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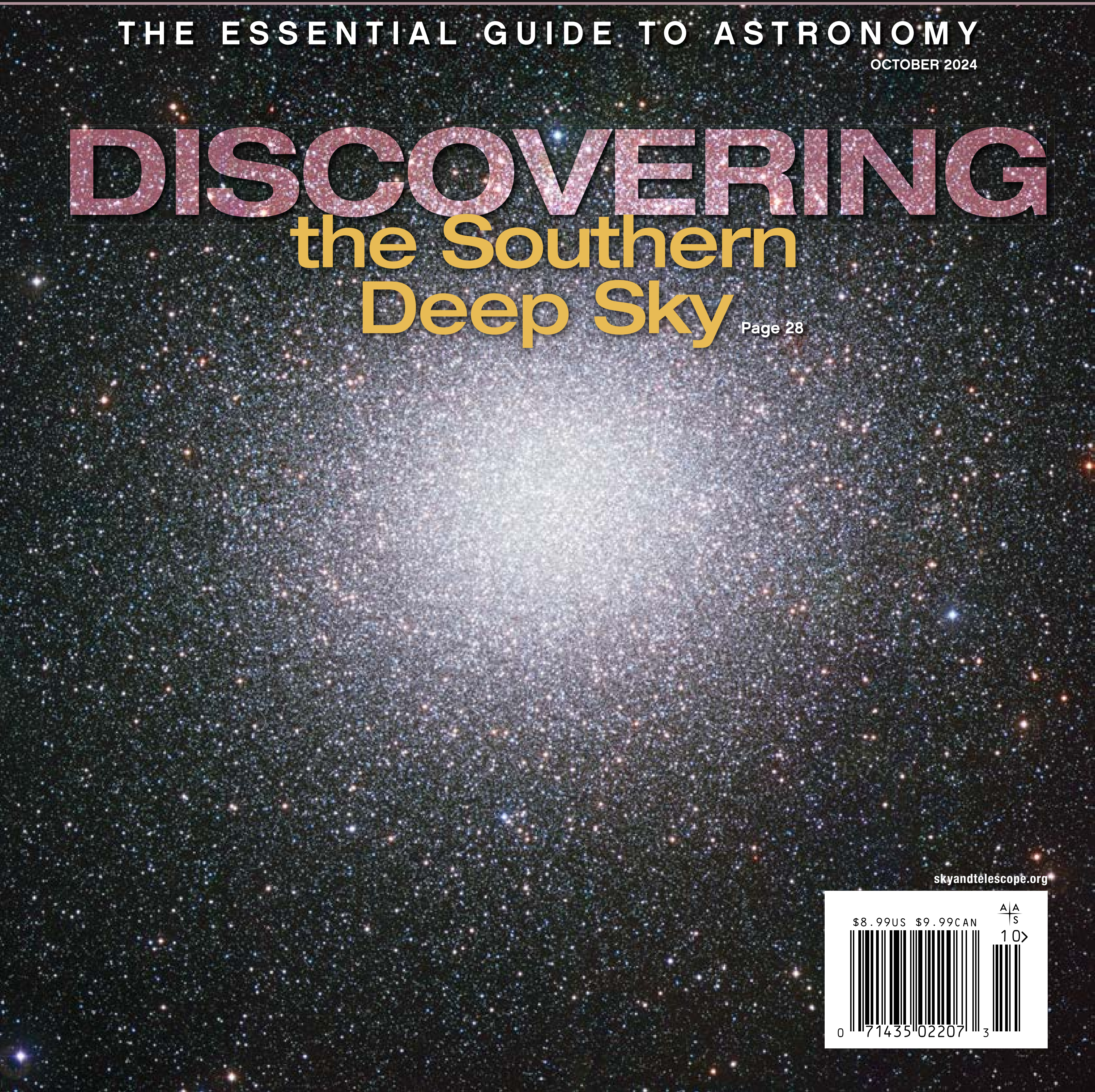
SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

OCTOBER 2024



DISCOVERING the Southern Deep Sky

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ON THE COVER

Southern globular cluster Omega Centauri (NGC 5139)
PHOTO: ESO

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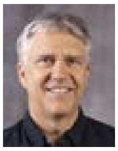
Sky of Plenty



OMEGA CENTAURI, the globular cluster adorning this month's cover, exemplifies what every astronomer knows about the Southern Hemisphere sky — it's shot through with celestial treasures. One glance at the table on pages 32–33, which is as rife with details as Omega Cen is with stars, gives a commanding impression of the southern sky's luxuriance.

Normally I wouldn't focus on a table in this column, but this one compiled by Glen Cozens, the author of our cover story on page 28, showcases that legendary abundance to a tee. In it, Cozens tabulates his choices for 60 of the finest objects one can observe south of –30° declination.

Many of the far-southern sky's most famous gems make the list, of course: the globular clusters Omega Cen and 47 Tucanae, the Tarantula and Eta Carinae nebulae, the Jewel Box and Wishing Well open clusters. Assorted other prizes also make the cut: The String of Pearls galaxy. The Southern Beehive open cluster. The Firebird, Prawn, and Cat's Paw nebulae. (The table lists all objects by their NGC, IC, or, in one case, Messier numbers, so you'll have to look up common names.)

▲ The Jewel Box Cluster, aka NGC 4755, captured by the Very Large Telescope in Chile

If you've observed from southern latitudes, some entries might spark memories. Seeing NGC 1365 on the table reminded me of when, during an *S&T* tour to Chile in 2022, I was treated to stunning views of the Great Barred Spiral Galaxy in both 16- and 45-inch scopes. And seeing NGC 6752, I remembered being surprised that the Great Peacock Globular could call to mind a brittle starfish, as it did to me one night.

Perhaps surprisingly, other celebrated objects lying below –30°S aren't found on Cozens' table. These include Messier 6 and Messier 7, the Butterfly and Ptolemy clusters, respectively, plus a few that I enjoyed observing on that Chile tour, such as the Grus Quartet of galaxies and the Meathook Galaxy in Volans, the Flying Fish. These aren't neglectful omissions on Cozens' part but yet another indication of just how multitudinous deep-south celestial wonders are.

So, too, are constellations, with many in the far-southern sky unfamiliar to stargazers up north. How many of us based in the Northern Hemisphere would recognize Musca, the Fly, or Columba, the Dove? Ara, the Altar, or Fornax, the Furnace? Horologium, the Clock, or Pyxis, the Magnetic Compass? All of these appear, using their shortened designations, on Cozens' table.

I hope you have as much pleasure as I did digging deep into the table — and, more importantly, get the chance sometime to dig deep into the far-southern sky itself.

Editor in Chief

ESO

SKY&TELESCOPE
The Essential Guide to Astronomy

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Lunar Lunacy

On behalf of lunar observing aficionados everywhere, and especially those of us in the Association of Lunar & Planetary Observers (ALPO), I'd like to thank *Sky & Telescope* for William Sheehan's "The Rise and Fall of the Lunar Society" (*S&T:* July 2024, p. 28) and Jerry Oltion and Cindy Krach's "Go Loony for Luna!" (*S&T:* July 2024, p. 34), as well as the many great columns by Charles Wood over the years.

As Jerry Oltion mentions in his piece, too many amateur astronomers consider the Moon problematic for their preferred observing tastes. Yet, once many of them spend time actually looking at even just a few lunar features, their appreciation of the Moon grows. After all, it's our nearest celestial neighbor, and it offers viewing challenges and opportunities unmatched in the visible universe.

Now in its 76th year, the ALPO (**alpo-astronomy.org**) has been helping amateur and professional astronomers become better skilled at observing this near-and-dear neighbor of ours for decades. Building on the efforts of our founder Walter Haas and distinguished members ranging from Antonín Rükl (author of *Atlas of the Moon*) to Robert Garfinkle (author of *Luna Cognita*), the ALPO has fostered a heightened appreciation of observing the Moon. Additionally, the ALPO offers lunar observing training programs and publishes a quarterly journal (*The Strolling Astronomer*) for all to both contribute to and enjoy.

We are gratified that *Sky & Telescope* would dedicate the time and effort to promote lunar observing. Thank you again and please continue your good work.

Ken Poshedly
Executive Director, Association of Lunar & Planetary Observers
Atlanta, Georgia

I enjoyed the focus on the Moon in the July 2024 issue. There were some great articles and images about our beloved nearest neighbor. I would like to invite readers who are interested in all things lunar to check out *The Lunar Observer* (TLO), the monthly newsletter published by the Association of Lunar & Planetary Observers. Those so inclined may submit their lunar images, drawings, and reports for inclusion in the TLO. The newsletter can be found at **https://is.gd/LunarObserver**.

David Teske
Lunar Topographic Studies Section
Association of Lunar & Planetary Observers
Louisville, Mississippi

▲ With no time to spare, Vic Palmieri captured this image of the rim of Sinus Iridum using only his smartphone.

As a dedicated lunar observer, I found having an image of the Moon on the front cover of the July 2024 issue of *Sky & Telescope* to be an unexpected delight. Many amateur astronomers ignore what the Moon can offer: craters, valleys, rills, ridges, faults, and interesting shadow effects caused by the ever-changing terminator. My well-worn copy of Antonín Rükl's *Atlas of the Moon* is a testament to my many evenings searching for these features.

Back in February, I was observing the terminator with a 4-inch Vixen achromatic refractor, searching for several difficult targets, but the seeing was not up to the task. Before calling it a night, I did a sweep of the lunar surface and came upon the rim of Sinus Iridum so beautifully illustrated by Cindy Krach in "Handle of Light" on page 39 of the July issue. The 3D illusion was remarkable. I wanted to take a photograph but quickly realized that setting up my astrophotography gear would take too much time, and the illusion would be lost. So as a last effort, I used my cell phone.

Vic Palmieri
Toms River, New Jersey

A Few Words for Ford

I am writing to express my disappointment that the otherwise excellent article "Rubin's Revolution" by Govert Schilling (*S&T:* June 2024, p. 34) makes no mention of the equally important work of Kent Ford in the determination of the rotation curves of spiral galaxies. It was Ford, not Rubin, who was responsible for the vast improvements to photomultiplier technology and greatly upgraded spectrographs that were necessary to provide reliable results.

I have no objection to Vera Rubin receiving great praise for her role in the research (she was criminally denied a Nobel Prize!), but I find it objectionable that most of the articles I have read about the new observatory tend to write off Ford's many crucial contributions to the project. Should this continue, Kent Ford's ingenious work could be largely forgotten.

William D. Fusfield
Pittsburgh, Pennsylvania

Govert Schilling replies: *Kent Ford, who passed away in 2023, was indeed important — that's why he is the main character in one of the chapters of my dark matter book,* The Elephant in the Universe. *Unfortunately, the critical contributions of American and Dutch radio astronomers to the rotation-curve measurements have also largely been forgotten — they provided crucial data for many more galaxies, well beyond their visible disks.*

JWST's Little Red Dots

I read "Distant Lights in the Darkness" by Fabio Pacucci (*S&T:* May 2024, p. 20) about recent discoveries made by the James Webb Space Telescope (JWST) with great interest. Discovering so many "little red dots" at such great distances is indeed intriguing. My question is if JWST's images are in false color, what characteristic of these newly found objects leads to them to being colored red in the visible spectrum?

Marc Pfeiffer
Washington, DC

Camille M. Carlisle replies: *The scientists are talking about infrared "colors" here. Astronomers refer to sources' colors even when discussing wavelengths outside the visible band. A "color" is the difference in magnitude measured between two different filters in the electromagnetic spectrum. When they say these sources are red, they mean that the emission at longer (redder) wavelengths is stronger than the emission at shorter (bluer) wavelengths.*

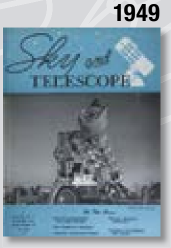
FOR THE RECORD

• On page 55 of "Great Balls of Fire" (*S&T:* July 2024, p. 55), NGC 6207 was cropped out of the image of M13. The much-fainter galaxy above M13 that remains is IC 4617.

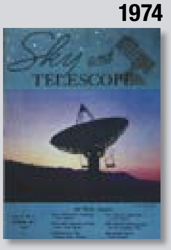
SUBMISSIONS: Write to *Sky & Telescope*, 1374 Massachusetts Ave., 4th Floor, Cambridge, MA 02138, USA, or email: letters@skyandtelescope.org. Please limit your comments to 250 words; letters may be edited for brevity and clarity.

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

1949



1974



1999

October 1949

Stars' Lives "[We] know very little about the evolution of the stars, because we observe only an infinitesimal fraction of a star's life span. It is as though we were expected to reconstruct the entire evolution of man after having been given a glimpse of a child during one second! But we are helped by the fact that in all probability there are now in our galaxy some stars which are billions of years old, while others may only have existed a few million years. Similarly, our hypothetical observer would be greatly enlightened if during his one-second survey of humanity he could see not only one child, but a large number of persons of different ages."

Sixth in a family tree of prominent astronomers from Germany and Russia, Otto Struve wrote an article for this magazine every month from 1949 until his death in 1963. He had been director successively of Yerkes and McDonald Observatories, Leuschner Observatory, and the National Radio Astronomy Observatory.

October 1974

Solar Flares "How narrowly beamed, if at all, are the bursts of radio noise emitted by the sun? One way to tell would be by simultaneous observations of the same flare from Earth and from a deep-space probe. . . . French radio astronomers C. Caroubalos and J. L. Steinberg used antennas located at Nançay, France, and aboard the Soviet spaceships Mars 3 in 1971–72 and Mars 7 in 1973.

"Observations of Type I bursts made at 169-megahertz frequency show that their radiation is strongly directional, sometimes being confined to a cone of 25-degree aperture angle. These radio events last a few seconds. The situation is more complicated for the slower bursts known as Type III. They can [span] earth-sun-spaceship angles as large as 80 degrees."

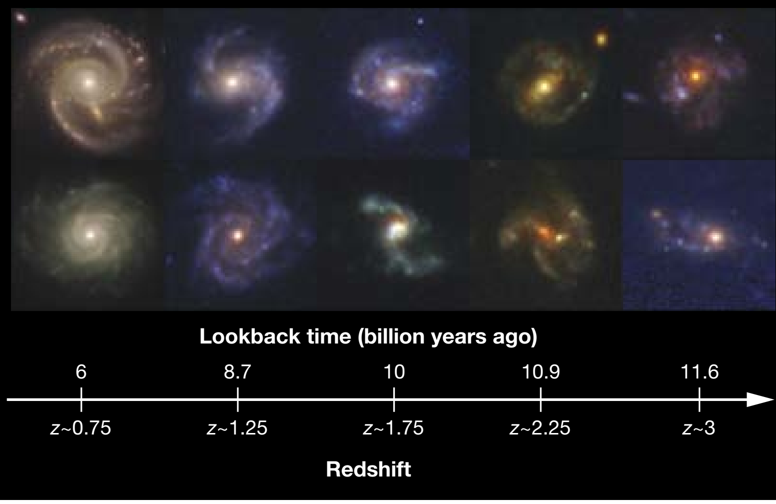
October 1999

Moon's Tail "Last November, while observing upper-atmospheric waves in western Texas, Steven M. Smith kept seeing a bright smudge in the images from his all-sky CCD system. At first he thought dew on the camera lens was to blame. But he and three Boston University colleagues later realized that they had serendipitously discovered a cometlike tail of sodium atoms blasted off the Moon during the Leonid meteor shower.

"Astronomers have known since the Apollo era that our Moon has a very tenuous atmosphere created by the micrometeoroids that continuously rain onto the lunar surface. . . . As team member Jody K. Wilson explains, last November's Leonid meteor shower caused a brief but dramatic increase in the amount of escaping sodium vapor, which was pushed away from the Moon and into a tail at least 500,000 kilometers long by the radiation pressure of sunlight."

COSMOLOGY

Spiral Galaxies Common in Early Universe



▲ As far back as the researchers could clearly see face-on galaxies in James Webb Space Telescope observations, a fraction of galaxies showed spiral patterns.

VICKI KUHN

IN A NEW STUDY of James Webb Space Telescope (JWST) observations, astronomers have found galaxies forming spirals earlier than expected.

Astronomers thought spiral galaxies emerged onto the cosmic scene about 6 or 7 billion years ago, because galactic gas had to settle down to create such patterns. But in a study published in the June 20th *Astrophysical Journal Letters*, astronomers examined JWST images of 873 galaxies near and far, calculating the fraction of spiral to non-spiral galaxies — and these data reveal more ancient origins.

"JWST has found four times more spirals than the Hubble [Space Telescope] did, at a time when the universe was only about 3 billion years old," says Vicki Kuhn (University of Missouri), who presented the team's findings at a press conference during the 244th meeting of the American Astronomical Society. Furthermore, the team found that even in the young universe, spirals still made up a third of all galaxies.

After selecting galaxies, the team inspected each one by eye. To classify a galaxy as spiral, multiple inspectors had to agree that spiral patterns were present. Going off of those classifications, the observed fraction of observed spiral galaxies appears to decrease from 48% to 8% as the team probes further back in time.

