 2180	Open cluster	—	22′	6^h 09.8^m	+4° 49′
NGC 2184	Open cluster	5.8	33′	6^h 11.7^m	–3° 36′

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

 by Ken Croswell

Dwarf Carbon Stars



Stars that shouldn't even exist may soon offer new clues to both the ancient universe and the galaxy's birth.

Of the many chemical elements that stars create, none is more vital to terrestrial life than carbon. About half the carbon in your body arose from red giants, which minted the element in their interiors and then dredged it up to their surfaces, transforming themselves into carbon stars. They cast the element away when they ejected their carbon-coated atmospheres and became white dwarfs.

As if beckoning their progeny on Earth, carbon stars boast beautiful ruby hues that have long attracted observers: "the most intense crimson, resembling a blood-drop," wrote 19th-century astronomer John Russell Hind of the carbon star R Leporis. Although this stellar gem is known as Hind's Crimson Star, William Herschel spotted it first, calling it "A bright garnet star . . . a most beautiful colour" four years after discovering the planet Uranus.

Giant carbon stars look even redder than ordinary red giants for two reasons. First, carbon compounds soak up the stars' blue and violet light. Second, the stars are shedding

▲ **CARBON DWARF** The slightly orange star at the center of this image is G77-61, the first carbon dwarf discovered. The image spans half a degree in Taurus. G77-61 remains the brightest and nearest known example of a carbon dwarf.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY their carbon-rich atmospheres, enshrouding themselves in dust that further reddens their light.

Most of the galaxy's carbon stars, though, are not the crimson giants glistening through your telescope. Instead, they're mere red dwarfs, much smaller than the Sun.

"There are *far* more dwarf carbon stars than giant carbon stars," says Bruce Margon (University of California, Santa Cruz), who nevertheless admits that few astronomers have heard of the stars. "If you go to any assemblage of astronomers and say 'What's a dwarf carbon star?', you just get blank stares."

THE PROTOTYPE

Name: G77-61

Constellation: Taurus

Distance from Earth: 255 light-years

Apparent Visual Magnitude: 13.9

Absolute Visual Magnitude: 9.4

Yet these little red stars tell two intriguing tales. The first is one of stellar evolution: How can a red dwarf, which doesn't create carbon, get so much of this element as to become a carbon star? The second is a promise for the future: possible new insight into the universe's first years, because many and maybe most carbon dwarfs belong to the galaxy's ancient stellar population, its halo.

They Might *Not* Be Giants

Astronomers found the first carbon dwarf in the 1970s, a red star in Taurus named G77-61. "G77-61 had extremely peculiar colors," says Conard Dahn (U.S. Naval Observatory, Flagstaff), who measured its brightness at different wavelengths. The star was fairly nearby — about 255 light-years from Earth, according to modern measures — but was as dim as Pluto, which meant the star was a red dwarf, not a red giant. At a 1975 Christmas party, Dahn told another astronomer how the star was redder than other red dwarfs of the same luminosity.

That conversation prompted astronomers at Lick Observatory to obtain the star's spectrum in January 1976. One of the observers, James Liebert (University of Arizona), phoned Dahn. "He says, 'You're not going to believe this, but it looks like a carbon star,'" Dahn recalls. "Knowing that carbon stars were giants, I said: 'Come on, what are you talking about here?'" The little red star in Taurus had the same carbon compounds as "normal" carbon stars: diatomic carbon molecules (C_2), methylidyne (CH), and cyanogen (CN).

Dahn later gave a talk about G77-61. "This just can't be — it cannot be a carbon star," he remembers one astronomer saying. "There has to be a misidentification." Yet today G77-61 is the prototype for the entire class of stars.

"The phrase 'dwarf carbon star' should be an oxymoron," Margon says. That's because a red dwarf generates energy by converting hydrogen into helium and produces no carbon. A carbon-smothered red dwarf is therefore akin to a kindergartner carrying handwritten calculus equations to school.

Just as you might suspect that the kindergartner didn't write those equations but instead had help from an older sibling, so Dahn's team attributed the carbon atop G77-61 to a companion star, whose light no one had ever seen. In this scenario, the companion was born more massive than the red dwarf and eventually expanded into a red giant, when it fused helium nuclei together to forge carbon. Some of this carbon then reached the star's surface. The giant showered carbon onto its red dwarf neighbor and soon shrank into a hot white dwarf. The white dwarf then cooled and faded so that the red dwarf now outshines it, which is why no one can see the white dwarf's light.

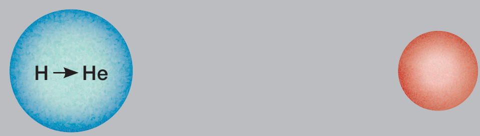
A decade later, a wobble in the red dwarf signaled an orbiting star with just the right mass to be a white dwarf, confirming this theory for the red dwarf's carbon. The red and white dwarfs orbit each other every 245 days.

But G77-61 was still unique, a stellar freak, the only dwarf carbon star ever seen. Further confirmation for the

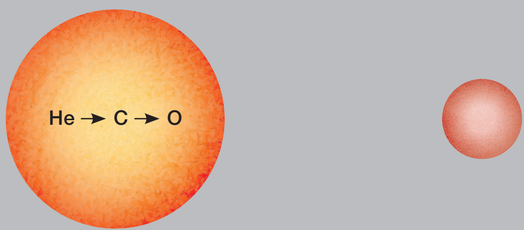
▼ **R LEPORIS** Hind's Crimson Star (left) blazes with a blood-red glow that puts G77-61's shine to shame. R Leporis and its other giant brethren are more deeply tinted than the dwarf because dust clouds surround their atmospheres and redden their starlight.

BOB FRANKE

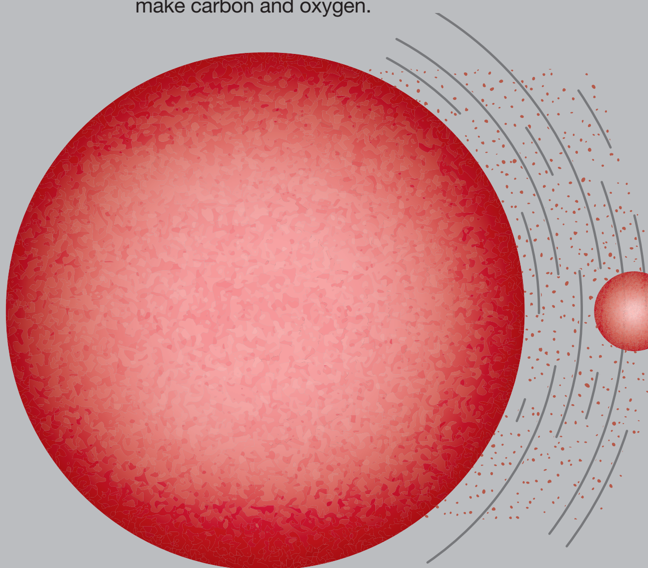
MAKING A CARBON DWARF Little red dwarfs become carbon stars when a companion showers them with the element.



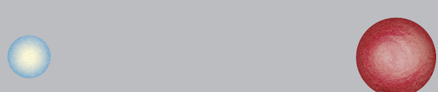
1. Long ago, a blue star a few times as massive as the Sun and a red dwarf were born together. Both stars fuse hydrogen into helium at their centers. (Stars are not to scale.)



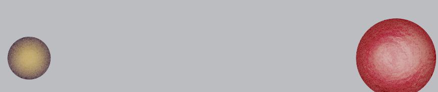
2. The blue star runs out of hydrogen at its core and expands into a red giant. The helium at its core eventually ignites to make carbon and oxygen.



3. Some of the carbon enters the giant's atmosphere. (The carbon might turn the star into a carbon giant like R Leporis.) During this stage the star sheds lots of mass. Some falls onto the red dwarf companion, changing it into a carbon dwarf.



4. The giant star casts off its atmosphere, exposing its hot core: a white dwarf.



5. Over billions of years, the white dwarf cools and fades so that observers can no longer see it.

TERRI DUBÉ / S&T

scenario explaining the star's odd nature came later, when Ulrich Heber (University of Erlangen-Nuremberg, Germany) and colleagues discovered a hot white dwarf in Cancer named PG 0824+289 that had a carbon dwarf companion. The pair presumably was a younger version of G77-61.

Meanwhile, in Seattle, a graduate student named Paul Green, whom Margon was advising, hoped to determine the Milky Way's mass by finding carbon giants in the outer halo and measuring their speeds. Because these stars are luminous, Green reasoned that those that look dim should be far away, possibly more than 100,000 light-years distant.

Instead, Green was shocked to find that three faint, previously known carbon stars had detectable proper motions, a sign the stars weren't bright giants at the edge of the galaxy but instead dim dwarfs much nearer to the Sun. "So right away," he says, "I got scared that my thesis was in jeopardy."