But some of the fainter spiral arms may have escaped detection. To take observational limitations into account, the team also determined the *intrinsic* spiral fraction. Taking a sample of closer galaxies, the team artificially altered them so that they would appear to be more distant, noting how spiral features disappeared. Based on how many spirals escaped detection at greater distances, the team deduced that around 35% of galaxies already had spiral arms some 12 billion years ago, when the universe was one-sixth of its current age.

The details of early galaxy formation remain unresolved, and this discovery only complicates our picture of galactic evolution. Numerous theories have been put forth on the formation mechanism of spiral arms and their link to star formation, from rippling density waves to tidal pulls from other galaxies (*S&T:* Mar. 2023, p. 14). Knowing when spiral galaxies emerged onto the cosmic frontier provides a crucial piece to this puzzle.

■ ARIELLE FROMMER

STARS

Did the Solar System Collide with an Interstellar Cloud?

MULTIPLE SAMPLES FROM Earth and the Moon show something that shouldn't be there: a radioactive isotope of iron, known as iron-60. The isotope is not produced on Earth or the Moon, and its half-life is 2.6 million years — way too short for it to be a leftover of the solar system's formative years. What's more, careful dating shows two relatively recent (and unexplained) spikes in iron-60 — one around 2.5 million years ago and possibly another around 7 million years ago.

Supernovae produce iron-60, but to explain observations, they must have exploded close enough to make the delivery, yet not so close as to cause a mass extinction. Presenting an alternative scenario, Merav Opher (Boston University) and colleagues suggested on

PLANET FORMATION

Webb Sees Evidence of Asteroid Collision Around Beta Pictoris

THE JAMES WEBB SPACE TELESCOPE (JWST) has found evidence that asteroids collided some 20 years ago around Beta Pictoris, a star 64 light-years from Earth. But that evidence rests not on what the telescope saw, but on what it didn't see.

Christine Chen (Space Telescope Science Institute) first studied the Beta Pictoris system with the Spitzer Space Telescope in 2004 and 2005. Back then, the system showed indicators in its infrared spectrum of crystalline silicates. But when Chen led a team in observing the system again in 2023, this time with JWST, those chemical fingerprints were gone. Chen presented results to the 244th meeting of the American Astronomical Society.

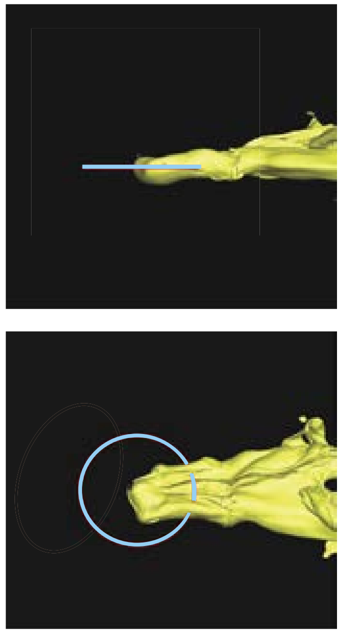
"The disappearance of the spectral features in the JWST observation is striking!" says Flavien Kiefer (LESIA-

June 10th in *Nature Astronomy* that an encounter with a cold, dusty cloud temporarily weakened a magnetic structure protecting the solar system, known as the *heliosphere*.

The heliosphere is a giant magnetic bubble around the Sun that shields Earth from interstellar particles. Due to the Sun's motion through the interstellar medium, the heliosphere has a comet-like shape, compressed in front with a tail behind. Currently, the constant flow of the solar wind pushes the closer boundary of the heliosphere out to around 120 astronomical units. (The Voyager 1 and 2 probes crossed this outer boundary of the heliosphere in 2012 and 2018, respectively.)

But if a vast, dense cloud of cold dust and gas encountered the solar system, Opher's team argues it could have collapsed the heliosphere, exposing our planet to the interstellar elements.

For the culprit, the team zeroed in on ribbon-like clouds in the Lynx constellation that appear to be moving straight away from us. Using a computer model to reproduce a collision a couple million years ago, Opher and her team show it would have squeezed the near end of the heliosphere to only about 0.22 a.u. — within Mercury's orbit around the Sun — exposing Earth to iron-60 and other particles for three-quarters of every year.



▶ Simulations show side (*top*) and "bird's-eye" (*bottom*) views of the heliosphere upon encountering the cold, dense cloud. (Earth's orbit is blue.)

"The idea is interesting and provocative," comments Brian Fields (University of Illinois, Urbana-Champaign), one of the scientists behind the supernova scenario. But we don't know the clouds' direction of motion exactly, so it's difficult to say yet whether the collision actually happened. We also don't know the clouds' full extent. While they're currently too small to have boosted iron-60 abundance for a million years at a time, they may well have been bigger in the past.

Regardless of the scenario — supernovae or interstellar clouds — Fields thinks it's a good thing to have multiple ideas to test out. "This is a healthy way for science to progress," he says.

■ **JAN HATTENBACH**

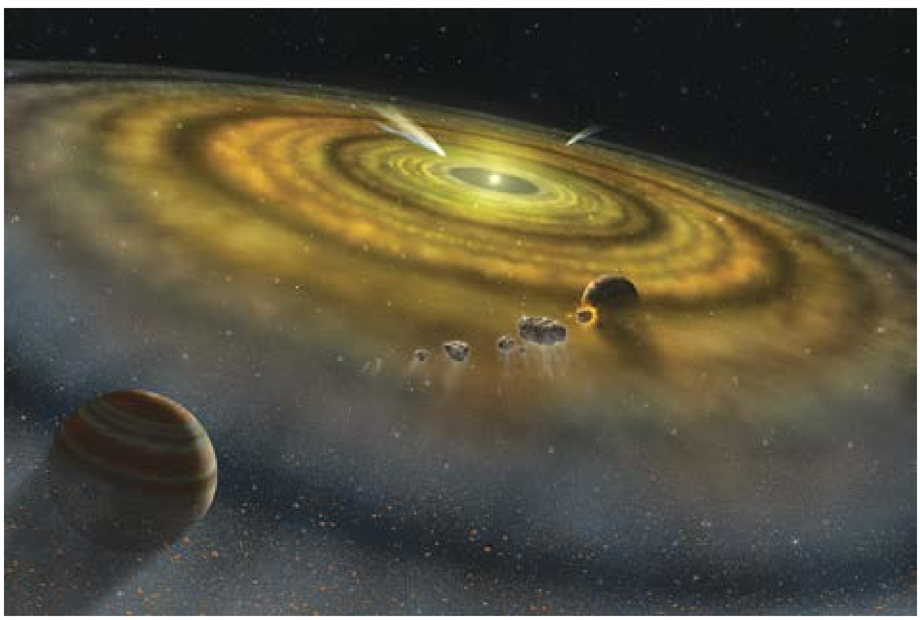
Observatory of Paris), who wasn't involved in the study. He adds that the Herschel Space Observatory saw the same features that Spitzer did in 2010 observations, meaning that they disappeared after only about a decade.

Two brighter regions of emission, centered on 18 and 23 microns, vanished between the Spitzer and Webb observations. They probably came from very small dust grains. Spectra comparisons also show that the overall level of light between 5 and 15 microns has decreased. That change probably came from hot dust released in the collision, which has also since disappeared. The young star's radiation, which exerts a force of its own, is likely responsible for blowing both the tiny grains and the hotter dust away.

The recent disappearance of the dust features suggests they were only recently created — perhaps right before the Spitzer observations. The collision likely occurred near the star, where terrestrial planets might form, pulverizing what would have been a "really large solar system asteroid," Chen says.

The collision isn't unexpected around the "teenage" system: Though Beta Pictoris has lost the gaseous disk of its infancy, it's still in the midst of tumultuous planet formation. But while astronomers thought that collisions occur continually in such systems, these data show we can witness the individual impacts that make new worlds.

■ **MONICA YOUNG**



▶ This artist's concept shows the 20 million-year-old star Beta Pictoris from the outer edge of its planet-forming disk.

SIMULATED IMAGE OF HELIOSPHERE: OPHER ET AL. / *NATURE ASTRONOMY*, 10 JUNE 2024 / CC BY 4.0; BETA PICTORIS ILLUSTRATION: NASA / FUSE / LYNETTE COOK

STARS

Astronomers Trace Star Cluster Origins

PRESSING THE COSMIC rewind button, astronomers have shown that many stellar groups in the solar neighborhood were themselves once organized into larger gatherings that have since split. The work, published June 10th in *Nature* and presented at the 244th meeting of the American Astronomical Society, paints a picture of the massive stellar nurseries that created many of the young stars within 3,000 light-years of the Sun.

Cameren Swiggum (University of Vienna, Austria) and colleagues started with the catalog compiled by the European Space Agency's Gaia mission, which provides stars' positions in space as well as their velocities. "We can take the velocity vectors that we see for each of these star clusters, and we can just flip it backwards," Swiggum explains.

By tracing the clusters' motions back in time, the team hoped to find out where they came from. And what they found is that some of the clusters' tracks converge. Swiggum and colleagues traced the motions of 272 clusters over the past 30 to 50 million years, finding that 155 of the clusters traveled from one of three origin points — huge stellar nurseries that birthed dozens of clusters each.

The results appear trustworthy, says Alice Quillen (University of Rochester), who wasn't involved in the current study. "The fact that the birthplaces in the backwards integrations were confined to small regions seems really nice and suggests their orbit integration is robust," she explains.

Large stellar nurseries also produce more massive stars, whose evolution plays out fast and furious. The team estimates that 200 stars born inside the clusters have since exploded in supernovae. The energy these supernovae pumped into the galaxy might have carved out some of the dust-bounded shells that astronomers have observed nearby. For example, Swiggum says, supernovae in Collinder 135 and its natal family of star clusters might be responsible for clearing out the 3,000-light-year-long galactic supershell known as GSH 238+00+09, first identified in the 1990s.

▲ The Collinder 135 star cluster

■ MONICA YOUNG

See visualizations at https://is.gd/Cr135.

RADIO

Short-lived, But a Start: Radio Astronomy from the Moon

THE TOUCHDOWN OF Intuitive Machines' Odysseus lunar lander, the first of NASA's Commercial Lunar Payload Services Program, didn't go as planned: Coming in hot due to navigation issues, the spacecraft broke a leg and ended up tipped at an angle. Despite that setback, though, the Radio wave Observations at the Lunar Surface of the photo Electron Sheath (ROLSES) experiment aboard the lander successfully returned data from the Moon.

◀ An artist's illustration shows Odysseus as it was meant to land. The ROLSES antennas extend to either side of the spacecraft.

"All was not lost," says Jack Burns (University of Colorado, Boulder). He presented an update on the short-lived mission during a press conference at the 244th meeting of the American Astronomical Society, noting that the team even managed to collect unplanned scientific measurements while en route.

ROLSES consisted of four wire antennas connected to a radio spectrometer, all of which weighed 14 kilograms (30 pounds). The team designed it to investigate how the Moon's porous surface scatters radio waves.

The ROLSES team ended up with two opportunities to collect data. The first occurred when a glitch caused one of the 2.5-meter (8-foot) antennas to deploy midflight, when the spacecraft was still 10,000 km (6,000 miles) from the Moon. Taking advantage, the team collected 1½ hours of data with the radio spectrometer, detecting Earth's radio emissions. The unplanned deployment enabled an unexpected repetition of an experiment Carl Sagan concocted in 1993, when he asked the Galileo mission to obtain a similar observation of Earth on the way to Jupiter. ROLSES has now redone that experiment with better time resolution and higher frequencies. Studying Earth in this way provides a reference point for future lunar telescopes' detection of exoplanet signals.

ROLSES's second opportunity for data collection came after landing. The original experiment called for eight days of data collection, but the spacecraft's angle cut that time to only 20 minutes. Nevertheless, the device deployed its antennas, gathered data, and returned it to Earth.

ROLSES serves as a precursor to future, more advanced lunar radio observatories. But first, the experiment is getting a second chance: ROLSES 2 will head to the Moon on another commercial lander in 2026.

■ JAVIER BARBUZANO

BLACK HOLES

Supermassive Black Holes Can Swivel Their Jets

SUPERMASSIVE BLACK HOLES can power speedy trains of plasma that exit their host galaxies, shooting across millions of light-years into intergalactic space. A new, comprehensive study of more than a dozen galaxy groups shows that these powerful and extensive jets can swivel, completely changing their direction over surprisingly short timescales.

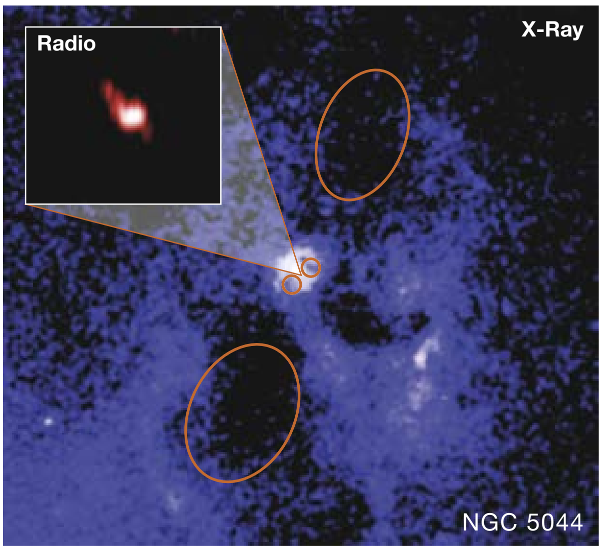
Black hole jets sweep up the hot gas around galaxies, leaving behind bubbles of largely empty space. These bubbles then "rise," their buoyancy carrying them gently away from the galaxy. They can thus serve as a record of ancient jets. Using the Chandra X-ray Observatory, Francesco Ubertosi (University of Bologna, Italy) and colleagues examined such cavities in 16 galaxy groups and clusters, comparing them against radio images of the present-day jet, from the Very Long Baseline Array in New Mexico. They published their results in the January 20th *Astrophysical Journal*.

In four of the 16 systems that the team examined, the current jet points more than 45 degrees away from the bubbles of *all* previous jets. And of all the jet-bubble pairs under investigation, about a third show such large misalignments.

The implications are huge, literally: The behemoth black holes themselves must be tilting their axes of rotation over remarkably short time periods. Black holes are known to *precess*, wobbling on their rotation axis like a top; however, precession wouldn't result in such large changes. Ubertosi and colleagues rule out projection and environmental effects, too. Instead, they suggest that there has been a change in the black holes' feeding patterns, such as the rate or direction from which gas falls into the black hole. In some cases, that adjustment must have taken place within only 1 million years.

Ubertosi's team acknowledges that the ideas they propose can't explain all of the observations — some changes are too great and occurred too quickly. But Preeti Kharb (Tata Institute of Fundamental Research, India), who has studied this phenomenon in the past, notes that determining how fast these black holes typically feed or how long such meals usually last is itself notoriously difficult. Understanding these results will take time, she says: "The answers may lie in the future."

■ MONICA YOUNG



◀ The central galaxy of the NGC 5044 cluster hosts a black hole that powers a radio-emitting jet (*inset*). X-rays reveal empty spaces (red ovals) cleared by previous jets, which pointed in other directions.

X-RAY: NASA / CXC / UNIV. OF BOLOGNA / F. UBERTOSI; RADIO INSET: NSF / NRAO / VLBA; IMAGE PROCESSING: NASA / CXC / SAO / N. WOLK

IN BRIEF

Hubble Transitions to New Observing Mode

The Hubble Space Telescope restarted science operations in a new observing mode on June 14th, after experiencing recurring issues with one of its three remaining gyroscopes. The telescope is now operating using a single gyro, which is the minimum Hubble needs to slew, point, and track objects. Although all six gyroscopes were replaced in a 2009 repair mission, three failed in the intervening years. Then a fourth gyro began acting up, relaying faulty data. Resets offered only a temporary reprieve, and it's now shut off permanently to allow for more consistent operations. Of the two good gyros left, one is being held in reserve. Meanwhile, star trackers, magnetometers, and Sun sensors are taking up the slack. The new "one-gyro" mode has a slower slew rate, so tracking objects closer than the orbit of Mars or nabbing transient events is no longer possible. Overall observing efficiency will also decrease, down from 85 orbits' worth of observations every week to 74. Nevertheless, since the transition the iconic telescope has released several new observations.

■ DAVID DICKINSON

Dwarf Star Caught Speeding

A rare *hypervelocity star* is racing through our galaxy, just 400 light-years from Earth. The discovery was possible thanks to the *Backyard Worlds: Planet 9* citizen science project, in which thousands of volunteers look for moving objects in more than 14 years' worth of data from NASA's Wide-field Infrared Survey Explorer (WISE) mission. At the recent 244th meeting of the American Astronomical Society, Adam Burgasser (University of California, San Diego) announced Backyard World's discovery of a fast-moving object (designated CWISE J124909.08+362116.0). Burgasser used the W. M. Keck Observatory in Hawai'i to obtain a near-infrared spectrum of the star, which best matched spectra of a type of low-mass star known as *L subdwarfs*. The team also used the spectrum to help measure the star's position and speed, estimated at about 450 km/s (1 million mph). "This is where the source became very interesting," Burgasser says, "as its speed and trajectory showed that it was moving fast enough to potentially escape the Milky Way."

■ COLIN STUART

Voyager 1 Update NASA announced June 13th that the Voyager 1 spacecraft is now returning data from all four of its instruments (*S&T:* Sept. 2024, p. 11). The instruments study plasma waves, magnetic fields, and particles.

Europa Clipper

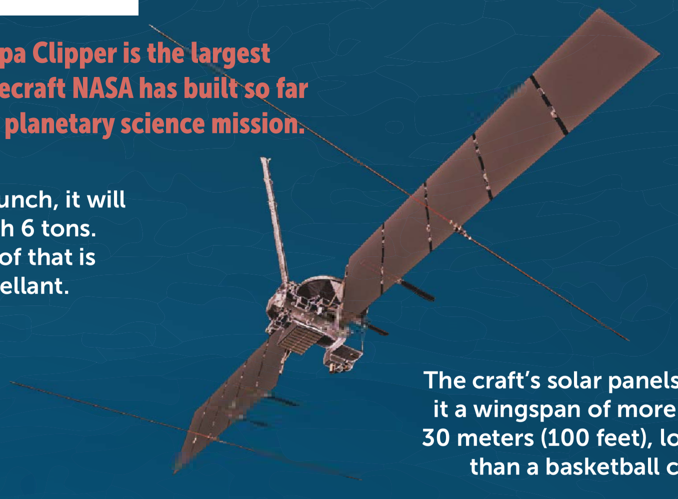
NASA's latest mission to the outer solar system is Europa Clipper, scheduled to launch in October. Clipper will visit Jupiter's moon Europa, taking remote measurements to explore the moon's subsurface ocean as well as the ocean's connection with the icy surface. The spacecraft will reach Jupiter in April 2030 and make its first Europa flyby the following year.

Why Europa? Fellow Jovian moons Ganymede and Callisto also appear to have subsurface oceans (*S&T:* Apr. 2022, p. 14). But Europa's icy shell is much thinner, and scientists have spotted hints of geyser activity. The ocean may also be in direct contact with a rocky seafloor, instead of an underlying layer of ice. Perhaps there are hydrothermal vents?

By Camille M. Carlisle, Terri Dubé & Beatriz Inglessis

THE CRAFT

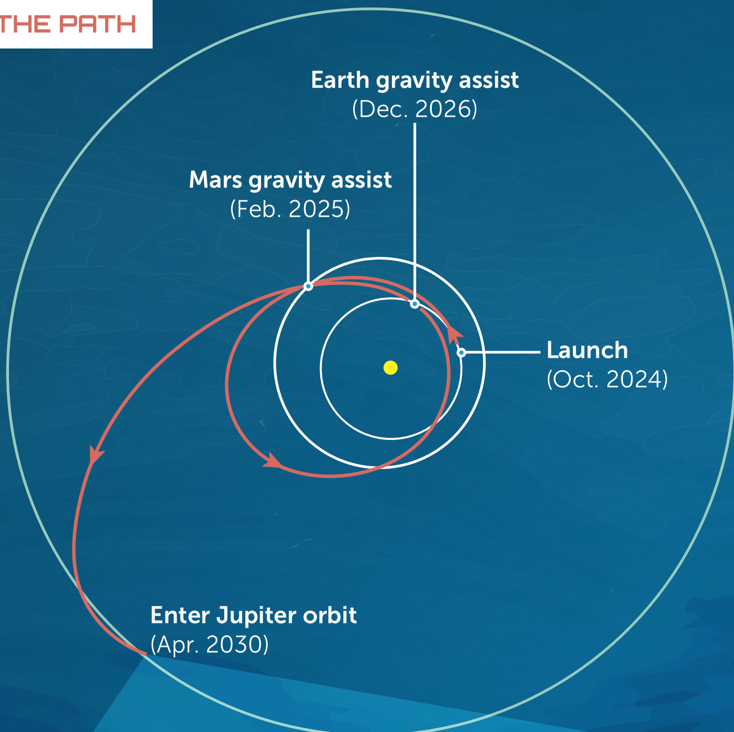
Europa Clipper is the largest spacecraft NASA has built so far for a planetary science mission.



At launch, it will weigh 6 tons. Half of that is propellant.

The craft's solar panels give it a wingspan of more than 30 meters (100 feet), longer than a basketball court.

THE PATH



THE SCIENCE

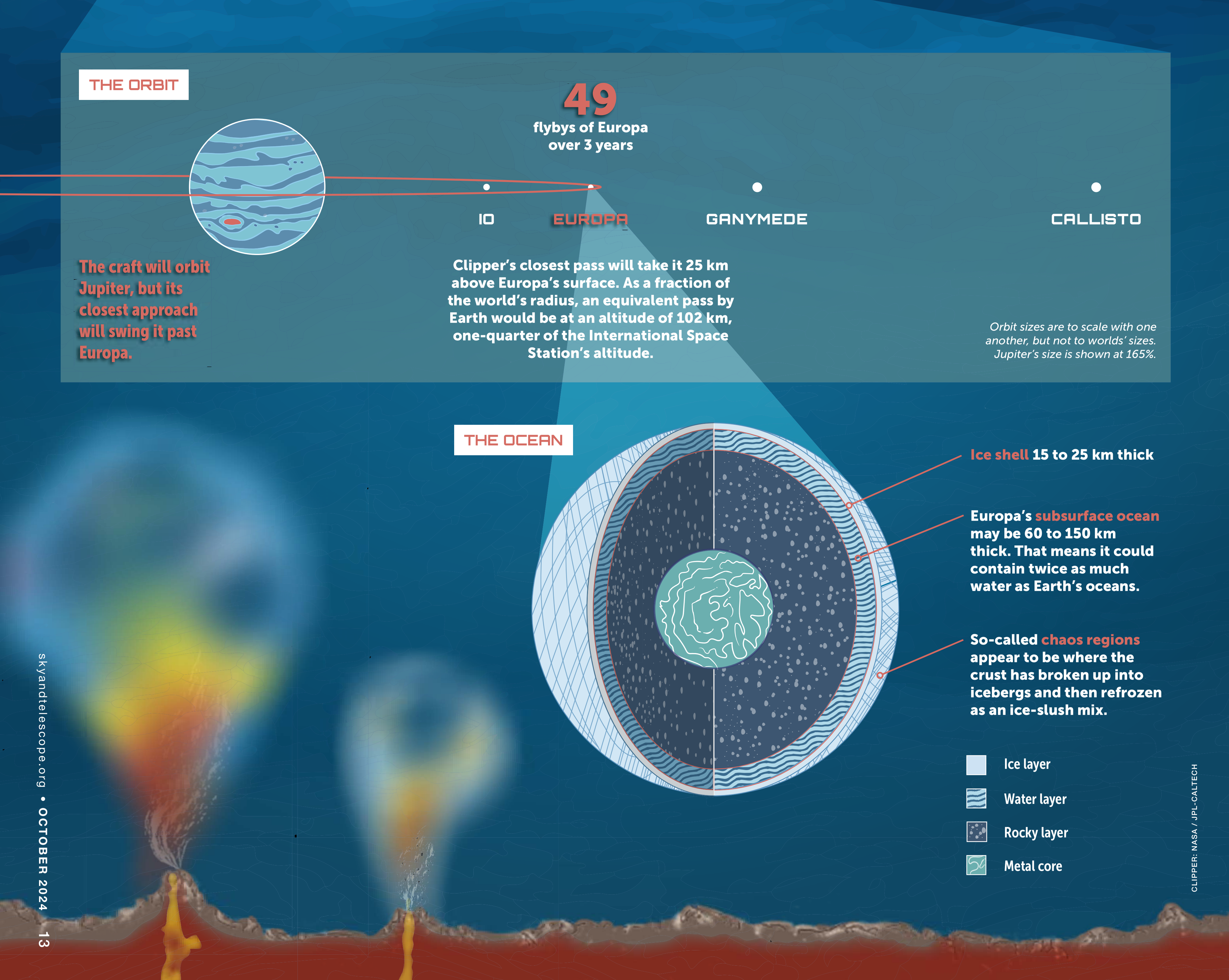
The craft will have nine science instruments, including two cameras. It will also have instruments to study the moon's magnetic environment.

SCIENCE OBJECTIVES:

Determine the icy shell's thickness and how it interacts with the ocean below

Investigate the ocean's composition and determine if it has the ingredients to sustain life

Study the surface geology and how features formed, look for recent activity (geysers?)


THE ORBIT
49
flybys of Europa over 3 years
IO
EUROPA
GANYMEDE
CALLISTO
The craft will orbit Jupiter, but its closest approach will swing it past Europa.
Clipper's closest pass will take it 25 km above Europa's surface. As a fraction of the world's radius, an equivalent pass by Earth would be at an altitude of 102 km, one-quarter of the International Space Station's altitude.
Orbit sizes are to scale with one another, but not to worlds' sizes. Jupiter's size is shown at 165%.
THE OCEAN
Ice shell 15 to 25 km thick
Europa's subsurface ocean may be 60 to 150 km thick. That means it could contain twice as much water as Earth's oceans.
So-called chaos regions appear to be where the crust has broken up into icebergs and then refrozen as an ice-slush mix.
Ice layer
Water layer
Rocky layer
Metal core
CLIPPER: NASA / JPL-CALTECH

 by Emily Lakdawalla

ASTEROID IMPACT:

ESA / SCIENCE OFFICE

HERA Artist's concept of the European Hera spacecraft with its CubeSats Milani and Juventas, exploring the Didymos-Dimorphos system

THE AFTERMATH

Scientists' attempt to change an asteroid's course succeeded. Now the Hera mission will give us an up-close look at the results.

Even a small asteroid is bigger than a city block. If it were to hit Earth, it could annihilate a city. Could we change its path in advance and avoid impact?

On November 24, 2021, NASA launched the Double Asteroid Redirection Test (DART) to find out.

To be clear, Earth was not in danger. DART was a test run — an experiment to see what would happen if we tried to move a space rock by slamming something into it.

DART rendezvoused with the binary asteroid 65803 Didymos-Dimorphos as the pair made a close approach to Earth. Although classified as a near-Earth object (NEO), the binary's orbit doesn't intersect Earth's, at least not for the foreseeable future. It is a Mars-crosser, with a perihelion just outside Earth's orbit. (It wouldn't have been wise to perform the first-ever test of shifting an asteroid's path on an actually hazardous target.)

On September 26, 2022, DART crashed into Dimorphos, the smaller member of the pair, at a speed of 6 km/s.

"That actually was a huge accomplishment," says DART coordination lead Nancy Chabot (Johns Hopkins University Applied Physics Laboratory). One of the mission's goals was "demonstrating the technology of how you could target a small asteroid, that you've never seen before, in space, at high speed, and impact it with a kinetic impactor."

The collision created a cloud of debris visible from Earth — and much celebration. But punching a space rock isn't ultimately what excites scientists about this project. They want to know exactly what kind of effect the hit had on Dimorphos and its orbit around Didymos. "How well does this technique work for planetary defense, if you did have the need to deflect an asteroid?" Chabot asks.

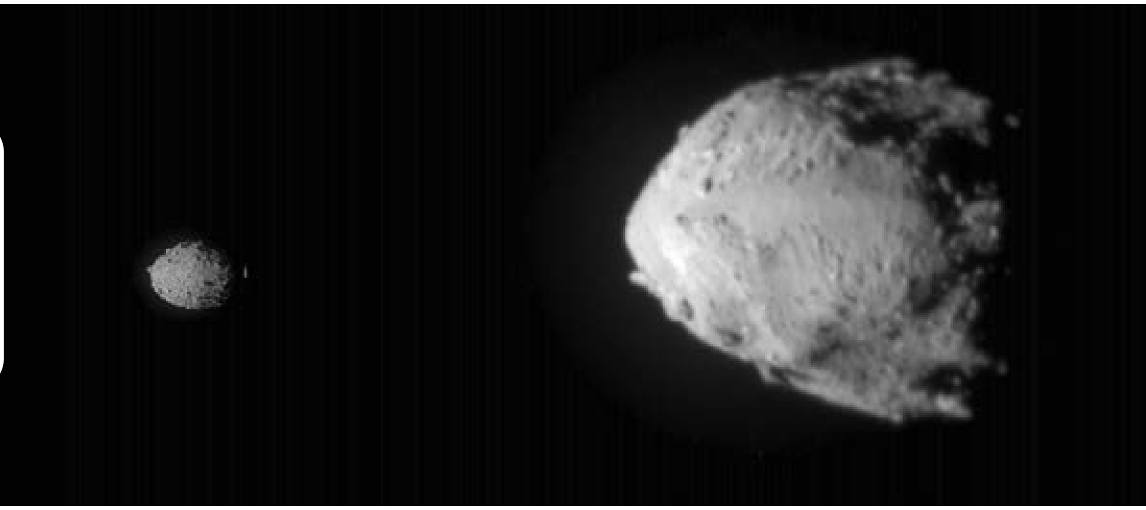
To have any hope of applying the result of DART's test to asteroids that actually pose a threat, geophysicists need to understand how the crash transformed Dimorphos's shape and orbit. Earth-based observations have given some information, but soon scientists will see the damage up close: The European Space Agency's Hera mission launches in October to examine the aftermath four years post-impact.

Get It Before It Gets Us

So far, our searches have yielded not a single asteroid that poses a deadly impact risk. But planetary scientists estimate

▼ **ASTEROID PAIR** This composite image shows the asteroids Dimorphos (left) and Didymos (right), oriented with their north poles up and with each asteroid and the distance between them to scale. The views of Didymos and Dimorphos are both mosaics of DRACO images from the DART spacecraft. The pole-to-pole height of Dimorphos is roughly 115 meters, and that of Didymos is roughly 600 meters.

NASA / JOHNS HOPKINS APL



NEARLY NOSE TO NOSE
The Didymos-Dimorphos pair form quite a close binary: Only one Didymos would fit in the space that separates it from Dimorphos.

that there are thousands of asteroids out there that we haven't discovered yet, and what we don't know could hurt us.

Back in 2005, recognizing the need for asteroid discovery, Congress directed NASA to "detect, track, catalogue, and characterize the physical characteristics of near-Earth objects equal to or greater than 140 meters in diameter." The act set a goal of achieving 90% completion of the survey within 15 years.

An asteroid 140 meters (460 feet) in diameter could dig a crater a couple kilometers across, large enough to devastate a city. While a direct hit to a city is unlikely, an ocean impact could cause a tsunami that would devastate many coastal cities.

25,000
Estimated number of near-Earth asteroids larger than 140 meters across

44%
Fraction of these asteroids we've discovered so far

Scientists estimate that there are about 25,000 larger-than-140-meter NEOs out there. To date, we've only found 44% of them. NEOs in orbits interior to Earth's are especially difficult to spot, because they hide in the Sun's glare.

To prevent an impact, we need to do two things: find a dangerous asteroid, and move (or remove) it from its path. The two basic ideas are disruption and deflection.

Disruption — that is, blowing it up — would require the launch of nuclear bombs into space. Testing such a strategy would be politically controversial, to put it mildly. Disruption's effects are also difficult to predict: Will a bomb actually destroy the threat, or just spread out the damage in a scattershot of smaller falls?

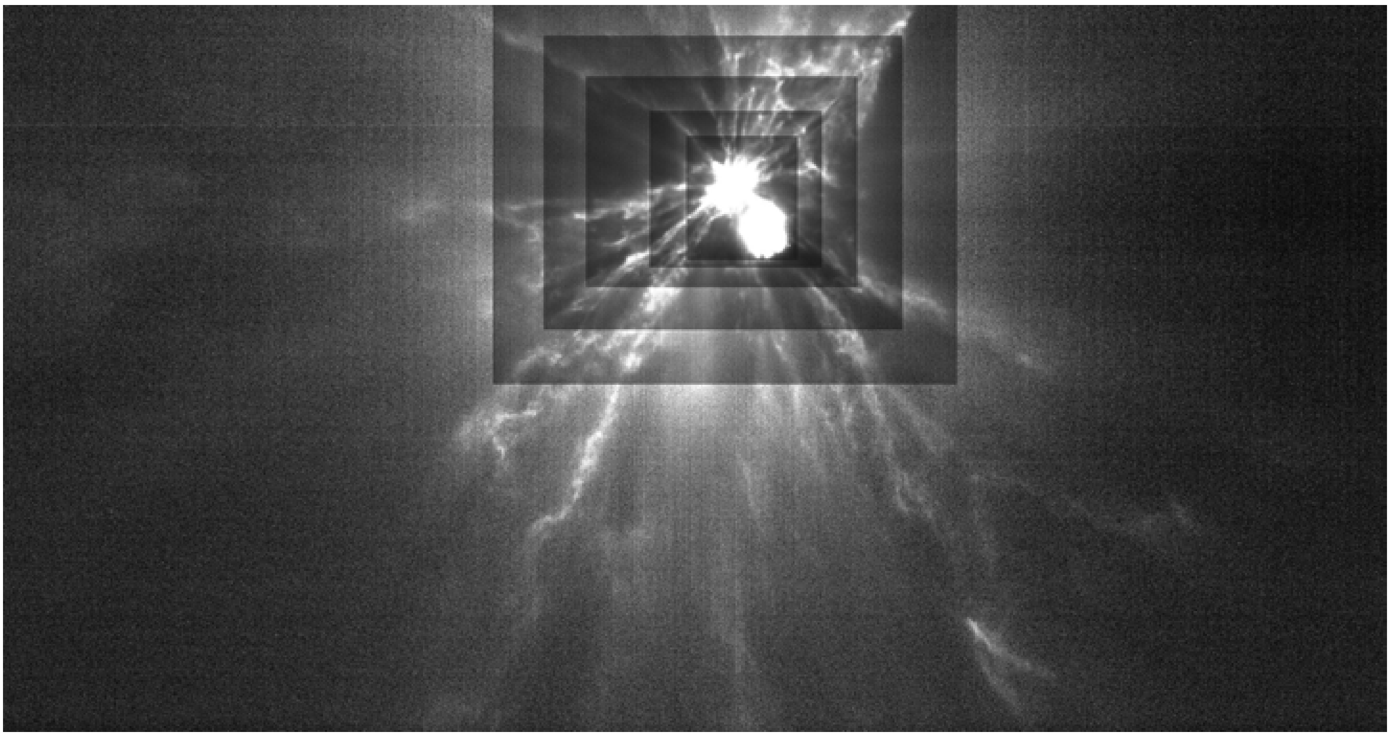
Deflection is the safer strategy, but it requires years' worth of advance warning of a potential impact. A tiny change now in an asteroid's orbital speed could alter when it crosses Earth's path years later by many minutes. Earth travels in its orbit at about 100,000 kilometers per hour (more than 60,000 miles per hour), or one Earth diameter every 7 minutes. So 7 minutes' difference in the length of an asteroid's year is all we need.