And indeed it was. Thwarted by the scarcity of carbon giants in the distant halo, he devoted his dissertation to dwarf carbon stars instead. After moving to the Harvard-Smithsonian Center for Astrophysics, he spent years mining the Sloan Digital Sky Survey. In 2013, he reported 729 new carbon dwarfs, far outnumbering all previous discoveries put together.

Stellar Time Capsules

With so many carbon dwarfs now known — "The carbon dwarfs vastly, *vastly* outnumber the carbon giants," says Jay Farihi (University College London) — astronomers can explore them further. For one thing, all carbon dwarfs seem to have white dwarf companion stars, just as theory predicts. In 2018, Lewis Whitehouse (also University College London), Farihi, Green, and their colleagues reported detecting companion stars orbiting 21 of the 28 carbon dwarfs the scientists monitored. "Our results are consistent with a 100% binary fraction," Farihi says.

Ironically, many carbon dwarfs belong to the very population Green had originally wanted to study: the stellar halo, whose oldest members date back to the Milky Way's birth. Although the stellar halo constitutes a pittance of the galaxy's total stellar mass, it carries an enormous amount of information about the distant past.

Because we live in the Milky Way's disk, most nearby stars are disk stars. But halo stars stand out by their kinematics — that is, their motions relative to us. The Sun and the other disk stars revolve fast around the galactic center, whereas halo stars don't. As we pass them by, they therefore appear to move fast relative to us. Dahn's team recognized from the start that G77-61 had the kinematic hallmarks of the halo.

Nor is G77-61 a fluke. "Carbon dwarfs give us the potential for a lot of clues on the birth of the Milky Way," Farihi says. In 2018, his team analyzed the kinematics of more than 600 carbon dwarfs. Whereas only about 0.1% of stars near the Sun belong to the halo, a whopping 30% to 60% of carbon dwarfs are halo members and most of the rest belong to another old stellar population, the thick disk.

"They are waving a flag at you saying, 'I am a very old star,'" Margon says. But why should carbon dwarfs favor the halo? First, Margon says, it takes a long time for a star to become a red giant, then a white dwarf, and then a white dwarf so cool and faint that a mere red dwarf outshines it.

Second, Farihi says, halo stars possess little oxygen, having formed before supernova explosions shot much oxygen into the galaxy. In most stars, oxygen outnumbers carbon and soaks up the carbon by making carbon monoxide. To create a carbon star, "you need to flip the carbon-to-oxygen ratio," Farihi says, so that carbon is free to form carbon compounds other than carbon monoxide. Because the halo has little oxygen, a halo star can convert a companion into a carbon star by giving it just a small amount of carbon, explaining why so many carbon dwarfs occupy the galaxy's oldest population.

Moreover, the prototype carbon dwarf seems to be especially old. The typical halo star's iron-to-hydrogen ratio is 2% solar. But in 2005 Bertrand Plez (University of Montpellier, France) and Judith Cohen (Caltech) reported they had found that G77-61's iron abundance is just 0.009% solar. That's shockingly low, even by halo standards, and suggests the star arose near the dawn of time.

And the other carbon dwarfs? Alas, no one knows. "It's hard work," Green says. The stars are faint, which impedes extracting elemental abundances from their spectra. Furthermore, deriving such numbers for carbon-rich stellar atmospheres is difficult. Nevertheless, Margon's team recently obtained spectra that suggest not all carbon dwarfs are as extreme as the prototype.

"So right away, I got scared that my thesis was in jeopardy."
–PAUL GREEN

Still, G77-61's meager iron abundance hints that some of its carbon dwarf peers could offer insights into the primordial era when the first stars shone and exploded, catapulting chemical elements into space. Although those stars have died, the elements they forged survive on the surfaces of ancient long-lived stars like G77-61, which means that carbon dwarfs could help reveal the nature of the first stars and in particular how massive they were.

Thus, the little red stars that most astronomers have never even heard of may preserve fossil records of the short-lived superstars that lit the early universe and ended the cosmic dark ages more than 13 billion years ago.

■ **KEN CROSWELL,** who earned his PhD at Harvard University for studying the Milky Way's halo, has written for *National Geographic*, *New Scientist*, and *Scientific American*. He is the author of eight books, including *The Alchemy of the Heavens* and *The Lives of Stars*.

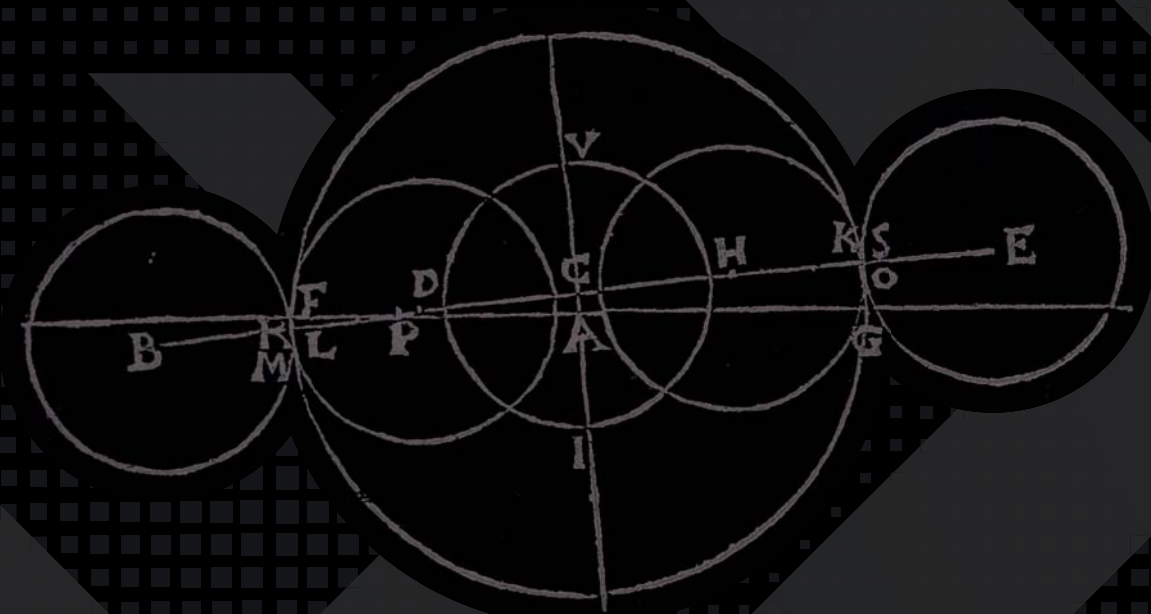
Carbon dwarfs are challenging amateur targets at best. Here we've listed a few that are well-placed during January, February, and/or March for Northern Hemisphere observers. We've also listed several carbon giants for comparison, but note that these are variables so their magnitudes are approximate.

Select Carbon Stars

Object	Type	Mag(v)	RA	Dec.	Approx. distance (l-y)
G77-61	dwarf	13.9	$03^h\ 32.6^m$	+01° 58′	255
2MASS J0933-0031	dwarf	14.6	$09^h\ 33.4^m$	–00° 32′	487
2MASS J0818+2234	dwarf	16.2	$08^h\ 18.1^m$	+22° 34′	1,320
2MASS J0742+4659	dwarf	16.7	$07^h\ 43.0^m$	+46° 59′	482
UU Aur	giant	5.3	$06^h\ 36.5^m$	+38° 27′	1,600
BL Ori	giant	6.0	$06^h\ 25.5^m$	+14° 43′	2,280
W Ori	giant	6.1	$05^h\ 05.4^m$	+01° 11′	3,290
X Cnc	giant	6.4	$08^h\ 55.4^m$	+17° 14′	2,930
W CMa	giant	6.6	$07^h\ 08.1^m$	–11° 55′	1,800
R Lep	giant	7.8	$04^h\ 59.6^m$	–14° 48′	1,360

Right ascension and declination are for equinox 2000.0.

TRANSGENERATIONAL SPACEFLIGHT by Jake Rosenthal



Kepler's Dream, Today's

The great astronomer Johannes Kepler played a central role in the evolution of spaceflight.

We live in a world made of our ancestor's dreams, where extraordinary feats have become commonplace. Most people alive today have never witnessed a time when we did not capture exquisite images of planets, stars, and galaxies; when we did not regularly shuttle members of our species to a residence orbiting 250 miles above Earth; when we did not plunge spacecraft into the depths of the cosmos, scattering them throughout the solar system and beyond. In the ages before these feats, launching anything into space was mere fantasy, a collaboration of the mind and the pen. Firmly earthbound, we looked up, told stories about far-off worlds, and imagined what it might be like to visit them.