Tilting at Windmills

DART and Hera originated in the early 2000s as an ESA mission study concept named Don Quijote. In the proposal, two spacecraft would rendezvous with an asteroid; one would crash into it, while the other would watch the aftermath and measure the effects. Don Quijote went unfunded, however, because two spacecraft were deemed too costly.

Then, in April 2009, attendees at an international planetary-defense conference in Granada, Spain, sounded the alarm about the lack of funding for testing methods to deflect a potentially hazardous asteroid. Chabot was present, along with Applied Physics Laboratory (APL) colleagues Andy Cheng and Andy Rivkin.

Afterward, Rivkin says, "Andy Cheng realized that you could do [a deflection test] with just one spacecraft, if you did it in a binary system and changed the orbit of an asteroid moon around the asteroid." The change in orbital period of the satellite would be detectable with Earth-based telescopes — no second spacecraft required.



ASI / NASA / APL

▲ **SPLAT** This LICIACube image reveals plumes of ejecta streaming from Dimorphos after impact. Each rectangle represents a different level of contrast, revealing fine structure in the plumes.

IMPACT DRAMA Astronomers used the 4.1-meter Southern Astrophysical Research Telescope in Chile to catch this view of the dust and debris two days after impact. At this time, the tail stretched more than 10,000 km long — about three-quarters of Earth's diameter.

CTIO / NOIRLAB / SOAR / NSF / AURA / T. KARETA (LOWELL OBSERVATORY), M. KNIGHT (U.S. NAVAL ACADEMY), IMAGE PROCESSING: T. A. RECTOR (UNIVERSITY OF ALASKA ANCHORAGE / NSF'S NOIRLAB), M. ZAMANI & D. DE MARTIN (NSF'S NOIRLAB)

Cheng's idea received community support at subsequent conferences, and NASA's Planetary Defense Coordination Office funded its development in 2017.

Meanwhile, in 2012, Cheng and Patrick Michel (Cote d'Azur Observatory, France) launched a collaborative study between APL and ESA called the Asteroid Impact and Deflection Assessment (AIDA). AIDA substantially reproduced the Don Quijote concept with two fully independent missions. One was NASA's DART. The other was the Asteroid Impact Mission (AIM), an ESA orbiter that would reach Didymos before DART and be in place to watch the impact.

DART proceeded toward launch, but ESA turned AIM down in 2016. A slimmed-down version of AIM, named Hera, was finally approved in 2019. As with DART, Hera's funding rationale was based on ESA's planetary-defense priorities, not scientific exploration goals.

The long road to funding meant that Hera would not launch until October 2024 and would arrive four years after DART. It was frustrating to miss the big event, but "not too much happens in four years in space," says Hera science team member Julia de León (Canaries Institute of Astrophysics, Spain). "There's not enough time for space-weathering effects to alter or cover the crater."

The Perfect Target

DART targeted the Didymos-Dimorphos pair from the mission's inception. The binary members were just the right size, with the right kind of orbit, and would be in the right place at the right time.

Previous radar imaging from the Arecibo radio observatory indicated that the diameters of the two bodies were about 780 and 160 meters. At 160 m, the moon Dimorphos was small enough that a spacecraft hit should change its orbit, yet large enough to represent the class of asteroid that poses the greatest impact risk, because astronomers predict that almost half of the objects in this size range remain undiscovered.

The Didymos-Dimorphos pair also presented the perfect target for Earth-based observers. The pair is an eclipsing binary: The asteroids cast shadows on each other and occasionally even cross each other as seen from Earth's point of view. Ground-based telescopes can time these *mutual events* from the telltale dips they produce in the binary's light curve.

Even the location was good: Didymos's close approach to Earth in late September and early October 2022 occurred under optimal observing conditions. Didymos was nearly at opposition, well lit and observable all night long, and a new Moon one day before impact provided dark skies for the main event.

For six years leading up to launch, astronomers around the world measured the binary's light curve. By launch day, they knew Dimorphos's orbital period with exquisite precision: 11 hours, 55 minutes, 17.86332 ± 0.01116 seconds. DART would have to change this orbital period by 73 seconds in order for the change to be detectable from Earth using one month's worth of post-impact observations. "At least 73 seconds" became DART's definition of success.

DART Start

But scientists were loath to settle for a distant view and, with only one spacecraft, DART wouldn't be able to observe its own impact. The Italian Space Agency stepped in, contributing the Light Italian CubeSat for Imaging of Asteroids (LICIACube). DART released LICIACube 15 days before impact, on a course that would give it a ringside seat to the event.

DART itself snapped images rapidly as it bore down on the binary. The images showed ovoid worlds with boulder-strewn surfaces, and Didymos had a lumpy outline thanks to large impact craters on its surface. Both were somewhat smaller than predicted from the Arecibo imaging.

All the observational astronomy work permitted DART's navigators to set up the geometry of the impact with the best possible conditions. The autonomous navigation performed admirably, tracking brighter Didymos at first and then successfully switching to target Dimorphos when it could reliably separate the two. DART crashed almost head-on into Dimorphos, as hoped, with an impact angle only 17° away from vertical.

LICIACube's cameras watched the event unfold, the little craft snapping 426 images in 5 minutes as it passed within 58 km of the pair. The CubeSat remained in contact with Earth for another month, downlinking its data, before communication was lost.

LICIACube images revealed a dramatic splat of ejecta thrown off in a wide cone, with streamers of material curving through space. Dozens of meter-sized boulders were clearly visible, speeding away from the impact site. "There was a ton of ejecta," Chabot said, a sight that the team greeted with "relief and joy."

Fireworks Show

Earth-based telescopes that watched the system at the moment of impact immediately saw a plume of dusty material, moving at kilometer-per-second speeds. The plume scattered sunlight, dramatically brightening the Didymos system as seen from Earth.

Ejected material lingered in the Didymos system for at least 24 days, enveloping it in a comet-like coma. The ejecta either re-impacted Dimorphos, hit Didymos, or left the system entirely. Solar radiation pressure pushed on the escaping material, spreading it out into a tail. This pressure affects smaller particles more than larger ones, so the tail was size-sorted, with fine dust traveling farthest and larger, meter-size rocks staying close to the main bodies. Eventually, the tail stretched more than 70,000 km behind the binary.

Astronomers estimate that more than 10 million kilograms (10,000 tons) of material escaped into the tail. It's a small fraction of Dimorphos's 4 billion kilograms but impressive, given that at impact DART weighed 0.006% as much as the ejecta.

DART's effects will be long-lasting. In a century, scientists predict, some of the tail dust may become meteors on Mars. In a millennium, some may create falling stars on Earth.

How Much Did It Move?

Worldwide, 28 telescopes contributed more than 38,000 exposures and 224 light curves from July 2022 through February 2023, when Didymos became too faint for quality observations.

Only 12 hours after impact, the great Goldstone radio telescope in California confirmed the deflection attempt was a success, finding that the orbital period of Dimorphos had shortened by half an hour.

Radar observations continued through Didymos's closest approach to Earth in early October and confirmed that the orbital period had decreased by a whopping 33 minutes, plus or minus a minute — much longer than the mission requirement of 73 seconds. This change corresponds to a tightening of Dimorphos's orbit of more than 30 meters.

Over the subsequent months, observations indicated that, weeks after impact, the orbital period had shortened by an additional 20 to 30 seconds.

Meanwhile, the binary's brightness decreased for eight days post-impact, but then that dimming paused. At the same time, astronomers noticed the development of a secondary tail. One possible explanation is a second impact, like an earthquake aftershock: a large ejecta fragment crashed into Didymos or Dimorphos.

It's tempting to link the two oddities: Maybe the orbital period shrank in two discrete steps, one caused by the DART impact and the other by an "aftershock" impact eight days later. But the data can't tell us if that's the case, or if the period change was a more continuous process.

NASA / ESA / STSCI / JIAN-YANG LI (PSI), IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI)

GROWING TAILS These Hubble images capture how the impact debris evolved over time. The ejecta initially formed a cone shape that then transformed into a larger coma cocooning the binary. Meanwhile, sunlight swept the debris back into a comet-like tail, which briefly split in two as shown here.

Momentum Conundrum

The impact was clearly successful at moving Dimorphos. To generalize to other asteroids, though, mission scientists need to determine a value called the *momentum enhancement factor*, referred to as *beta* (β) for short. We know DART's mass and velocity at the time of impact, so we know how much momentum it contributed.

If Dimorphos's momentum had changed by exactly as much as DART carried, beta would equal 1, and Dimorphos's period would have changed by 7 minutes.

That's not what happened. The fountains of ejecta and dramatic slowing indicate that DART achieved beta much greater than 1, which is very good news for planetary defense.

Unfortunately, it's hard to pin down how much greater than 1 the momentum enhancement factor is. The mission team's best estimate — based on a detailed, three-page mathematical description of how to calculate beta — is that little DART punched with the weight of a spacecraft 2.4 to 4.9 times its mass.

If we ever do need to change the path of a hazardous asteroid, we'll need to know this number with more precision. That factor-of-two uncertainty translates into a similar amount of uncertainty about how large (or fast, or close) an asteroid we could deflect, and it could affect the choice between deflection and a much riskier attempt at disruption.

To determine beta more precisely, we'll need to know Dimorphos's mass. Current data don't tell us the precise mass, because Didymos contains 99% of the combined system mass, and the uncertainty in the measurement is larger than Dimorphos's contribution, whatever it is.

Post-impact observations also strongly suggest that we know even less about Dimorphos's size and shape now than we did right after impact, because the moon's shape has changed.

▲ **GOING DOWN** This is the last complete image taken of Dimorphos by DART, about two seconds before impact. The image shows a patch of surface 31 meters wide.

Dimorphos Metamorphosis

Dimorphos's orbit is not quite circular. When an orbit is oblong, it *precesses*: The long axis of the orbit's ellipse slowly rotates around the object that it's orbiting. The dominant factor controlling the precession rate is the influence that the two bodies' shapes have on their gravitational pulls on each other.

A sphere orbiting a sphere in a circular orbit won't precess. An ellipsoid orbiting an ellipsoid on an elliptical orbit will.

Astronomers found that, following the DART impact, Dimorphos's orbit was precessing quite a lot, much faster than it had before: 6.7° per day. One or both bodies must have changed shape — and it wasn't Didymos.

DART hit an oblate body that was almost uniformly wide at the equator, about 175 meters, but squashed pole-to-pole to about 115 meters. Think of an exercise ball you've sat directly on top of, and you'll have the right idea. That shape is expected, because rotation induces flattening. (Earth is also a little squashed, thanks to its spin.)

NASA / JOHNS HOPKINS APL

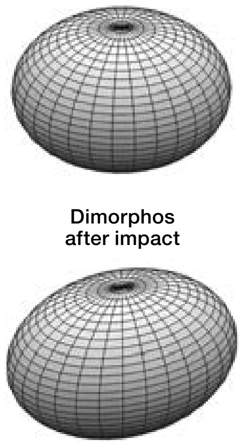
For its orbit to precess as quickly as it does today, Dimorphos must now be shaped more like a flattened rugby ball than a flattened sphere. Pole-to-pole, it's the same diameter as before. But it's stretched and squashed around its equator, 190 meters long and only 150 meters wide, according to recent work by Shantanu Naidu (NASA's Jet Propulsion Laboratory) and others.

How could a golf-cart-size spacecraft's crash into a stadium-size world have such a big effect? The answer, in short, is that Dimorphos isn't one body — it's a multitude of boulders and grains barely held together by gravity.

Every world has a shape that is a balance between two forces: gravity and strength. Liquids and gases flow to fill in gravitational lows, so liquid and gaseous worlds are spherical, except for the flattening induced by their rotation.

If the force of gravity is strong enough — that is, if a world is massive enough — solid ice and rock will also flow (albeit slowly), filling in gravitational lows to make a world spherical. No matter its composition, a world shaped into a sphere by gravity is said to be in *hydrostatic equilibrium*.

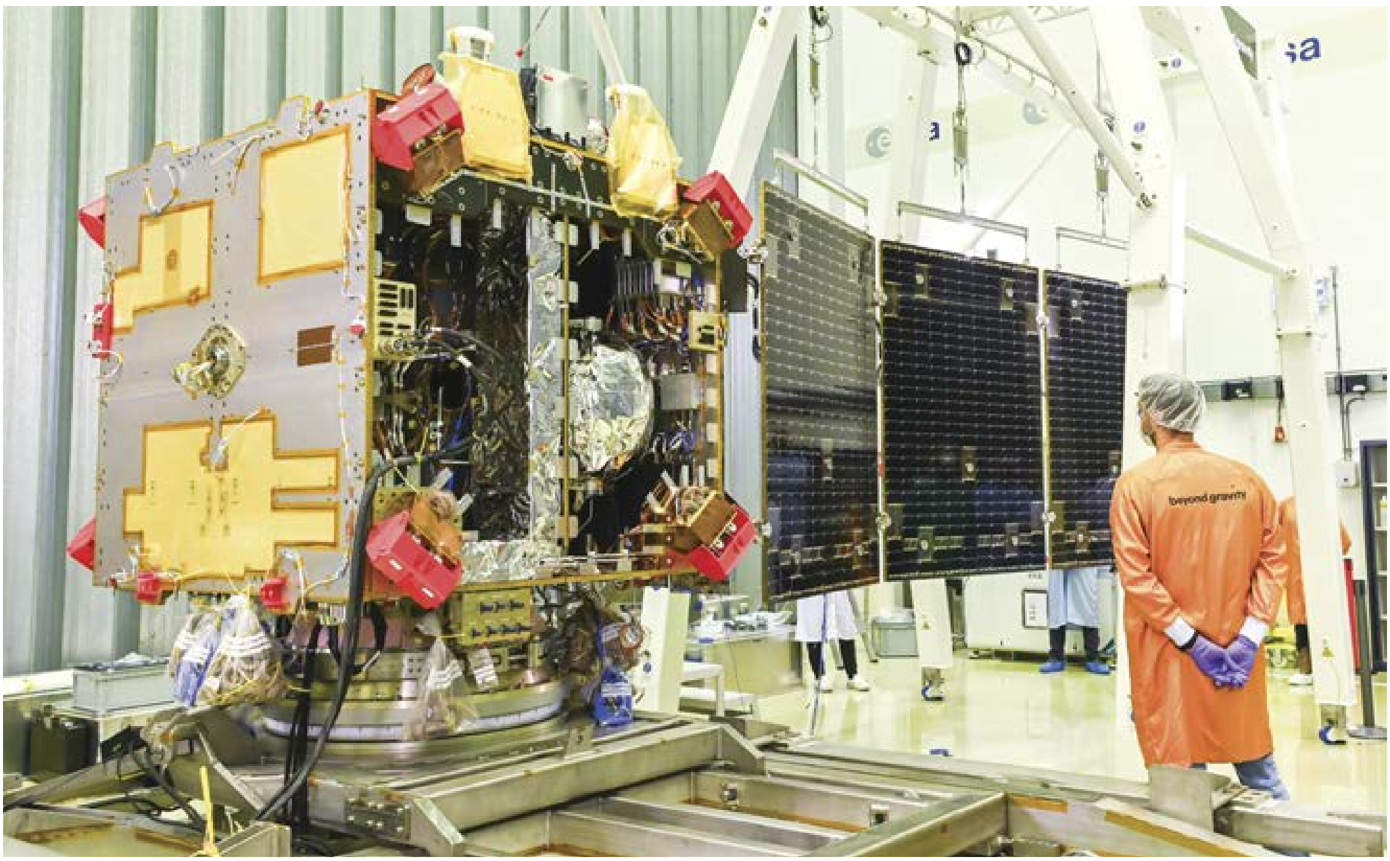
Ice has some strength; rock is stronger; metal is stronger yet. Small bodies can be significantly nonspherical, because their strong materials hold up against their weak gravity.



This is true even for rubble piles like Dimorphos. This asteroid and its NEO brethren appear to originate from collisions within the main belt of asteroids between Mars and Jupiter. There, occasional smashups shatter larger worlds into countless smaller pieces. Gravity can reassemble these smaller pieces into agglomerations of rubble, but worlds of Dimorphos's size have too little mass for the pieces to be pressed together with the force necessary to make a uniformly round object.

Instead, they wind up in a regime balanced between strength and gravity. Individually, their ingredients are strong, their boulders holding fast to their potato shapes against gravity. But like a liquid, the assemblage of boulders has no cohesion at all. Thus gravity molded spinning Dimorphos into the squashed-sphere shape you'd expect for a body in hydrostatic equilibrium, and when DART hit it, the asteroid splashed like water.

If Dimorphos had had any internal strength, the DART crater would have been perhaps 10 meters across. But based on the ejecta spray in LICIACube's images, the crater must



▲ **HERA STRETCHES A WING** Team members inspect the Hera spacecraft with one of its two solar-panel wings attached. The panels are supported here by a frame because they're designed to operate in zero gravity.

DIMORPHOS BEFORE AND AFTER: NASA / JPL-CALTECH; HERA: ESA-SJM PHOTOGRAPHY

–1 MIN 13 SEC
Minimum change detectable in Dimorphos's orbital period from Earth

–7 MIN
Change predicted if DART simply transferred its momentum to Dimorphos on impact

–33 MIN 15 SEC
Actual change in Dimorphos's orbital period

POW LICIACube captured this image a few minutes after DART slammed into Dimorphos.

have been so big that the initial cavity reached nearly to the asteroid's center.

The impact disturbed half of Dimorphos and completely changed its shape. Its shape is likely still changing. It's excruciating not to see all this change happening.

Hera: Better Late than Never

Hera's launch window opens October 7th. After a two-year cruise, the craft will reach Didymos and Dimorphos in late December 2026.

Once Hera arrives, it will conduct a reconnaissance mission familiar to fans of ESA's Rosetta mission to Comet 67P/Churyumov-Gerasimenko (*S&T:* May 2017, p. 14). Ground controllers will operate Hera at an initial standoff distance of 20 to 30 km, until they gain confidence in moving through the gravitationally complex system. The spacecraft will deploy two CubeSats into independent orbital missions and then descend closer.

Hera's most important work will be to measure the mass of Dimorphos. The team also hopes to measure the surface and internal properties and map the aftereffects of the impact on both bodies, especially the size and shape of the impact crater that DART left. That is, if there even is a visible crater — moving rubble may have erased it as the asteroid settled. "Fingers crossed," de León says.

Hera's payload includes a variety of survey instruments. The Asteroid Framing Cameras (AFCs), a pair of monochrome cameras based on the one that flew to Vesta and Ceres on the Dawn spacecraft (*S&T:* Dec. 2016, p. 16), will enable optical navigation before arrival and mapping afterward. They will track the tiny wobbles that the two bodies induce in each other's spins, permitting the all-important measure of the asteroids' individual masses.

Another imager, this one an off-the-shelf commercial instrument called HyperScout H, will take multispectral visible and near-infrared color images. De León heads HyperScout H as principal investigator.

Joining these will be the Planetary Altimeter (PALT). PALT will map the surface with laser ranging to an accuracy of 0.5 meter. Combining camera and laser data will yield exceedingly detailed models of the asteroids' shapes and, hence, their volumes.

Rounding out Hera's payload, a thermal infrared imager (TIRI) provided by Japan will map the asteroids' surfaces and also examine how the granular bodies heat and cool. That information is key to predicting an asteroid's orbital evolution around the Sun, because absorbing and reradiating solar heat can change small asteroids' orbits over time.

Hera's two CubeSats will support the surveying effort, each serving a different purpose. The satellite Milani carries a 4-channel multispectral imager for compositional mapping. The other, Juventas, has a gravimeter and low-frequency radar instrument. Juventas will map the complex gravity field around the two bodies and probe the interior of Dimorphos, enabling scientists to measure the asteroid's mass and interior structure in a way that's complementary to the method Hera will use.

The Hard Part

Hera's precision measurements will enable mission designers to translate DART's test into guidance for future missions. It will document the effect DART had on Dimorphos, which probably excavated the asteroid to its very core. It seems we have the power to reshape worlds, albeit small ones.

But to quote Stan Lee: With great power comes great responsibility.

An asteroid impact is most likely to happen in the oceans that cover two-thirds of the globe. Forty percent of Earth's population lives in coastal areas. Most countries do not have indigenous space programs and will rely on those with launch capability to mitigate the threat.

Who gets to decide how to respond? What if one country's response to the threat reduces that country's risk but increases the risk to others? How do we communicate a potential threat to the world without causing panic? And if an asteroid is unstoppable, how will we work together to move people out of harm's way?

It's happy news that the Double Asteroid Redirection Test succeeded. We now know we can move an asteroid.

Let's hope we never have to.

■ Contributing Editor **EMILY LAKDAWALLA** is a planetary geologist, science writer, and space artist. Find her work at **lakdawalla.com/emily**.

ASI / NASA

TOUR OF THE GIRAFFE by Ken Hewitt-White

Glitter and a Ghost

ALAN DYER

Celestial treasures bright and dim highlight a region in western Camelopardalis.

As constellations go, Camelopardalis is a dud. First off, it's not a camel — it's a giraffe. The astro-ungulate is relatively large yet presents no recognizable outline, its broad panorama mustering a grand total of three Bayer stars: 4.3-magnitude Alpha (α), 4.0-magnitude Beta (β), and 4.6-magnitude Gamma (γ). I have never bothered to look for them.

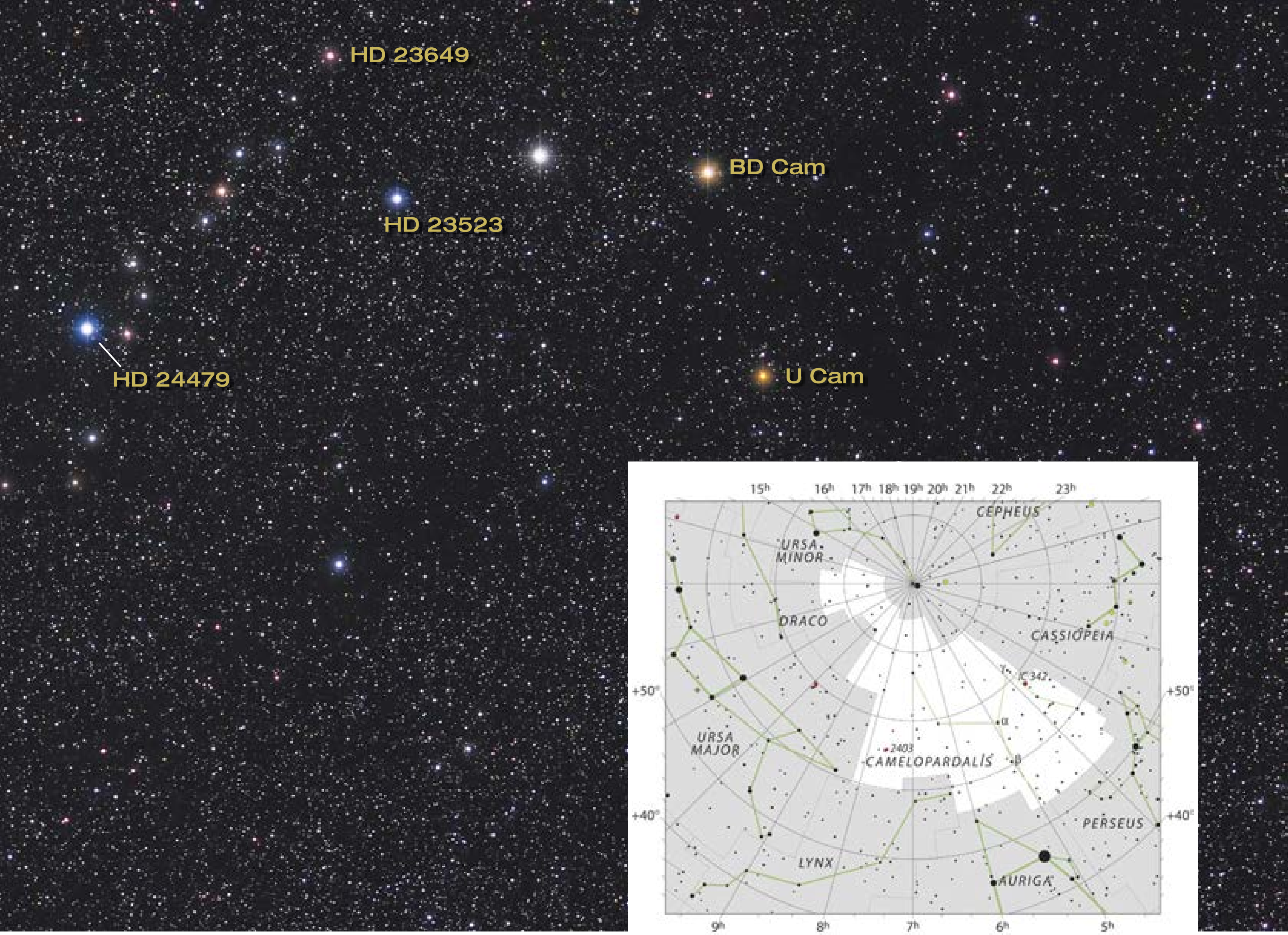
On the plus side, Camelopardalis is circumpolar for all of Canada and much of the United States. Numerous deep-sky objects are scattered across its vast, four-season expanse. A few years ago, my longtime observing colleague, Vancouver amateur Lee Johnson, suggested we explore the extreme western part of the constellation. There, he said, a narrow strip centered on right ascension 4 hours and stretching from declination +61° to +68° houses several interesting targets. This slender portion of the Giraffe (not its famously long neck but, alas, its rear end!) climbs high on October evenings.

Our "Camel" ramble starts small and ends big — I began with modest optics in my suburban yard, but the project culminated with Lee and I wielding hefty Dobsonian telescopes at an alpine site.

Cascading Starlight

Entering the region at declination +63°, we encounter a chain of stars initially noted in 1980 by Franciscan friar Lucian J. Kemble. The Canadian amateur astronomer had swept up the strikingly straight alignment in his binoculars, recording it as "a beautiful cascade of faint stars tumbling from the northwest down to the open cluster NGC 1502." Kemble mailed a description of his serendipitous sweep to *Sky & Telescope*'s veteran Deep-Sky Wonders columnist Walter Scott Houston, and Scotty published it in the December 1980 issue.

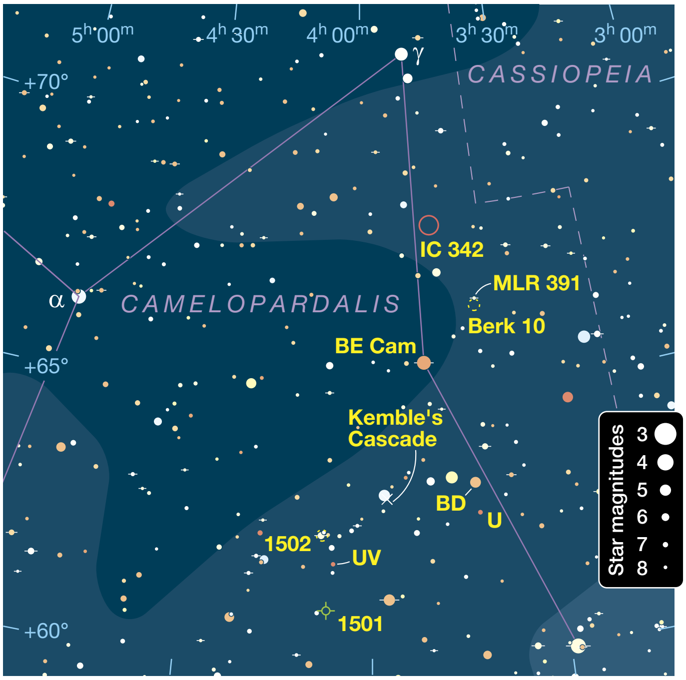
S&T's doyen of the deep admitted he hadn't done much Giraffe spotting: "I was shocked the night I first turned to the area with my binoculars, for there was a totally unexpected gem. In this pallid corner of Camelopardalis, tumbling steeply southeastward, was a celestial waterfall of dozens of 9th- and 10th-magnitude stars. Down it went,



over 2½°, before splashing into NGC 1502." Scotty didn't get the particulars quite right — the stars are fewer in number, somewhat brighter, and span 2.4° of sky — but his evocative description nicely amplified Kemble's original wording. He dubbed it **Kemble's Cascade**, and the name stuck.

The Cascade resides in westernmost Camelopardalis, the Giraffe. As the chart above right indicates, the sprawling but barren expanse of Camelopardalis is surrounded by familiar constellations such as Ursa Major, Cassiopeia, Auriga, and Perseus. The latter group provides an easy star-hop route

▲ **CASCADING STARLIGHT** Delicate and delightful, Kemble's Cascade is a jagged, 2.4°-long row of faint stars that looks remarkably straight in binoculars. Colorful stars in and around the Cascade show to great effect in small telescopes.



▶ **RUMP ROMP** Several interesting stars and deep-sky objects lie along the hind end of Camelopardalis, near right ascension 4 hours. The open cluster NGC 1502 is a splash of starlight at the foot of Kemble's Cascade. South of the Cascade is the planetary nebula NGC 1501. Northward, above the orange variable star BE Cam, is an obscure cluster named Berkeley 10, plus a huge, dim galaxy listed as IC 342. The double stars of NGC 1502 are labeled on the image on page 24.

to the Cascade: A line drawn from 2nd-magnitude Algol (Beta Persei) north-northeastward past 1.8-magnitude Mirfak (Alpha Persei), extended 14°, crosses the "waterfall" near its midpoint, marked by the Cascade's 5.0-magnitude beacon star, HD 24479. My tripod-mounted 10×50 binos reveal a dozen stars (excluding the beacon) ranging from magnitude 6.8 to 8.5. The stream splashes from HD 23649 at the northwestern end, past the beacon, down to HD 25443 at the foot of the waterfall.

A short-focus telescope greatly enlivens the Cascade. My 4¼-inch (108-mm) f/6 Newtonian, equipped with a wide-angle 30-mm eyepiece yielding 22× (delivering a 3° field of view), captures the entire Cascade and picks up 21 stars down to about magnitude 10.0. The tally is similar in my 4.7-inch (120-mm) f/7.5 apochromatic refractor. Your total will depend on sky conditions, telescope size, and the stars you think qualify as card-carrying Cascaders. My count of 21 includes a faint sideways pair near each end of the chain, plus the brilliant beacon, and a dim star hanging south of it.

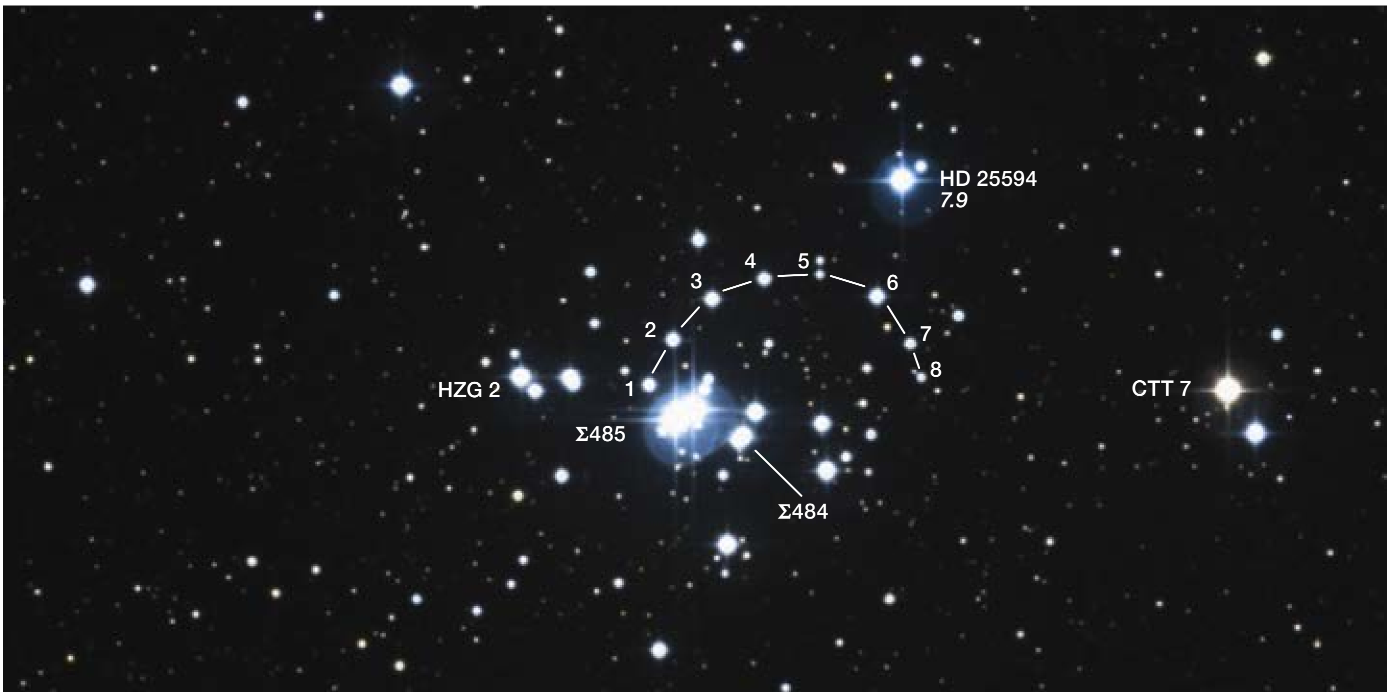
While most of the Cascade gleams blue-white, two 7.9-magnitude stars, HD 23649 (at top) and HD 24065 (halfway down to the beacon), are reddish-orange. There's more color just westward, where three dominant stars — they outshine the Cascade — form an east-west, 0.9°-long bent row. The 5.8-magnitude easternmost star is blue-white, the 4.8-magnitude middle sun is yellow, and the row ends at 5.1-magnitude **BD Camelopardalis**, an orange variable star. Only 0.6° south of BD Cam is 7.0-magnitude **U Camelopardalis**, a ruby-red carbon star. Likewise, 0.3° south of the Cascade's foot is another carbon star, the 7.6-magnitude ruddy ember **UV Camelopardalis**.