The pathbreaking 17th-century astronomer Johannes Kepler (*S&T:* Aug. 2019, p. 58) authored such a story — a travelogue, an amalgam of science and fiction, detailing a voyage from Earth to the Moon. His work relates what a journey of this kind entails as people traverse the expanse of space between the two worlds and the discoveries that await them on the other side. It's titled *Somnium* (*The Dream*).

The origins of *Somnium* trace back to Kepler's early life. As a student in 1593, he composed a dissertation in which he speculated about the appearance of Earth from the vantage of the Moon. An advocate of the controversial Sun-centered universe, Kepler intended to support one of the theory's assertions: a rotating Earth. Those who opposed heliocentrism maintained that such dramatic movements would be felt or otherwise obvious to the senses. Kepler hypothesized that the apparent motionlessness of Earth is an illusion; the planet spins unbeknown to terrestrial observers because they partake in the rotation. Meanwhile, those same observers witness the Moon traversing the nighttime sky. Kepler

KEPLER'S ECLIPSE DIAGRAM: LIBRARY OF CONGRESS; ECLIPSE FROM ORBIT: NASA EPIC TEAM; BACKGROUND PATTERN: SAICLE / SHUTTERSTOCK.COM

Reality

▲ *Left:* Johannes Kepler was the first scientist to explore in detail how the universe would appear to an observer on the Moon. In this diagram, he shows how a total solar eclipse on Earth would appear from outer space. *Right:* On August 21, 2017, NOAA's Deep Space Climate Observatory fulfilled Kepler's prophecy by photographing a total solar eclipse crossing North America.

▶ This posthumous portrait of Johannes Kepler was engraved by the 19th-century British illustrator Frederick Mackenzie.

Kepler's Antecedents

Johannes Kepler was one of the most original scientific thinkers of all time. It seems likely that he invented the idea of stationing an observer on the Moon all on his own. But he later encountered some similar ideas in the Greco-Roman authors Plutarch and Lucian, which he ended up referencing extensively in *Somnium*.

Plutarch is best known as a biographer, but he also wrote an influential treatise titled *On the Face Which Appears in the Orb of the Moon*. It dissented from the mainstream Greco-Roman theory that the Moon is a perfect sphere — a theory that struggled mightily to explain the Moon's familiar dark splotches. Instead, Plutarch suggested that the Moon is a complex, irregular world much like Earth and is very likely inhabited.

Two or three generations later, the satirist Lucian of Samosata wrote two works describing journeys to the Moon. His *True History* is a sequence of ever-more-whopping tall tales culminating with the hero's ship being swept up by a whirlwind to the Moon, where he joins the lunar army in a war with the Sun for the right to colonize Venus. In Lucian's *Icaromenippus*, the hero flies to the Moon by strapping bird wings to his arms. There he encounters the goddess Selene, who is indignant with all the scientists who claim that she is a spherical body orbiting high above Earth and shining by the reflected light of the Sun. The hero then proceeds on to Heaven, where he is stripped of his wings and escorted back to Earth by the messenger-god Mercury.

Lucian created delightful farces by juxtaposing contemporary science with traditional religion and mocking both. He didn't really care about exploring the cosmos; his genius was for exploring human foibles. But *Icaromenippus* does have one strikingly modern scene in which the hero looks down from the Moon onto Earth and sees how petty we all are in the grand scheme of the universe.

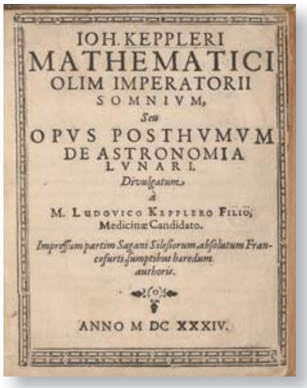
—TONY FLANDERS

imagined what someone would experience if uprooted from our planet and planted on the lunar surface: The motions of the Moon go undetected, while those of Earth are revealed.

Kepler's dissertation challenged the prevailing Earth-centered model of the universe, and unfortunately for him, the professor in charge of dissertations was deeply entrenched in the geocentric worldview. Typically, a dissertation would have been the subject of public debate, but Kepler's writing was denied an audience. Wary of protesting this ruling, Kepler fell silent on the matter. He shelved the work, awaiting a time when circumstances would swing in his favor.

When Kepler returned to the dissertation 16 years later, he decided to reframe it as a dream. He believed that in this context, geocentrists could dismiss objectionable material as inventions of his imagination. Thus, if portrayed as fiction, his thoughts on astronomy might evade censorship.

During this period of revision, Kepler also introduced a passage that addresses lunar flight itself. In telling this stage of the journey, he harks back to the ancient Greeks, with whom literary voyages beyond Earth originated. The stories of antiquity were facetious in their treatment of space travel, recounting humans being lofted into the heavens by whirlwinds or transported across space by gods (see the boxed text on the previous page). Kepler follows this precedent; his explorers require the services of a spirit to convey them between worlds. However, amidst this homage to the ancients, Kepler breaks new ground with an earnest discussion of the practical problems of spaceflight.


IOH. KEPPLERI
MATHEMATICI
OLIM IMPERATORII
SOMNIVM,
Seu
OPVS POSTHVMVM
DE ASTRONOMIA
LVNARI.
Divulgatum
à
M. LUDOVICO KEPPLERO FILIO,
Medicinæ Candidato.
Impressum partim Sagani Silesiorum, absolutum Francofurti, sumptibus hæredum authoris.
ANNO M DC XXXIV.

◀ The title page of *Somnium* reads as follows: "By Joh. Kepler, formerly Imperial Mathematician, *Somnium*, or *Posthumous Work on Lunar Astronomy*," followed by publication information.

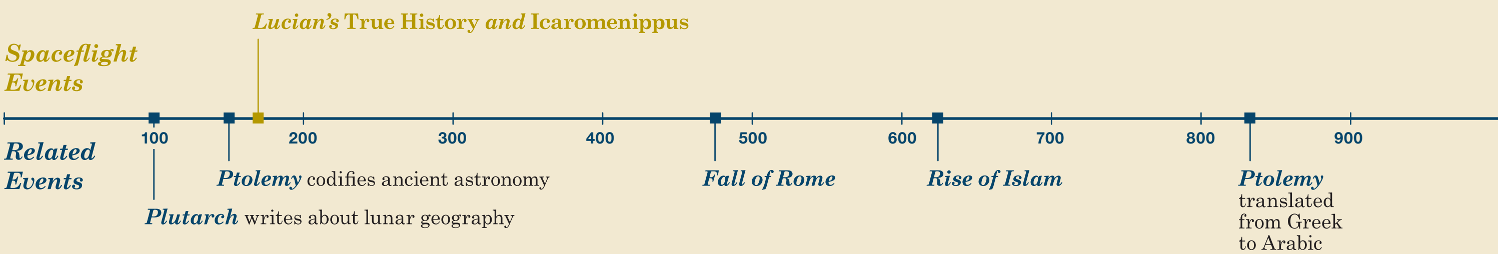
Kepler speculated that space is permeated with a deadly barrage of solar radiation. Therefore, Moon flights must be scheduled for a lunar eclipse, when Earth is situated between the Sun and Moon, generating a shroud of darkness in which the voyagers find safe passage.

The rigors of launch are compared to the detonation of explosives. The ascent so jars the explorer that he requires sedation. His body must be fastened and protected, lest his limbs be horrifically torn away. But at the end of this torturous episode, the explorer coasts peacefully to the Moon without any further application of force.

A close inspection of the Moon reveals perilous terrain. Here, Kepler indulges in what he called lunar geography. In *Somnium*, he describes the Moon's features as dwarfing those of Earth. Mountains tower above all earthly peaks, and chasms plummet to depths far below the greatest terrestrial trenches. The climate is no more tame. Each day and night on the Moon causes huge swings in temperature, blistering heat giving way to severe cold.