◀ **COLORFUL STARS** Adjacent to Kemble's Cascade, a row of three stars ends at orangey BD Camelopardalis, lower right in this image. North of BD Cam is the pretty double star ΟΣΣ 36 (top right). Its 6.9-magnitude blue primary and 8.3-magnitude white secondary are 45.9″ apart.

Bonus Glitter

The bonus prize, introduced in Scotty Houston's column all those years ago, is **NGC 1502**. The 5.7-magnitude Cascade Cluster (as I call it) shows in my 10×50s as a tiny splotch of glitter ¼° northeast of the aforementioned foot star, 6.8-magnitude HD 25443.

The Cascade Cluster is officially 20′ in diameter and contains five dozen stars. In my backyard scopes, however, NGC 1502 offers fewer than 20 stars in a splatter about 7′ across. A boxlike core group is dominated by **Σ485**, a headlight binary



CASCADE CLUSTER NGC 1502 at the foot of Kemble's Cascade contains about 60 stars in a roughly 20′-wide area. Some 3,000 light-years from Earth, the cluster is identifiable in binoculars but looks best in a telescope. The double star Σ485 dominates the cluster; its southern component is itself an eclipsing binary system known as SZ Cam. The arc of stars labelled 1 through 8, described by the author in the main text, shows at least partly in small backyard telescopes, and in its entirety in larger scopes under a dark sky.

STAR TRIO: ALAN DYER; NGC 1502: POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY sporting 6.9-magnitude yellow-white components 18″ apart. The other stars, 9th magnitude and fainter, are blue-white. Decorative outliers garnish the scene. A 7.9-magnitude blue star (HD 25594) sits 4½′ northwest of Σ485. About 8′ west, a colorful, 44″-wide double, **CTT 7**, boasts an 8.1-magnitude golden-yellow primary and 9.5-magnitude blue-white secondary. Nice stuff.

The rectangular core features Σ485 and three lesser tandems. The core four span less than 5′, running east-west, and their separations range from 18″ to 42″. The easternmost set lies east-west; the others stand roughly north-south. In my little reflector at 20×, all I see is the glare pair, Σ485. Some adjacent sparkle pops using averted vision but disappears when I look directly at it. Upping to 72× produces all four tandems and — wait for it — exactly six stars outside the core.

Thankfully, the apo refractor extracts additional dots. Straw-tinted Σ485 is the primo pair at 30×. The other sets are discernible, as are a few peripheral stars, and increased magnification clarifies all four sets. Moreover, patient staring reveals a delicate arc of stars curving northwestward from the compact core. At 100×, I count four extremely faint arc stars (labelled 1, 2, 3, and 4 in the photo on page 24) and after a gap, two more (labeled 6 and 7). The glints in the arc are no brighter than 12th magnitude — quite a catch for a 4.7-inch scope in suburbia.

Observing open clusters at high magnification might seem counterintuitive, but when I pile on the power, I'm often surprised at what I find. In NGC 1502, the easternmost star of the pairing east of Σ485 is a double listed as **HZG 2**, whose 9.5- and 10.7-magnitude suns are separated by 17.2″ — an easy split in the apo at 100×. The southern star of the duo immediately west of Σ485 is a tight binary, **Σ484**, whose 9.6- and 10.5-magnitude components are a scant 5.6″ apart. The apo resolves Σ484 (barely!) at 200×.

Dim Donut

To access the fainter objects along our chosen corridor of Camelopardalis, Lee and I hit the highway. In August 2022, we made our annual pilgrimage to the Mount Kobau Star Party in southernmost British Columbia, where we enjoyed a week of decent weather. What follows is a recap of our best after-midnight scoping session.

We began at the foot of Kemble's Cascade and a deeper examination of NGC 1502, using Lee's 17.5-inch f/4.5 Dobsonian and my almost identical 18-inch. The cluster was ablaze in both big reflectors, but there were dim sparks, too. We nabbed three feeble attendants hugging the Σ485 duo, then glimpsed among the arc stars a 15th-magnitude double (labeled 5 in the photo on page 24) and a final arc-ending star (labeled 8). Delightful!

Next, we dipped our dueling Dobs below the foot of the Cascade to UV Cam (the ruddy ember mentioned earlier), then continued south-southeastward 1° to a planetary nebula cataloged as **NGC 1501** (it's situated 1.4° due south of the Cascade Cluster). Unlike the dazzling cluster, NGC 1501 is a

NOT A DONUT The planetary nebula NGC 1501 exhibits a donut-like shape in amateur telescopes, but the shell of ejected gas is hardly empty. Its dim central sun yields a spectrum similar to that of a carbon-rich Wolf-Rayet star. The specimen here, which might be a binary system, pulsates rapidly.

GARY IMM

mere puff of smoke. In telescopes, the 11.5-magnitude nebula exhibits a Jupiter-size annulus, 56″ by 48″ in extent, enclosing a 14.5-magnitude central star. A 7.5-magnitude field star stands guard 10.5′ to the east-southeast.

We scrutinized NGC 1501 in steps. Starting at approximately 60×, our Dobsonians presented a diminutive disk, only a hint of a hole, and no central star. At 100×, the ring structure became obvious, though the bluish-grey donut appeared round, not elliptical, and the central star still wasn't cooperating. The star was coaxed to life at around 150× when we used averted vision. Sadly, the star vanished whenever we applied a narrowband nebula filter. An Ultra-High Contrast (UHC) filter did give us a clearly defined donut set against a black sky, and the contrast was even stronger with a doubly ionized oxygen (O III) filter.

Higher magnification really perked up the planetary. In our scopes at around 250×, unfiltered, the donut shape became slightly elliptical — darker at the ends, brighter along the sides. Viewed through a UHC filter, the northern side was marginally more luminous than the southern side, the nebula exuded a mottled texture, and the hole was dusky, not black. Check the photo above; you'll see that the middle of NGC 1501 is filled with blotchy nebulosity. The central star beams through the blotch in photos, but not visually when filtered. In truth, the high-power field was dim when viewed through a UHC filter — even more so with an O III. To us, an unfiltered NGC 1501, its central star alight, was the most pleasing.

Phantom Cluster

After indulging in donuts (the edible kind, in our kits), Lee and I returned to Kemble country, climbed up the Cascade, and charted a star-hop route northward through the northern portion of our "Camel" tour. Entry to this area was provided by the easternmost star, HD 23523, in the colorful bent row next to the Cascade. From that 6th-magnitude point, we directed our Dobs northward 2¼° to 4th-magnitude **BE Camelopardalis**, an irregular variable star that looked deliciously orange at low power. The orange light was also a warning signal indicating, "Faint fare ahead."

As Lee admired the citrusy hue of BE Cam, I shifted my scope ¾° northwestward to a pair of stars, magnitudes 7.8 and 8.7, spaced 1½′ apart. Another ¼° onward took me to 7.9-magnitude HD 22563. From there, I veered north-northwestward for ½°, past a gateway of two 10th-magnitude stars 4½′ apart, to intercept a cluster that was trying awfully hard not to be seen. The little blighter wasn't on Lee's original list, but I noticed the cluster symbol while charting our star-hop, and you'll see it plotted as "Berk 10" on the chart on page 23.

The shy customer was **Berkeley 10**, named for the Berkeley Open Cluster Program — in 1958, astronomers at the University of California at Berkeley published a catalog of 88 obscure star clusters and stellar associations. Number 10 on the Berkeley list is populated with some 50 stars strewn across 12′ of sky. Those aren't bad numbers; however, except for a couple of 11th- and 12th-magnitude outliers glimmering on the cluster's southern periphery, the members of Berkeley 10 are all 13th magnitude and fainter. I needed upwards of 100× to separate the meager stardust from its surroundings. Berkeley 10 grudgingly coughed up maybe two dozen stars.

Mercifully, the phantom family was signposted several arcminutes to the south by the 10th-magnitude gateway stars I passed earlier, and a similar distance northward by a 10½′-wide, right-angle triangle of similarly bright markers. Ya can't miss 'em. Better yet, there's a tiny treat in the triangle — its vertex is denoted by a wee wisp of a binary cataloged as **MLR 391**. Its 10.0- and 10.3-magnitude components, 1.9″ apart, were a tight split in the 18-inch at 158×. A treat, indeed.

This particular Berkeley open cluster is certainly a bare-bones specimen. But if you think Berkeley 10 is a challenge, buckle up — we're going to trade the phantom for a ghost.

Hidden Galaxy

The ghost is **IC 342**, a huge face-on spiral galaxy only 11 million light-years away. From Berkeley 10, the big spiral should've been an easy three-hop hike. We independently raised our scopes almost 1° northeast to 5.8-magnitude HD 23005, veered north-northeastward 1.4° to reach 6.3-magnitude HD 23662, then hopped 0.6° southwest to the target. I got there a second or two before Lee. Scanning the field at low power, I muttered something unpleasant and shouted: "Waddya see?" My keen-eyed companion replied: "Nothing, nada, zilch!"

IC 342 claims a visual magnitude of 8.4. Fabulous — except, the light is spread across an area some 22′ in diameter. The galaxy's *surface brightness* is a ghostly 15.2 magnitudes per square arcminute. Yikes. And IC 342's pale visage suffers a second indignity: The face-on behemoth lies close to the band of the Milky Way, so its light is attenuated by interstellar dust and gas. Someone possessing a dry sense of humor (not us) has christened it the Hidden Galaxy.

Fear not. Amid the foreground scatter across the face of IC 342 are a half-dozen 11th- to 14th-magnitude stars in a 6′-long string, slanted northwest-southeast. Spot the string and you've got the galaxy — even if you can't see it. But we did notice something odd. Approximately 2½′ east-northeast of the string's brightest point (10.8-magnitude TYC 4327-903-1) was a dim star and, immediately south of it, another "star" *not* pinpoint sharp. That fuzzy bit turned out to be the central hub of the Hidden Galaxy.

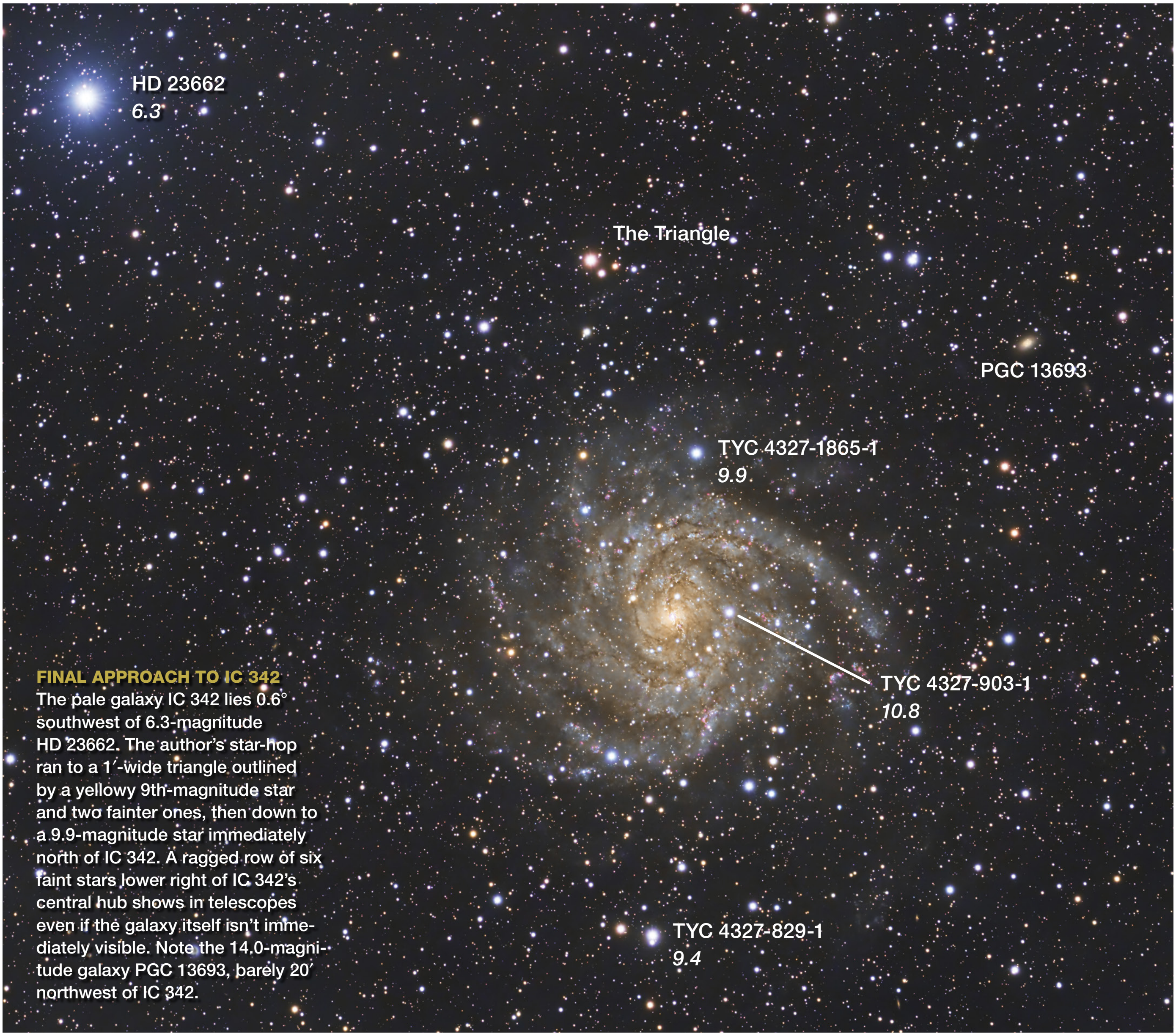
Nailing any facet of IC 342 (other than the hub) was an exercise in dark adaption, observing technique, and patience. Lee suggested I select a wide-field 30-mm ocular, then gently nudge my Newtonian back and forth to deter-

Lee's List

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Kemble's Cascade	Asterism	—	2.4°	$03^h 57.4^m$	+63° 04′
BD Camelopardalis	Variable star	5.1	—	$03^h 49.5^m$	+65° 32′
U Camelopardalis	Carbon star	7.0	—	$03^h 41.8^m$	+62° 39′
UV Camelopardalis	Carbon star	7.6	—	$04^h 05.9^m$	+61° 48′
NGC 1502	Open cluster	5.7	20′	$04^h 07.8^m$	+62° 20′
Σ485	Double star	6.9, 6.9	18″	$04^h 07.9^m$	+62° 20′
CTT 7	Double star	8.1, 9.5	44″	$04^h 06.7^m$	+62° 21′
HZG 2	Double star	9.5, 10.7	17.2″	$04^h 08.2^m$	+62° 20′
Σ484	Double star	9.6, 10.5	5.6″	$04^h 07.7^m$	+62° 20′
NGC 1501	Planetary nebula	11.5	56″ × 48″	$04^h 07.0^m$	+60° 55′
BE Camelopardalis	Variable star	4.5	—	$03^h 49.5^m$	+65° 32′
Berkeley 10	Open cluster	—	12′	$03^h 39.6^m$	+66° 29′
MLR 391	Double star	10.0, 10.3	1.9″	$03^h 39.2^m$	+66° 40′
IC 342	Spiral galaxy	8.4	22′	$03^h 46.8^m$	+68° 06′

The name Camelopardalis is 14 letters long, and by coincidence Lee Johnson's western Camel tour contains 14 objects.