In time, Kepler proved correct in his assessment of the climate; however, he was wrong about the size of lunar mountains and many other matters, including the presence of life. Kepler populated the lunar landscape with a diverse community of bizarre creatures. He even included a detailed description of how intelligent beings might have built the

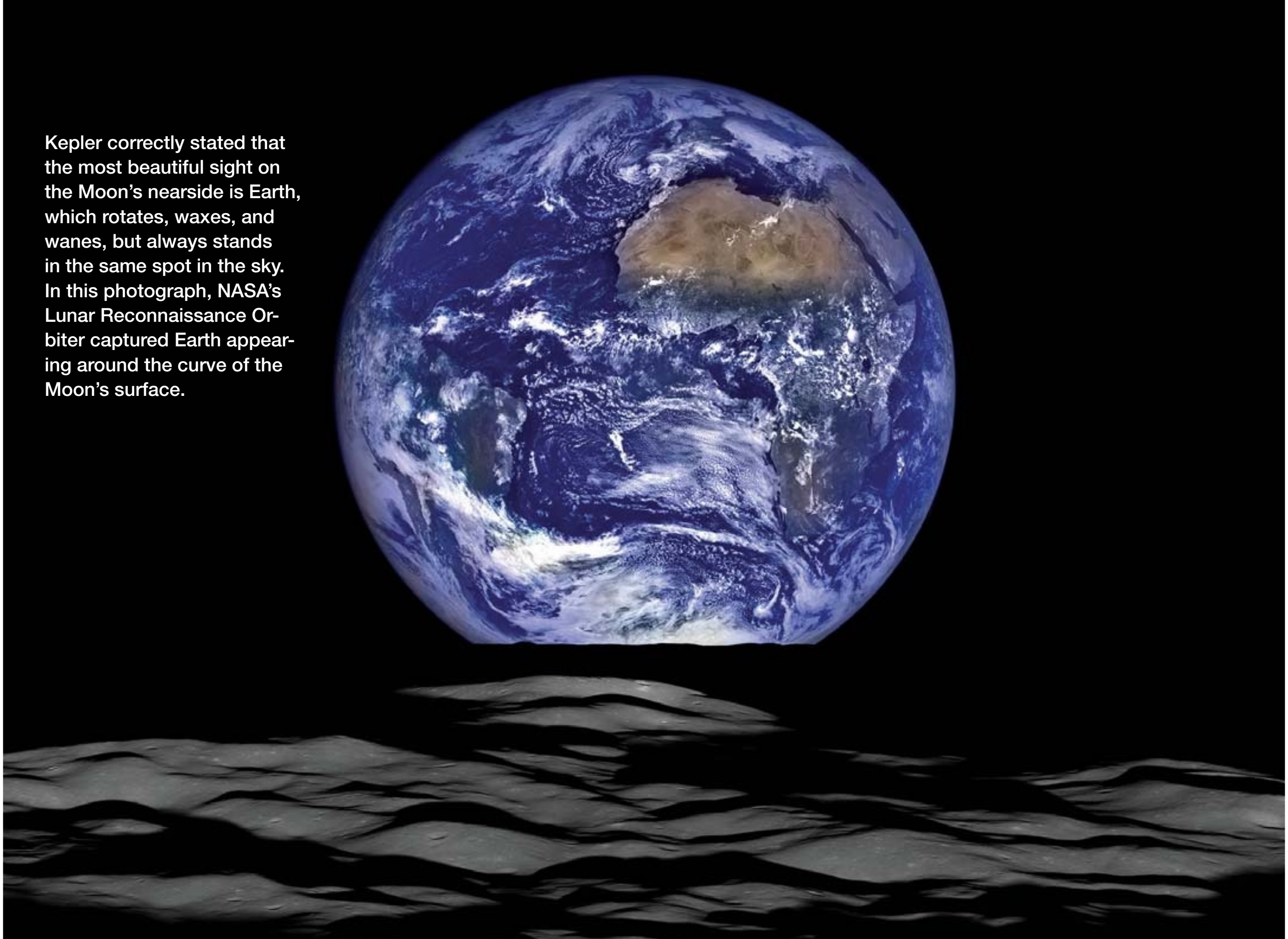
SOMNIUM TITLE PAGE: LIBRARY OF CONGRESS



The First Spaceflight Manifesto

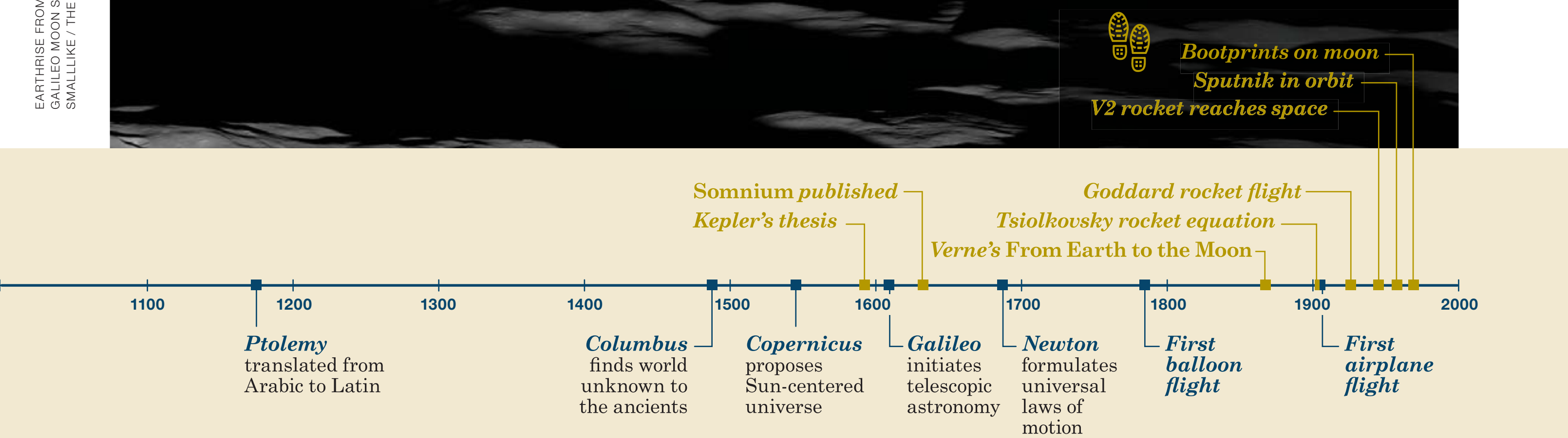
While Johannes Kepler was working on the first version of *Somnium*, his great contemporary Galileo Galilei heard of a new device that made distant objects appear bigger. Galileo built his own telescope (as we now call it), turned it to the night sky, and in one year he discovered that the Milky Way comprises innumerable faint stars, confirmed Petrarch's theory of complex lunar topography as shown in the sketches on the facing page, discovered Jupiter's four bright moons, and observed their changing patterns. That was a severe blow to the geocentric theory, because it proved that at least four objects orbit something other than Earth! He published these results in 1610 in a short pamphlet entitled *Sidereus nuncius* (*Starry Message* or *Messenger*) that electrified the scientific community.

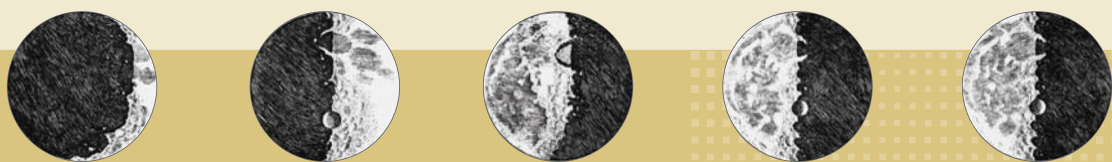
Kepler was thrilled by the pamphlet. He wrote an open letter to Galileo titled *Conversation with the Starry Messenger* that discusses the new revelations in detail. Toward the end, he mentions the possibility that both the Moon and Jupiter are inhabited and proceeds to say, "But as soon as somebody demonstrates the art of flying,



Kepler correctly stated that the most beautiful sight on the Moon's nearside is Earth, which rotates, waxes, and wanes, but always stands in the same spot in the sky. In this photograph, NASA's Lunar Reconnaissance Orbiter captured Earth appearing around the curve of the Moon's surface.

EARTHRISE FROM LRO: NASA / GODDARD / ARIZONA STATE UNIVERSITY; GALILEO MOON SKETCH(ES): WIKIMEDIA COMMONS; BOOTPRINT ICON: SMALLLIKE / THE NOUN PROJECT





settlers from our species of man will not be lacking." And then he proposes that he and Galileo prepare the charts to be used by these explorers.

This appears to be the very first time that anyone wrote about colonizing other worlds not as a fantasy or satire, not even as an interesting possibility, but rather as something that is destined to happen.

Many people wrote about spaceflight and alien life after *Sidereus nuncius*, drawing parallels with the New World discovered 118 years earlier by Christopher Columbus. It's a testament to Kepler's unique genius that he was thinking about visiting alien worlds when he was a student, 14 years *before* the telescope was invented.
—TONY FLANDERS

lunar craters which, he thought, were too perfectly circular to have been formed by nature. He was unaware of the rocky debris bombarding the Moon, excavating the circles.

He speculated that the inhabitants shelter in caves to protect themselves from extremes of heat and cold, especially on the Moon's farside, where the long lunar night is unrelieved by Earth's glow.

Recalling the hostility that he encountered in his youth, Kepler entrusted the manuscript of *Somnium* to various colleagues for review. He sought to understand how his writing would be received. This decision, he believed, prompted the hardships that soon visited his family.

Kepler's mother, Katharina, was argumentative and temperamental. She quarreled with neighbors and local authorities. Elderly, alone, and the object of public contempt, Katharina was susceptible to the storms of superstition that raged in 17th-century Europe (and America). She was arrested on charges of witchcraft — taken in the night and whisked away in a linen chest.