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.



FINAL APPROACH TO IC 342 The pale galaxy IC 342 lies 0.6° southwest of 6.3-magnitude HD 23662. The author's star-hop ran to a 1′-wide triangle outlined by a yellowy 9th-magnitude star and two fainter ones, then down to a 9.9-magnitude star immediately north of IC 342. A ragged row of six faint stars lower right of IC 342's central hub shows in telescopes even if the galaxy itself isn't immediately visible. Note the 14.0-magnitude galaxy PGC 13693, barely 20′ northwest of IC 342.

RON BRECHER

mine if my dark-adapted eye could register anything. The nudging worked: There in the field of view was a vaguely circular mist — like breath on a windowpane — perhaps 12′ across. The amorphous glow widened to about 20′ in Lee's 21-mm Ethos eyepiece. His prized Ethos yielded 100× and a 1° field, resulting in a generous amount of black sky around the near-nothingness.

We took turns gazing at the ghost, and our patience paid off when we teased out a bland band of haze southwest of, and parallel to, the string-of-six. The gently curving filament established the outer portion of one spiral arm. A second filamentary band on the northeastern side of the galaxy was the segment of an opposite arm. Those nebulous nuances were definite in the 21-mm Ethos and at higher magnification, too. Yet for all our efforts, and despite the near-perfect observing conditions, the full spiral structure eluded our scrutiny.

Special Specter

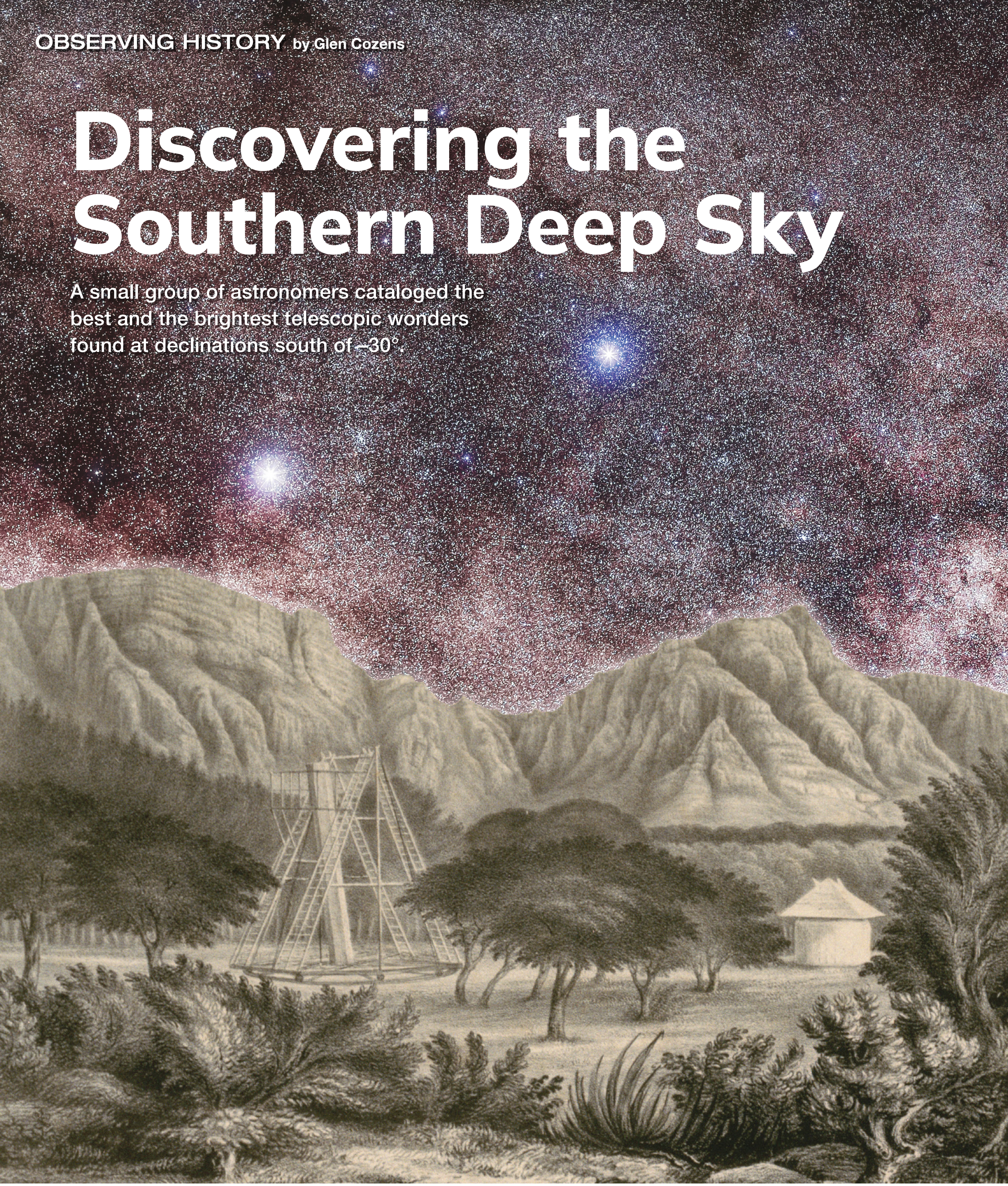
IC 342 can be caught in small optics — Lee and I detected it in 10×42 binoculars — but obtaining a truly satisfying telescopic view proved tricky. For us, the three keys to at least partial success were very dark skies, relatively short-focus Newtonian reflectors, and low to medium magnification.

IC 342 challenged and inspired us. While embracing the subtle characteristics of this cosmic specter in our Dobsonians, it wasn't lost on us that we beheld a colossal galactic metropolis not unlike our Milky Way Galaxy, just beyond our Local Group. It was a sublime and rewarding sight.

■ Contributing Editor **KEN HEWITT-WHITE** would like to dedicate the "Camel" tour to the memory of his friend Lee Johnson, who died suddenly before he could assist with the preparation of this article.

Discovering the Southern Deep Sky

A small group of astronomers cataloged the best and the brightest telescopic wonders found at declinations south of –30°.



Prior to 1825, astronomers knew of only 45 deep-sky objects south of declination –30° — a region we can call the far-southern sky. Aside from a few naked-eye clusters, most were found during initial, tentative forays by Northern astronomers, mainly working at the limits of European latitudes. In 1781, Charles Messier published his catalog of 103 deep-sky objects he recorded while searching for comets. Messier found four globular clusters between declinations –30° and –32.4°. His contemporary, William Herschel, mainly observed from Slough, near London, England. Herschel undertook a systematic survey of the sky that ultimately yielded 2,500 “nebulae” as he called them — but only 13 of his finds had declinations south of –30°, and none farther south than –32.8°.

One astronomer contributed to that initial tally from a non-European location. Observing from South Africa, Nicolas-Louis de Lacaille discovered 24 objects (mainly open clusters) during 1751–52. Then, as now, exploring this rich swath of the heavens requires a latitude adjustment.

Expanding Horizons

Cataloging the far-southern sky began in earnest with just a handful of astronomers: In addition to Lacaille, they were James Dunlop, John Herschel (son of William), Lewis Swift, Williamina Fleming, DeLisle Stewart, and Royal Harwood Frost.

Lacaille (1713–1762) traveled to South Africa in 1751 to determine Earth’s radius and to create a star catalog — a crucial tool for navigation and timekeeping, particularly on ships where pendulum clocks did not perform reliably. He

◀ **THE 20-FOOT BEAST** John Herschel’s 20-foot-long, 18¼-inch-aperture, speculum-mirror reflector set up at Table Mountain, South Africa. The hut on the right housed a 5-inch refractor. The rendering presented here was drawn by Herschel himself.

▲ **SOUTHERN PANORAMA** Crux, the Southern Cross, is strongly associated with the splendors of the southern night sky. Its four prominent stars adorn the right side of this image along with the dark Coalsack Nebula, while the duo of Alpha and Beta Centauri dominate the left half. Within the borders of Crux lie numerous deep-sky treasures, including the Jewel Box Cluster, NGC 4755 (below left of Beta Crucis — the leftmost star of the Cross), which the author ranks as one of the southern sky’s finest deep-sky objects.

MILKY WAY: ALAN DYER; HERSCHEL’S TELESCOPE: ROYAL MUSEUMS GREENWICH set up an observatory in the courtyard of a house on Strand Street in Cape Town, where he used a small refractor of 13-mm (½-inch) aperture. Between August 23, 1751, and July 18, 1752, he cataloged 9,766 southern stars and recorded 42 nonstellar objects. Twenty-four objects in his list were new: 17 open clusters, four globular clusters, two nebulae, and a spiral galaxy, later included in Messier's catalog as M83. Most of the objects Lacaille found can be seen with the naked eye.

After his return to Paris, he published his *Catalog of Nebulae of the Southern Sky*, in which he categorized his observations into three types of nonstellar objects: nebulae, nebulous star clusters, and nebulous stars. He wrote:

> *I have found a great number of the three types of nebulosities in the southern part of the sky, but I do not flatter myself to think that I have noticed them all, especially those of the first and third types, because they can only be perceived after twilight and in the absence of the moon. However, I do hope that the list is passably complete in regard to the most remarkable of the three types . . . The so-called nebulous stars offer to the eyes of the observers a spectacle so varied that their exact and detailed description can occupy astronomers for a long time.*

Along with his star and nebulae catalogs, Lacaille also named 14 new southern constellations still in use today. However, the astronomer's career was cut short. As David S. Evans wrote in his 1992 biography, *Lacaille: Astronomer, Traveler*, "On the night of March 19 [1762] he suffered from a periodic fever, and his physicians bled the poor man again, but he fell into a coma and died on the 21st" aged just 49.

A Scotsman Down Under

Seventy-four years after Lacaille's sky survey, Scotsman James Dunlop (1793–1848) became the second major explorer of the far-southern deep sky. Dunlop arrived in Sydney, Australia, in November 1821 with his employer, Governor Sir Thomas Brisbane (1773–1860), and the colony's new astronomer, Christian Carl Ludwig Rümker (1788–1862). Dunlop's duties were to maintain the telescopes and other equipment in Governor Brisbane's observatory at Parramatta, 24 km (15 miles) west of Sydney. In March 1822 Rümker and Dunlop started cataloging southern stars; however, in June 1823, Rümker left the observatory after disputes with Brisbane. Prior to leaving, Rümker had only recorded 2,300 of the 7,385 stars that were ultimately included in *The Brisbane Catalogue*, published in 1835.

When Brisbane left Australia in December 1825 to return to Scotland, the astronomical instruments he'd brought with

▶ **STAR MAPPER** Nicolas-Louis de Lacaille discovered the best southern clusters, two nebulae, and a galaxy with a modest refractor of 13-mm (½-inch) aperture. Eleven of his finds appear in the author's selection of the finest southern deep-sky treasures.

▶ **DEEP-SKY DIVER** Scotsman James Dunlop discovered hundreds of southern clusters, galaxies, and objects in the Magellanic Clouds in 1826 while observing near Sydney, Australia. His name dominates the table of deep-sky splendors presented on pages 32 and 33.

him — including the 3¾-inch-aperture transit instrument — remained at Parramatta Observatory so that Dunlop could continue work on the star catalog. After completing that on March 2, 1826, he moved to a friend's place in Marsden Street, Parramatta, where he began surveying the sky for the clusters and nebulae that he'd come across while cataloging the stars. For his deep-sky work, Dunlop built a 9-foot-long reflecting telescope fitted with a 9-inch-aperture speculum-metal primary mirror, which had the light-gathering equivalent of a modern 6-inch reflector.

In just seven months, from April 27 to November 24, 1826, he discovered 155 open clusters, 50 galaxies, 40 nebulae, 28 globular clusters, and four planetary nebulae. Also included in his catalog were many faint double stars, which he believed to be nebulae due to the limited resolution of his homemade telescope.

Dunlop was also the first to record the numerous clusters and nebulae dotting the Large and Small Magellanic Clouds. His technique was to allow the Clouds to drift through the eyepiece of his stationary telescope. When an object appeared, he recorded the time and the distance north or south from the center of his field of view. In other areas of the sky, he swept north and south along the meridian, describing each object and noting its south polar distance and the sidereal time.

Dunlop left Sydney on February 4, 1827, and returned to Scotland, where he again worked as an astronomer for Brisbane. In December that year, the Royal Society published *A catalogue of nebulae and clusters of stars in the southern hemisphere, observed at Paramatta in New South Wales* in its *Philosophical Transactions*. On February 8, 1828, the president of the Royal Astronomical Society of London, John Herschel, presented gold medals to Thomas Brisbane and James Dunlop for their astronomical efforts. At that time, Herschel praised Dunlop for his "zealous, active . . . industrious and methodical work." Herschel also said, "the optical power of Lacaille's telescope was far too feeble to afford much insight into the physical constitution of the objects determined with it . . ." Regarding the work performed by Dunlop and Brisbane in the Southern Hemisphere, he added, "the astronomers of Europe may view, with something approaching to envy, the lot of these their more fortunate brethren."

Dunlop returned to Parramatta in November 1831 as superintendent of the Observatory, but he found it damaged by rain and white ants. Although he repaired the facility, poor health and a lack of support hampered his work. He resigned in 1847 and died a year later.

(continued on page 34)

NGC 3132

▶ PROLIFIC PIONEER British astronomer John Herschel was the first to scan the whole sky with a large telescope from both England and South Africa. His famous father, William, was also a prolific observer and taught John how to make telescope mirrors.

HERSCHEL: LIBRARY OF CONGRESS / SCIENCE SOURCE; NGC 3132: THE HUBBLE HERITAGE TEAM (STSCI / AURA / NASA)

Discoverers of NGC and IC Objects South of Declination –30°

Years	Discoverer	Total
1834-1838	John Herschel	952
1898-1901	DeLisle Stewart	541
1826	James Dunlop	277
1903-1904	Royal Harwood Frost	114
1885-1898	Lewis Swift	82
1751-1752	Nicolas-Louis de Lacaille	24
1893-1907	Williamina Fleming	15
1784-1793	William Herschel	13

60 Finest Deep-South Objects

Object	Type	Const.	Disc.	Year	Mag(v)	Size	RA	Dec.
NGC 55	Galaxy	Scl	Dunlop	1826	7.9	31.2′ × 5.9′	0^h 15.1^m	-39° 13′
NGC 104	Globular cluster	Tuc	Lacaille	1751	4	50.0′	0^h 24.1^m	-72° 05′
NGC 300	Galaxy	Scl	Dunlop	1826	8.1	19.0′ × 12.9′	0^h 54.9^m	-37° 41′
NGC 346	Nebula	Tuc	Dunlop	1826	—	14.0′ × 11.0′	0^h 59.1^m	-72° 11′
NGC 1097	Galaxy	For	W. Herschel	1790	9.5	9.4′ × 6.6′	2^h 46.3^m	-30° 17′
NGC 1261	Globular cluster	Hor	Dunlop	1826	8.3	6.8′	3^h 12.3^m	-55° 13′
NGC 1291	Galaxy	Eri	Dunlop	1826	8.5	11.0′ × 9.5′	3^h 17.3^m	-41° 06′
NGC 1313	Galaxy	Ret	Dunlop	1826	8.7	9.2′ × 7.2′	3^h 18.3^m	-66° 30′
NGC 1316	Galaxy	For	Dunlop	1826	8.5	11.0′ × 7.2′	3^h 22.7^m	-37° 12′
NGC 1365	Galaxy	For	Dunlop	1826	9.6	11.0′ × 6.2′	3^h 33.6^m	-36° 08′
NGC 1380	Galaxy	For	Dunlop	1826	9.9	4.0′ × 2.4′	3^h 36.5^m	-34° 59′
NGC 1512	Galaxy	Hor	Dunlop	1826	10.3	8.9′ × 5.6′	4^h 03.9^m	-43° 21′
NGC 1532	Galaxy	Eri	Dunlop	1826	9.9	11.6′ × 3.4′	4^h 12.1^m	-32° 52′
NGC 1553	Galaxy	Dor	Dunlop	1826	9.4	4.5′ × 2.8′	4^h 16.2^m	-55° 47′
NGC 1566	Galaxy	Dor	Dunlop	1826	9.7	8.2′ × 6.5′	4^h 20.0^m	-54° 56′
NGC 1792	Galaxy	Col	Dunlop	1826	10.2	5.2′ × 2.6′	5^h 05.2^m	-37° 59′
NGC 1808	Galaxy	Col	Dunlop	1826	9.9	6.5′ × 3.9′	5^h 07.7^m	-37° 31′
NGC 1851	Globular cluster	Col	Dunlop	1826	7.1	12.0′	5^h 14.1^m	-40° 03′
NGC 2070	Nebula	Dor	Lacaille	1751	—	30.0′ × 20.0′	5^h 38.7^m	-69° 06′
NGC 2477	Open cluster	Pup	Lacaille	1751	5.8	20.0′	7^h 52.2^m	-38° 32′
NGC 2516	Open cluster	Car	Lacaille	1751	3.8	22.0′	7^h 58.1^m	-60° 45′
NGC 2808	Globular cluster	Car	Dunlop	1826	6.2	14.0′	9^h 12.0^m	-64° 52′
NGC 2818	Planetary nebula	Pyx	Dunlop	1826	11.2	1.4′	9^h 16.2^m	-36° 38′
NGC 3114	Open cluster	Car	Dunlop	1826	4.2	35.0′	10^h 02.6^m	-60° 06′
NGC 3132	Planetary nebula	Vel	J. Herschel	1835	9.2	1.5′	10^h 07.0^m	-40° 26′
NGC 3199	Nebula	Car	Dunlop	1826	—	20.0′ × 15.0′	10^h 17.4^m	-57° 55′
NGC 3201	Globular cluster	Vel	Dunlop	1826	6.9	20.0′	10^h 17.6^m	-46° 25′
NGC 3293	Open cluster	Car	Lacaille	1751	4.7	5.0′	10^h 35.9^m	-58° 14′
NGC 3372	Nebula	Car	Lacaille	1751	—	120.0′ × 120.0′	10^h 45.1^m	-59° 52′
NGC 3532	Open cluster	Car	Lacaille	1751	3	50.0′	11^h 05.7^m	-58° 44′
NGC 3581	Nebula	Car	J. Herschel	1834	—	—	11^h 12.0^m	-61° 18′
NGC 3621	Galaxy	Hya	W. Herschel	1790	9.7	12.3′ × 6.8′	11^h 18.3^m	-32° 49′
NGC 3699	Planetary nebula	Cen	J. Herschel	1834	11.3	0.8′	11^h 28.0^m	-59° 57′
NGC 3766	Open cluster	Cen	Lacaille	1751	5.3	15.0′	11^h 36.2^m	-61° 37′
IC 2948	Nebula	Cen	Frost	1904	—	45.0′ × 40.0′	11^h 39.1^m	-63° 27′
NGC 3918	Planetary nebula	Cen	J. Herschel	1834	8.1	0.4′	11^h 50.3^m	-57° 11′
NGC 4755	Open cluster	Cru	Lacaille	1751	4.2	10.0′	12^h 53.7^m	-60° 22′
NGC 4945	Galaxy	Cen	Dunlop	1826	8.4	19.8′ × 4.0′	13^h 05.4^m	-49° 28′
NGC 5128	Galaxy	Cen	Dunlop	1826	6.8	25.7′ × 20.0′	13^h 25.5^m	-43° 01′
NGC 5139	Globular cluster	Cen	Halley	1677	5.3	55.0′	13^h 26.8^m	-47° 29′
NGC 5189	Planetary nebula	Mus	Dunlop	1826	8.2	2.3′	13^h 33.5^m	-65° 58′
M83	Galaxy	Hya	Lacaille	1751	7.5	12.9′ × 11.5′	13^h 37.0^m	-29° 52′