Kepler came to his mother's defense, entangling himself in a grueling campaign to prove her innocence. He worked diligently to reveal the natural forces underlying the supposed evidence of witchcraft. After six long years, Katharina was acquitted and exiled, warded off by the promise that her return would mean her death.

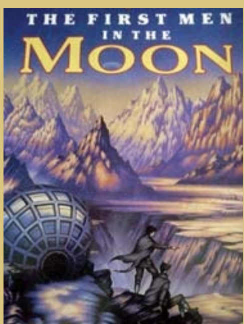
A grief-stricken Kepler reflected on his mother's arrest and the ordeal that followed. He imagined that a copy of *Somnium* had escaped his colleagues and had been read by one of his mother's enemies. Parts of the text are blatantly autobiographical; for instance, the explorer, like Kepler, was apprenticed to the Danish astronomer Tycho Brahe. Kepler suspected that his mother was, correspondingly, likened to the explorer's mother — a mysterious vendor of drugs and a friend to spirits. So, Kepler feared, it was *Somnium* that had aroused suspicions of sorcery and cries of witchcraft.

The case for Kepler's culpability is tenuous. It seems much more likely that Katharina was just another innocent victim of the paranoia and fear that were rampant in her time. However, Kepler blamed himself, convinced that he had penned

Kepler's Legacy

Like almost all scholarly works of the 17th century, Kepler's *Somnium* was written in Latin, making it inaccessible to the general public. But the small community of scientists interested in alien life and spaceflight took note of the book from the moment that Kepler first circulated his manuscript among his colleagues.

John Wilkins's 1638 book *The Discovery of a World in the Moone* is sprinkled with references to Kepler, including a short discussion of spaceflight at the end. Internal evidence suggests that he heard about *Somnium* secondhand rather than reading one of the rare copies that had been published just four years earlier.



In 1640 Wilkins expanded his brief note about spaceflight into a discussion of its problems and possible solutions, far more detailed and sophisticated than anything Kepler attempted. It ends with a clarion call to fly to the stars "despite those who choose to crawl on their bellies like reptiles." Written in nontechnical terms for a lay audience, *The Discovery of a World in the Moone* provoked a brief and wildly premature burst of spaceflight enthusiasm.

Jules Verne and H. G. Wells, the fathers of modern science fiction, both mention Kepler's theory of an inhabited Moon. And an offhand reference to "Kepler's sub-volvani" in Wells's 1901 book *The First Men in the Moon* makes it clear that Wells took the idea of selenites sheltering from extremes of heat and cold in a honeycombed Moon directly from *Somnium*, though he channeled Kepler's vision into a much deeper and more disturbing narrative.

All the early rocket pioneers cited Verne or Wells as having inspired them to investigate spaceflight, so the causal chain linking Kepler to real-life space rockets is surprisingly short. And through Verne and Wells, Kepler's influence on popular culture is incalculably huge.

—TONY FLANDERS

Appropriately enough, the bright young lunar craters Kepler and Copernicus have overlapping ray systems. Johannes Kepler thought that craters were artificial constructs.

COVER OF *THE FIRST MEN IN THE MOON*: WORLD HISTORY ARCHIVE / ALAMY STOCK PHOTO; KEPLER AND GALILEO CRATERS: NASA / GSFC / ARIZONA STATE UNIVERSITY

▶ The Kepler spacecraft, shown here launching in 2009, discovered more than 2,600 exoplanets in its nine-year lifespan. Carl Sagan, among others, insisted on naming it after the great 17th-century advocate for exploring alien worlds.

the very evidence that locked her away. He assumed a responsibility that was never his and was plagued by guilt for the rest of his life.

When Kepler returned to *Somnium*, he set out to dispel the misrepresentation of his work and mischaracterization of his mother. Accordingly, he supplemented the manuscript with footnotes containing elucidations of lunar geography, discussions of telescopic observations, and rebukes of those who (he believed) had weaponized his words against an innocent woman. The remarks — 223 in all — are many times longer than the main text, and required a decade to complete.

Kepler's *Somnium* was a lifelong exercise in scientific investigation, imagination, and patience. But illness struck Kepler down before the manuscript made it to print. His son Ludwig took charge of the manuscript, which was finally published in 1634, four years after Kepler's death.

Combining a mystical framework, a weak narrative, and a profound but rambling scientific treatise, *Somnium* is not an easy read. While the book had a deep effect on some of Kepler's contemporaries (see the discussion on the facing page), others were confused, and most were probably unaware of its existence. Not until the mid-20th century was *Somnium* studied in earnest. We now recognize it as the first modern contemplation on lunar geography and spaceflight.

A far cry from the doctoral dissertation from which it sprang, the completed *Somnium* is more than an effort to promote and popularize the Sun-centered universe. It's a prophecy about the potential of science and the promise of our species. Kepler believed that space travel was indeed possible, that someday humanity would construct ships suited to the cosmic seas and sail for uncharted worlds.

More than three centuries elapsed after Kepler's death before humans attained spaceflight — before they propelled themselves into the heavens, braving that dangerous expanse, destined for the Moon. Then, far from home, those voyagers beheld Earth from aloft — its lands adorned by vibrant hues, its oceans peeking through wispy clouds — and darkness stretching in every direction. But marooned in a time long past, Kepler was never to know of humanity's rendezvous with the Moon and the bootprints impressed in its surface.

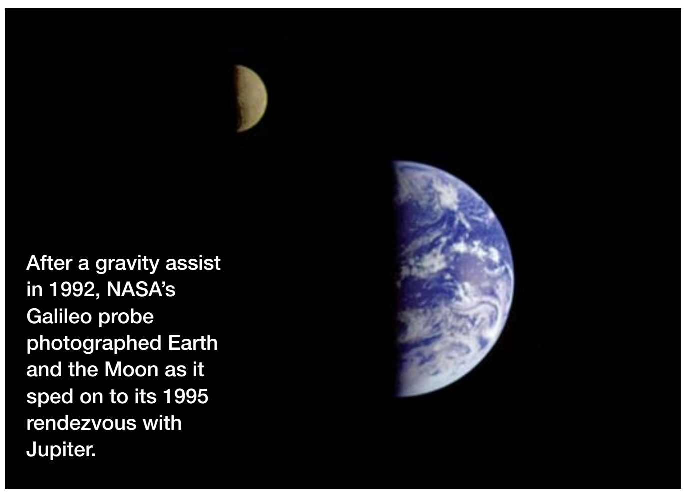
While our capabilities and technologies far surpass those of Kepler's time, our fundamental situation remains the same. We reckon with the blank regions on our maps — all that lies outside our line of sight and beyond our reach. We stare out at the universe through a pinhole, fated to know hardly any of it — just our little corner, perhaps, and a few remote fragments, here and there. We try mightily to force a retreat of the boundary separating knowledge and ignorance. Yet when we cross one frontier, we discover a new one. So we do what we can, in the time we have, to light up the darkness in which we live, and bequeath a universe a little less unknown.

Each generation that follows us will gaze up with wide eyes and see the universe for the first time. Our successors will access perspectives yet unseen, behold wonders yet unimagined, and reveal the cosmos as it has never been known to us nor any human before. And we, islanded in our own time, reach into theirs, helping to create a future that we cannot live to experience directly.

Space travel is an endeavor owed to the labor of multitudes — to the generations past who developed the technology and garnered the scientific know-how to propel us into the universe. Now, the time is ours to carry on this remarkable undertaking. Today, it is we, the most recent iteration of humankind, who make the unthinkable plausible and the extraordinary commonplace. We are the next chapter in a story far greater than ourselves — a story spanning from the distant past to distant worlds. With every voyage beyond Earth, we fulfill the dreams of our ancestors and set the stage for our descendants to venture farther than we ever will.

■ **JAKE ROSENTHAL** is an aerospace engineer at NASA's Goddard Space Flight Center. He was born a quarter-century too late to witness humankind's first "giant leap," but at the right time to take part in the next.

FURTHER READING: The standard English translation of Kepler's *Somnium*, with ample commentary, is by Edward Rosen, Dover Publications, 2003. Marjorie Hope Nicolson's *Voyages to the Moon* (Macmillan Co., 1948), sadly long out of print, is a superb synopsis of spaceflight stories from ancient Greece to the first balloon flight in 1783.



After a gravity assist in 1992, NASA's Galileo probe photographed Earth and the Moon as it sped on to its 1995 rendezvous with Jupiter.

KEPLER SPACECRAFT LAUNCH: NASA / KIM SHIFLETT; EARTH AND MOON FROM GALILEO PROBE: NASA / JPL / ASU

Sky-Watcher's Esprit 150mm APO Refractor

Here's a large apochromat that produces a big bang for your buck.

▲ The Sky-Watcher Esprit 150mm ED Triplet Refractor is the largest aperture offered in the company's Esprit line of premium apochromatic telescopes. This hefty piece of glass will require a solid, medium-to-heavy-duty mount to fully realize its imaging potential.

Sky-Watcher Esprit 150mm ED Triplet Refractor

U.S. Price: $6,399 (includes case, rings, dovetail bars, 2-inch dielectric star diagonal, finderscope, and 2-inch field flattener)

skywatcherusa.com

What We Like

Imaging performance with included field flattener

Excellent optics

What We Don't Like

Mounting plate (dovetail bar)

Finder mount

WHEN I WAS MUCH YOUNGER than I'd care to relate, I spent lots of time eyeing those *S&T* back cover ads for 6-inch Unitron refractors. Surely, I thought, that large (and long) refractor would be the perfect telescope. On a cloudy night I could kick back and just gaze at the scope itself. While I've had glimpses through large APO refractors at star parties, the lure of these classical instruments always was just beyond my grasp. When I was presented the opportunity to review the Sky-Watcher Esprit 150mm ED triplet refractor, I finally had the chance to realize my expectations.

The Esprit 150ED on loan from Sky-Watcher USA arrived this past summer. It was shipped in a single, large box, and when removed from its rugged, fitted carrying case the scope is compelling just to look at. Though 2 mm shy of a 6-inch aperture, its smooth, glossy white finish and massive 3.4-inch focuser immediately convey that this is a quality instrument.

Fit and Finish

The Esprit 150ED comes with a top-notch carrying case, although "footlocker" might be a better description. The hinged 41 × 16½ × 13-inch case is covered in plastic laminate with metal-reinforced edges and corners. One end has two permanently mounted 3-inch-diameter hard rubber wheels, while the opposite end includes sturdy handles allowing a single person to roll the case across smooth surfaces. Inside is custom-fitted, high-density foam to accommodate the Esprit 150ED tube with its mounting rings and dovetail bar attached. A row of seven additional cutouts provide storage for the finderscope, field flattener, and other accessories. The case alone weighs 37 pounds. With the scope and accessories within, it tips the scales at more than 70 pounds, so those wheels are certainly useful.

Since the Esprit 150ED with its supplied 2-inch diagonal, finderscope, and a 2-inch 28-mm eyepiece weighs 32 pounds, it is a hefty load that may tax some medium-duty mounts. The tube assembly is rather front-heavy even with its massive 3.4-inch focuser. The three-element objective has two lenses made of BK7 glass and one of extra-low dispersion (ED) glass to eliminate color fringing. A metal lens cap slips onto the objective cell to protect the lens when not in use.

The scope includes a pair of heavy, cast-aluminum mounting rings, each with four ¼×20 threaded holes on their top side. The rings are spaced 12 inches apart when attached to the supplied dovetail bar. These threaded holes allow mounting additional accessories such as a guidescope or even a small computer (*S&T:* Sept. 2019, p. 66).

ALL PHOTOS BY THE AUTHOR

I was looking forward to using the scope with my 25-year-old Losmandy G-11 German equatorial mount but encountered a problem. The Esprit 150ED's Losmandy-style D-rail dovetail bar was too narrow for my G11's saddle. Tightening the clamps all the way down still allowed the dovetail bar to slide freely in the saddle. The D-rail was almost a millimeter narrower than the Losmandy mounting bars I had on hand. I switched the Esprit 150ED's tube rings to one of my Losmandy plates and was back in business. Note that users with Sky-Watcher and other mounts with the Losmandy D-system may not experience this issue.

The large 3.4-inch focuser of the Esprit 150ED is rotatable by loosening a large metallic "captain's wheel" collar with four ¾-inch machined pegs spaced 90° apart to help your grip. A mounting shoe for the supplied 8×50 right-angle finder attaches to the left side of the focuser.

The Esprit's dual-speed, rack-and-pinion focuser has very smooth motion with almost no backlash. A 2-inch compression-ring accessory adapter threads onto the end of the drawtube. Locking the focus position is done by pulling out a small lever located on the front of the focuser's gearbox, which was a little awkward in practice.

The supplied 2-inch dielectric mirror star-diagonal, as well as the 2-to-1¼-inch adapter, also incorporate non-marring compression rings secured with a thumbscrew.

One nice feature of the Esprit 150ED package is that the purchase price includes a zero-power, two-element field flattener to correct for field curvature when imaging with large-sensor cameras. It attaches to the scope in place of the 3.4-to-2-inch adapter on the focuser drawtube. A camera connects to the flattener using M48 threads.

This rigid, threaded connection between the focuser, flattener, and camera virtually eliminates potential weak points that can tip the camera and distort stars across the imaging plane. However, orienting the camera around the optical axis isn't as convenient as it would be with thumbscrews and a compression-ring-secured coupling. The desired camera orientation can be achieved by rotating the focuser or the telescope within its mounting rings, but doing either rotates the finder position. In some positions the finderscope's view was blocked by the guidescope I had mounted on the tube rings. Several times when imaging with the Esprit 150ED I wished that the finder wasn't mounted directly to the focuser, or the bracket could at least be moved to the other side of the focuser.

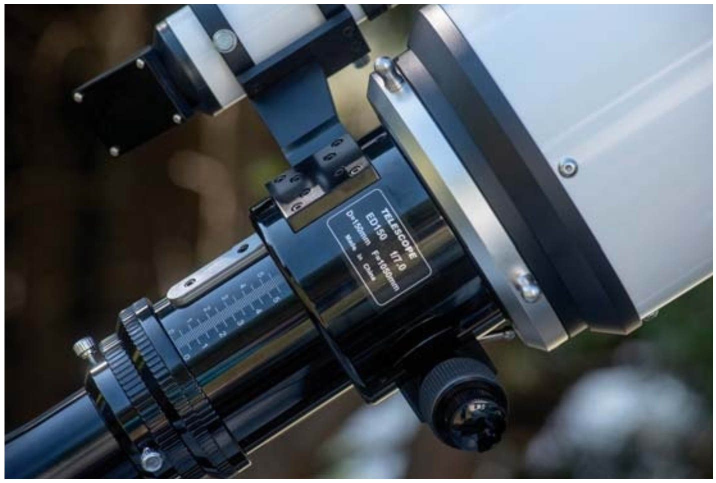
▲ The telescope's 150-mm f/7 (1,050-mm focal length) air-spaced, three-element objective incorporates one element made with FPL-53 extra-low-dispersion glass and two BK7 elements. Its retractable dewshield is secured with two thumbscrews.

While the scope's $6,399 price tag is very attractive for such a large triplet apochromatic refractor, the finderscope fell a little short of my expectations. It's an inexpensive 8×50 right-angle finder with a solid mounting bracket, but it has a narrow field of view and lacks any provision for illuminating its crosshairs.

Visual Impressions

The Esprit 150ED is an outstanding

▼ *Left:* A heavy-duty case included with the scope uses high-density foam with several recessed holes containing blue rubber balls. These nestle the telescope tube on all sides and allow room to reach around the scope to lift it from the case. *Right:* Weighing in at about 70 pounds with scope and accessories in tow, the case's hard rubber wheels allow one person to transport the scope over most surfaces.



▲ *Left:* The telescope's solid 3.4-inch rack-and-pinion focuser and mounted 8×50 right-angle finderscope are rotatable by loosening the large metallic "captian's wheel" ring with machined spokes. *Right:* A millimeter scale to aid in repeating focus positions is printed on the focuser drawtube. Also visible is the 10:1 fine-focus knob.

visual performer on a variety of objects. Star images were tiny and sharp to the edges of the field using a variety of eyepieces. There were no bluish or violet halos around bright stars, and the sky background was very dark, producing high-contrast views on deep-sky objects and double stars. Stellar Airy disks were clearly surrounded by an unbroken first diffraction ring and stood out vividly during periods of good seeing. With a Barlow to increase the scope's effective focal length, both Jupiter and Saturn revealed lots of fine detail and no distracting false color. Even pushing the magnification above 50× per inch of aperture with short-focal-length Tele Vue Nagler and Delos eyepieces, planetary views were still sharp and contrasty. Views of both planets riding low in my southern sky were consistently better than those I saw in my 11- and 14-inch Schmidt-Cassegrain telescopes.

Lunar views were equally impressive. The scope was free of any troublesome off-axis scattering or reflections no matter if the Moon was placed in the center of the field or near the edge. The Esprit 150ED's tube uses six internal baffles, which no doubt contributed to the lack of contrast-robbing scattered light.

White-light views of the Sun with a Baader Astro-Solar Safety Film filter gave great views of the photosphere's surface granulation that easily snapped into sharp focus, though no sunspots were visible during my testing period.

With all my visual tests, the focuser's movement was smooth and positive. All eyepieces I used during my tests reached focus with the included dielectric mirror star diagonal without the need for any extension tubes.

Imaging Performance

Many purchasers will see the Esprit 150ED as an imaging scope with included field flattener and relatively fast f/7 focal ratio.

Sky-Watcher included a T-ring adapter with M48mm threads for me to use with my Nikon D750 camera, and I was really looking forward to how the combination performed. The scope is advertised as having a corrected image circle 43-mm across, and my Nikon D750 full frame DSLR camera body with its 24 × 36-mm sensor has a diagonal measurement slightly greater than 43 mm. Even so, star images in the extreme corners were still tiny and round. There was some vignetting in the very corners and also a narrow strip of mirror-box vignetting along the bottom edge of the D750 frame, though flat-field calibration easily corrected these minor issues.

▼ A 2-inch dielectric mirror star-diagonal with non-marring compression rings is included with the scope, as is a 1¼-inch adapter (not shown).

▲ With the included field flattener, stars appeared about as round and sharp in the corners of the author's Nikon D750 DSLR frame as they were in the center of the field, as revealed by this image of the Lagoon Nebula with blowups of the extreme corners.

▶ The Esprit 150ED includes a dedicated field flattener to improve star images near the edges of the field of view on full-frame cameras. The flattener replaces the focuser's 2-inch accessory adapter, screwing onto the exposed threads.

Users with smaller detectors shouldn't experience vignetting at all.

To see how flat the field is, I focused a star near the center of my camera's field by evaluating the star's full width at half maximum (FWHM) diameter using *Backyard Nikon* software. Moving the star from the center of the frame to near the edge produced very little difference in the FWHM value, attesting to the Esprit 150ED's well-corrected field.

No focus change due to temperature variations was evident during my imaging tests. The 3.4-inch focuser had no problem keeping my camera aligned to the imaging plane no mater where in the sky the scope was pointed, and the focuser's locking mechanism, though a little awkward to access, held focus throughout every exposure.

In Conclusion

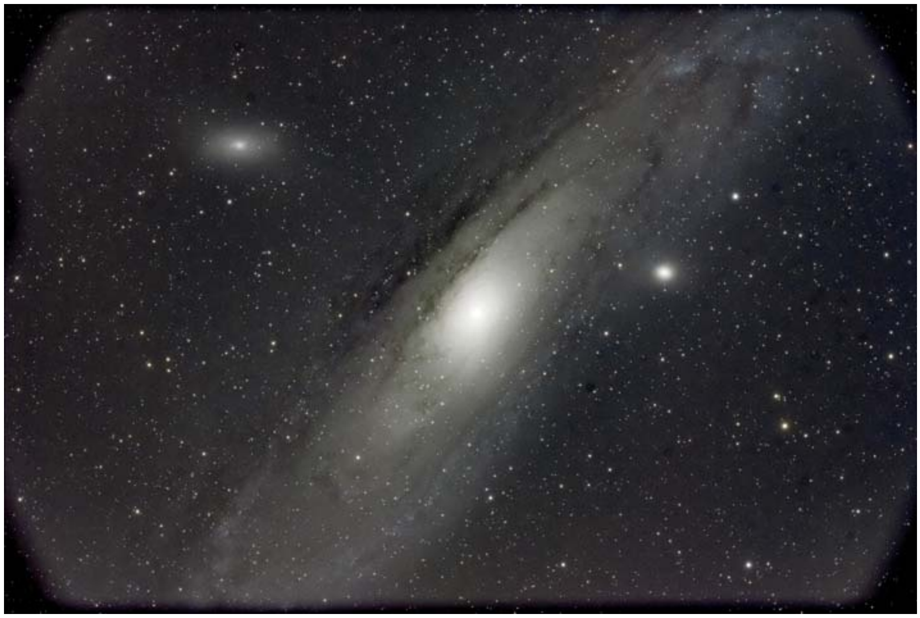
It's hard to imagine a purchaser being disappointed with any performance aspect of the Sky-Watcher Esprit 150ED. Visual observers will enjoy textbook star images across a wide field, and imagers will delight in its tight corner-to-corner star images across large imaging chips.

The weight and length of the scope will be an important consideration for mounting the scope. The scope worked well with my Losmandy G11, but one should probably consider this the minimum in mounting options for the heavy Esprit 150ED, especially if one adds on a large camera, filter wheel, and guidescope.

The scope gave me many memorable views of deep-sky objects, the Moon, and planets. Hooking a camera to the scope with the included field flattener resulted in exciting images of deep-sky objects with textbook star images across the entire field.

■ Contributing Editor **JOHNNY HORNE** still fantasizes about owning a large apochromatic refractor.

◀ Views of the Moon in the Esprit 150ED are sharp, with neither a hint of color fringing visible on the lunar limb, nor any scattered reflections even when placing the Moon outside of the field of view. This image centered on Sinus Iridium was recorded with a ZWO ASI290 high-speed video camera at the telescope's native f/7 focal ratio.



▼ This uncalibrated image of M31 — taken with a full-frame Nikon D750 and a 48-mm T-adapter — displays minor vignetting in the extreme corners of the field. Flat-field calibration reduces this to imperceptible levels.

▶ The Esprit 150ED excels at imaging nebulous deep-sky objects and handles bright stars well. This shot of the Pleiades (M45) is a stack of thirty 5-minute exposures with a Nikon D750 DSLR camera showing bright stars free of reflections or large, distracting halos.

▶ GEAR CONTROLLER

Software Bisque announces TheSky Fusion ($1,695), a compact, mountable control computer for your imaging system. TheSky Fusion simplifies imaging setups by powering and controlling a broad range of astro-imaging cameras, filter wheels, focusers, and other devices using a Linux operating system that eliminates the need for Microsoft Windows and its disruptive updates. It includes a pre-installed 64-bit professional edition of *TheSkyX* software configured for imaging. As a complete embedded system, TheSky Fusion draws much less power than a normal computer, and its fast performance shouldn't degrade over time. The unit includes a 64-bit Hex-Core 1.8 GHz CPU with 256 GB of mass storage space and 4 GB of RAM. A status display panel reports current operations and includes built-in GPS, eight Anderson Powerpole ports, four USB 3.0 ports, and an HDMI 2.0 monitor output. It can be controlled using any web browser through its built-in WiFi or its Ethernet port.

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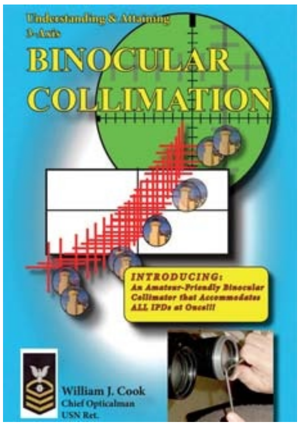

▲ BINOCULAR COMPENDIUM

Retired Navy Chief Opticalman William J. Cook releases new book for binocular aficionados: *Understanding & Attaining 3-Axis Binocular Collimation* ($19.95). Cook, whose previous book *Binoculars: Fallacy & Fact* we reviewed in the August 2018 issue on page 57, dispels common myths and misconceptions about binocular collimation prevalent online today. He delves into the nuances of true binocular collimation and what is required to achieve it with any set of field glasses currently available. Paperback, 68 pages, ISBN 978-1790983780.

William J. Cook
Available on amazon.com

▲ BIG OFF-AXIS GUIDER

Optec now offers the Sagitta Off-Axis Guider for large-format cameras (starting at $595). Optimized for large cameras, this guider features a 3-inch clear aperture that can accommodate large CCD or CMOS detectors. Its body thickness requires 1¼ inches of back focus, and its large 12.5-mm clear aperture pick-off prism can be independently focused with plenty of range to guarantee bright, sharp guide stars in most fields. The Sagitta Off-Axis Guider can be upgraded with a focus motor to permit remote operation, and a completely motorized version is available for $895.

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WOLF-RAYET BUBBLE

Douglas Struble

The colorful gas shell of WR 134 in Cygnus is the result of an energetic Wolf-Rayet star at the center of the image emitting intense radiation.

DETAILS: *Explore Scientific ED152 refractor with ZWO ASI1600MM-Pro CMOS camera. Total exposure: more than 19 hours through Hα and O III narrowband filters.*

◁ CYGNUS LOOP

Chuck Manges

This wide-field image of the Veil Nebula complex, a large supernova remnant, displays the two main segments of NGC 6992/6995 (top left) and NGC 6960 at right. At upper right is a fainter segment known as Pickering's Triangular Wisp.

DETAILS: *Celestron EdgeHD 11 with Hyperstar and QHY163M CMOS camera. 12-panel mosaic with a total of 8 hours exposure through both color and narrowband filters.*

▽ AIRGLOW IN ANDROMEDA

Jeff Dai

Strong greenish bands of airglow light up the sky over Lake Mugecuo in Sichuan, China, though they prove no match for the brightness of spiral galaxy M31 seen at the center of the image.

DETAILS: *Canon EOS 6D DSLR with 16-to-35-mm zoom lens at 16-mm, f/2.8. Total exposure: 15 seconds at ISO 12800.*

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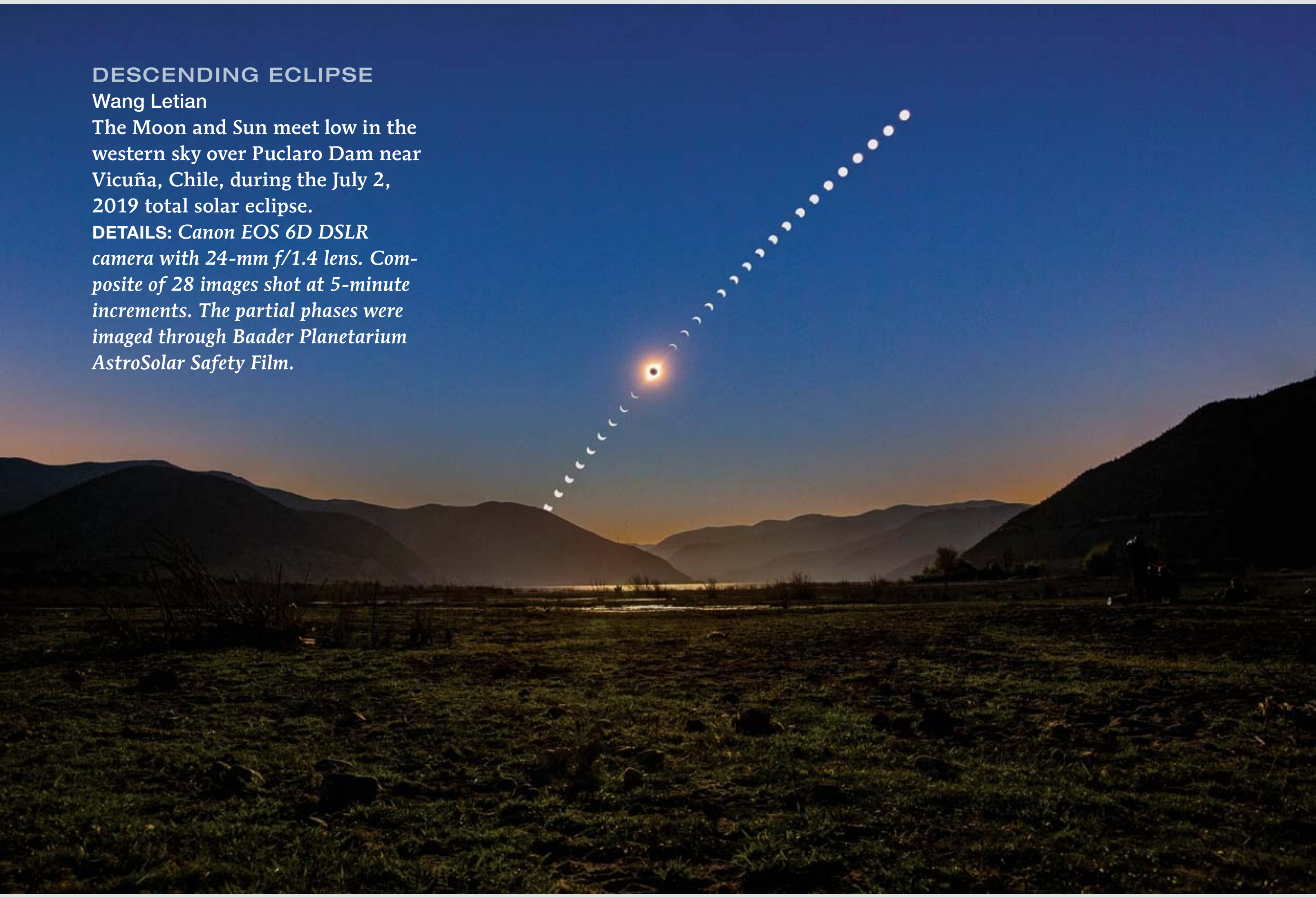
▷ NEBULA AND GARNET

Philipe Moussette

This colorful region is IC 1396, a large H II region in Cepheus ionized by the blue star HD 206267 near its center. At top left is the red supergiant star Erakis (Mu Cephei), also known as Herschel's Garnet Star. This star is estimated to be roughly 1,000× larger than our Sun. If it were to replace our Sun in the solar system it would envelop all the planets up to and including Jupiter.

DETAILS: *Takahashi FSQ-106 astrograph at f/3.6 with Canon EOS 6D modified DSLR. Total exposure: 40 minutes at ISO 1600.*



DESCENDING ECLIPSE

Wang Letian

The Moon and Sun meet low in the western sky over Puclaro Dam near Vicuña, Chile, during the July 2, 2019 total solar eclipse.

DETAILS: *Canon EOS 6D DSLR camera with 24-mm f/1.4 lens. Composite of 28 images shot at 5-minute increments. The partial phases were imaged through Baader Planetarium AstroSolar Safety Film.*

◁ SETTING TRANSIT

Tunç Tezel

In this image taken over Lake Uluabat in western Turkey, transiting Mercury appears as a tiny dot near the center of the Sun, just above the cloud that covers half the face and just left of center.

DETAILS: *Canon EOS 6D DSLR with 100-to-400-mm lens and 2× teleconverter. Total exposure: 1⁄800 second at ISO 800, f/16.*

▽ THE HUNTER'S BELT

Gabriel Santos

Several popular objects surrounding the belt stars of Orion are visible in this deep image, including M78 at lower left. The Flame Nebula (NGC 2024) is a little left of center, and IC 434 notched by the Horsehead Nebula is seen just right of the Flame Nebula. To the right is the Orion Nebula, M42, with smaller, comma-like M43. The entire field is awash in faint brownish dust with other areas of bluish reflection nebulosity. North is at left.

DETAILS: *Modified Canon EOS Rebel T5 DSLR with 135-mm lens at f/2.4. Total exposure: 100 minutes at ISO 800.*

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Imaging Nine Floors Up

You might be surprised at all the advantages over a dark-sky site.

THE NIGHT SKY IS NOW CLEAR and dark. With a limiting magnitude of 3.5, it's a good night. I set up the telescope for some deep-sky imaging.

My site is not ideal. I'm imaging from my 9th-floor, northwest-facing balcony in heavy light pollution amidst Toronto's population of five million. Having no convenient access to a dark sky, I work with what I have. Other amateurs who live in cities might not even try urban astronomy, figuring what's the point.

I used to observe in the usual way, eyeball to eyepiece, using my 20-cm Schmidt-Cass Go To telescope. Finding targets in a washed-out sky proved difficult, but I didn't give up. I wanted more. So I set the eyepieces aside and invested in an astronomical camera and a laptop. I then learned the best targets to image with my equipment and light-polluted skies without using filters. It changed everything.

Monochrome CCD/CMOS sensors are about three times faster than color cameras. They also have a wide spectral response that includes stellar wavelengths not produced by artificial lighting. Taking multiple exposures of 1 to 10 seconds each, totaling 10 to 20 minutes, reduces any tracking issues. Software then removes field rotation and sky brightness while at the same time enhancing my targets.

I can now image faint magnitudes. The telescope's limiting magnitude went from 12.5 visually to 15.5 on the live-image laptop and, after processing, to 18 with the full Moon and greater than 19 when moonless. My observing sessions are now longer, and they go much deeper into space. I've gained 7 magnitudes by switching to mono-imaging and lose just 1.3 magnitudes compared to a dark-sky site.

I have discovered many advantages of a balcony over a distant dark-sky location. Travel time from home to observing site is only seconds, and my set-up time is under 15 minutes. Nine floors up means no dew or mosquitoes, ever. I can "observe" from my living room, and, barring a blackout, I'll never run out of power. Maintaining dark adaptation is unnecessary, and I can easily see my way around the balcony site. Forgetting to bring critical items to a distant viewing site can be a big deal. With the balcony, I simply step inside to retrieve them.

A balcony also has full site security. No strangers, curiosity seekers, animals, property owners, or police with flashlights will ever show up. The balcony's concrete floor is flat, hard, and rigid. Equipment theft is not an issue, so my suitably protected telescope and equipment can stay on the balcony year-round.

Lastly, observing from a dark-sky site can involve costs for gas, vacation time, even hotels and restaurants. A balcony site's cost is effectively zero every time. I also know when it's clear for each balcony observing session. This contrasts with a distant dark-sky site, which might have clouded over by the time you reach it, or, worse, remains cloudy throughout your expensive cottage rental period. Ouch!

They say the best telescope to buy is the one you'll actually use. Well, the same is true for observing sites! This city astronomer can now smile.

■ **KEN PILON**, an urban astronomer for more than half a century, is a former editor of *'Scope*, the newsletter of the Royal Astronomical Society of Canada's Toronto Center.

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