Object	Type	Const.	Disc.	Year	Mag(v)	Size	RA	Dec.
IC 4406	Planetary nebula	Lup	Stewart	1899	10.2	1.8′	14^h 22.4^m	-44° 09′
NGC 6067	Open cluster	Nor	Dunlop	1826	5.6	15.0′	16^h 13.2^m	-54° 13′
NGC 6153	Planetary nebula	Sco	Copeland	1883	10.9	0.4′	16^h 31.5^m	-40° 15′
NGC 6188	Nebula	Ara	J. Herschel	1836	—	20.0′ × 12.0′	16^h 40.1^m	-48° 40′
NGC 6231	Open cluster	Sco	Hodierna	1654	2.6	14.0′	16^h 54.2^m	-41° 50′
IC 4628	Nebula	Sco	Barnard	1895	—	90.0′ × 60.0′	16^h 57.0^m	-40° 27′
NGC 6302	Planetary nebula	Sco	Barnard	1880	9.6	1.5′	17^h 13.7^m	-37° 06′
NGC 6334	Nebula	Sco	J. Herschel	1837	—	35.0′ × 20.0′	17^h 20.8^m	-36° 06′
IC 4651	Open cluster	Ara	Dunlop	1826	6.9	10.0′	17^h 24.9^m	-49° 57′
NGC 6397	Globular cluster	Ara	Lacaille	1751	5.3	31.0′	17^h 40.7^m	-53° 40′
NGC 6541	Globular cluster	CrA	Cacciatore	1826	6.3	15.0′	18^h 08.0^m	-43° 43′
NGC 6563	Planetary nebula	Sgr	Dunlop	1826	11	0.8′	18^h 12.0^m	-33° 52′
NGC 6723	Globular cluster	Sgr	Dunlop	1826	6.8	13.0′	18^h 59.6^m	-36° 38′
NGC 6727	Nebula	CrA	Schmidt	1861	—	80.0′	19^h 01.7^m	-36° 53′
NGC 6744	Galaxy	Pav	Dunlop	1826	8.5	20.1′ × 12.9′	19^h 09.8^m	-63° 51′
NGC 6752	Globular cluster	Pav	Dunlop	1826	5.3	29.0′	19^h 10.9^m	-59° 59′
IC 5150	Planetary nebula	Gru	Gale	1894	11	2.2′	21^h 59.6^m	-39° 23′
NGC 7793	Galaxy	Scl	Dunlop	1826	9.1	9.3′ × 6.3′	23^h 57.8^m	-32° 36′

Data courtesy Wolfgang Steinicke. 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.

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(continued from page 31)

Herschel Dives Deep

John Herschel (1792–1871) grew up in the shadow of his father's astronomical accomplishments. His father, William, discovered the planet Uranus in 1781 from Bath and 2,401 deep-sky objects while serving as the King's astronomer.

Following the death of William in 1822, John reobserved 73% of the objects his father had cataloged. In her 1895 book *The Herschels and Modern Astronomy*, Agnes Mary Clerke noted:

> *Almost from the beginning of his surveying operations, Herschel cherished the hope of extending them to the southern hemisphere. But during his mother's lifetime, he took no steps towards its realisation. The separation would have been cruel. Her death, however, on January 6th, 1832, at the age of eighty-one, removed this obstacle, and the scheme rapidly took shape. The station originally thought of was Parramatta, in New South Wales; but Dunlop's observations there anticipated him, and he reflected with disappointment that "the cream of the southern hemisphere had been skimmed" before his turn came. He learned afterwards that nothing important in the "sweeping" line had been done at Parramatta; he had virgin skies to explore.*

In November 1833, Herschel traveled to South Africa, taking his family and his father's 20-foot (18¼-inch aperture) telescope with him. He observed from Feldhausen, 11 km southeast of Cape Town, between March 8, 1834, and January 22, 1838.

The 20-foot reflector had a speculum mirror and was used as a front-view instrument to avoid the light loss resulting from a second reflection. Herschel's scope had a light-gathering capability similar to a modern 16½-inch instrument and collected seven times more light than Dunlop's scope. This allowed Herschel to dive deeper and find many new objects. Although he didn't have truly "virgin skies" (Lacaille had already recorded the finest open clusters and Dunlop the best globular clusters and galaxies), in four years of systematic observing at the Cape, Herschel discovered 649 new galaxies, 243 open clusters, 34 nebulae, 16 planetary nebulae, and 10 globular clusters south of declination –30°. He also cataloged 2,102 double stars and described the 1835 apparition of Halley's Comet.


OMEGA CENTAURI (NGC 5139)

ESO

In 1847 Herschel published *Results of Astronomical Observations Made during the Years 1834, 5, 6, 7, 8 at the Cape of Good Hope*. In it he recorded a total of 1,708 clusters, nebulae, and galaxies, which included 89 he previously saw from Slough. In the introduction, Herschel criticized Dunlop's catalog, writing:

> *Of the objects remaining, 135 are nebulae and clusters of my Father's catalogues, now, for the first time, reobserved; 9 are Messier's, 5 of which are identical with objects catalogued by Mr. Dunlop; and 206 others have also been identified, with more or less certainty (indicated by the absence or presence of the sign ?), with objects observed by Mr. Dunlop, and described in his Catalogue of Nebulae. The rest of the 629 objects, comprised in that catalogue, have escaped my observation; and as I am not conscious of any such negligence in the act of sweeping as could give rise to so large a defalcation, but, on the contrary, by entering them on my working lists (at least, until the general inutility of doing so, and loss of valuable time in fruitless search, thereby caused it to become apparent), took the usual precautions to ensure their rediscovery; and as I am, moreover, of opinion that my examination of the southern circumpolar region will be found, on the whole, to have been an effective one, I cannot help concluding that, at least in the majority of those cases, a want of sufficient light or defining power in the instrument used by Mr. Dunlop, has been the cause of his setting down objects as nebulae where none really exist. That this is the case, in many instances, I have convinced myself by careful and persevering search over and around the places indicated in his catalogue.*

As a consequence of Herschel's remarks, Dunlop's reputation as an astronomer was badly damaged. However, I believe that Herschel and his contemporaries were too quick to condemn Dunlop. After a careful study of Dunlop's original notes, and photographic and visual evidence from modern telescopes, I found that Herschel missed 123 objects recorded by Dunlop. Many of the remaining "missing" objects seem to be faint double stars that Dunlop simply could not resolve with his inferior telescope.

Additional Finds

Although Lacaille, Dunlop, and Herschel recorded the majority of bright far-southern deep-sky objects, four other astronomers, working at the end of the 19th century and beginning of the 20th century, made important contributions.

It was comets that caught the attention of American

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astronomer Lewis Swift (1820–1913). He observed Halley's Comet in 1835 and, remarkably, again 75 years later, in 1910. But during 1897 and 1898 while working at Echo Mountain north of Los Angeles, Swift searched the southern sky for nebulae with a 16-inch refractor. He discovered 82 galaxies from a declination of –30° to as far south as –45.6°.

At the end of the 19th century, photography began to make an impact on astronomical discoveries. In 1890, Harvard College set up a southern observatory at Arequipa in Peru, 1,015 km south of Lima. In 1898 the College installed a 24-inch astrographic refractor, which DeLisle Stewart (1870–1941) and Royal Harwood Frost (1879–1950) used to photograph the southern sky.

Between October 1898 and October 1901, Stewart examined these photographic plates and found 524 new galaxies (of which only 121 were brighter than 13th magnitude), seven open clusters, six globular clusters, three nebulae, and one planetary nebula lying south of –30° declination.

Frost continued making photographic plates at Arequipa after Stewart left, and between June 1903 and September 1904 he found a total of 110 new galaxies (only 13 brighter than magnitude 13), three nebulae, and one planetary nebula south of –30°.

The observatory at Arequipa was also equipped with a Bache 8-inch telescope, which used an objective prism to capture the spectra of all stars to about 8th magnitude. The photographic plates were shipped to Harvard College, where, between 1893 and 1907, the Scottish astronomer Williamina Paton Stevens Fleming (1857–1911) discovered 15 far-southern nebulae while examining the stellar spectra on the plates.

Exploring the Far Southern Deep Sky

If you're a deep-sky enthusiast and have never ventured far enough south to personally view this magnificent swath of sky, I heartily encourage you to follow in the footsteps of the astronomical pioneers I've featured in this article. To assist your explorations, I've compiled the table presented on pages 32 and 33. My list includes 10 open clusters, 10 globular clusters, 10 nebulae, 10 planetary nebulae, and 20 galaxies. The selection is based on my many years at the eyepiece of a telescope in Papua New Guinea and Australia. I have chosen what I regard as the most visually rewarding objects south of declination –30°. (Keen-eyed readers will spot the one target that's just barely north of that mark — an object I included because of its historical significance.)

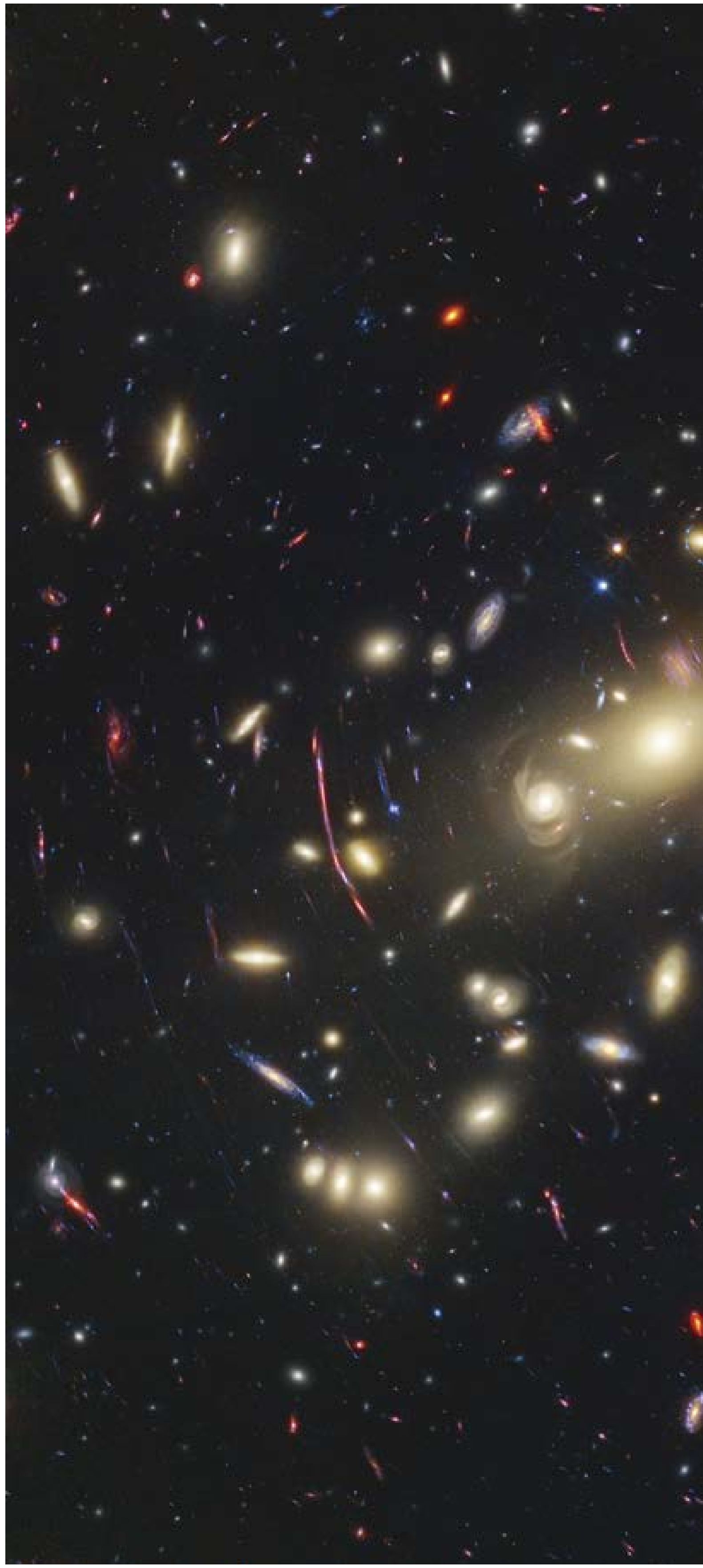
When a new comet is found, it's usually named after its discoverer, who is forever remembered for the achievement. But the observers who discovered most deep-sky objects are largely forgotten or simply unknown. Nicolas-Louis de Lacaille, James Dunlop, John Herschel, Lewis Swift, DeLisle Stewart, Royal Harwood Frost, and Williamina Fleming found the finest clusters, nebulae, and galaxies in the far-southern sky. Think of them the next time you're fortunate enough to be able to explore the deep-sky wonders found in this glorious expanse of the night sky.

■ **GLEN COZENS** completed a PhD at James Cook University (Townsville, Queensland, Australia) on the first three catalogs of southern star clusters, nebulae, and galaxies. He bought his first telescope in 1979 and has regularly observed the deep sky ever since.

 by José Diego & Steven Willner

Ancient Lights Magnified by Cosmic Lenses

Astronomers are using the gravity of galaxy clusters to explore stars in the early universe as well as the nature of dark matter.



NASA / ESA / CSA / STSCI / JOSÉ M. DIEGO (IFCA), JORDAN C. J. D'SILVA (UWA), ANTON M. KOEKEMOER (STSCI), JAKE SUMMERS (ASU), ROGIER WINDHORST (ASU), HAOJING YAN (UNIV. OF MISSOURI)

Clusters of galaxies are the most massive structures in the universe. They reside at the nodes of the cosmic web, akin to cities linked by a network of roads but in three dimensions. They contain anywhere from hundreds to thousands of galaxies, packed together in a vast swarm.

Clusters are more than their galaxies, however. The galaxies sit in a bath of very hot, X-ray-emitting gas, which contains more mass than all the galaxies combined. But even that mass is a small fraction of the total: About 85% of the cluster's mass is invisible dark matter, which in the most massive clusters can amount to more than 10,000 times the mass of the entire Milky Way Galaxy.

The huge concentration of dark matter, combined with the smaller but still enormous mass in gas and galaxies, warps the shape of space itself. This warping distorts and magnifies the light reaching us from distant galaxies behind the cluster from our perspective, making galaxy clusters the most powerful gravitational lenses in the universe.

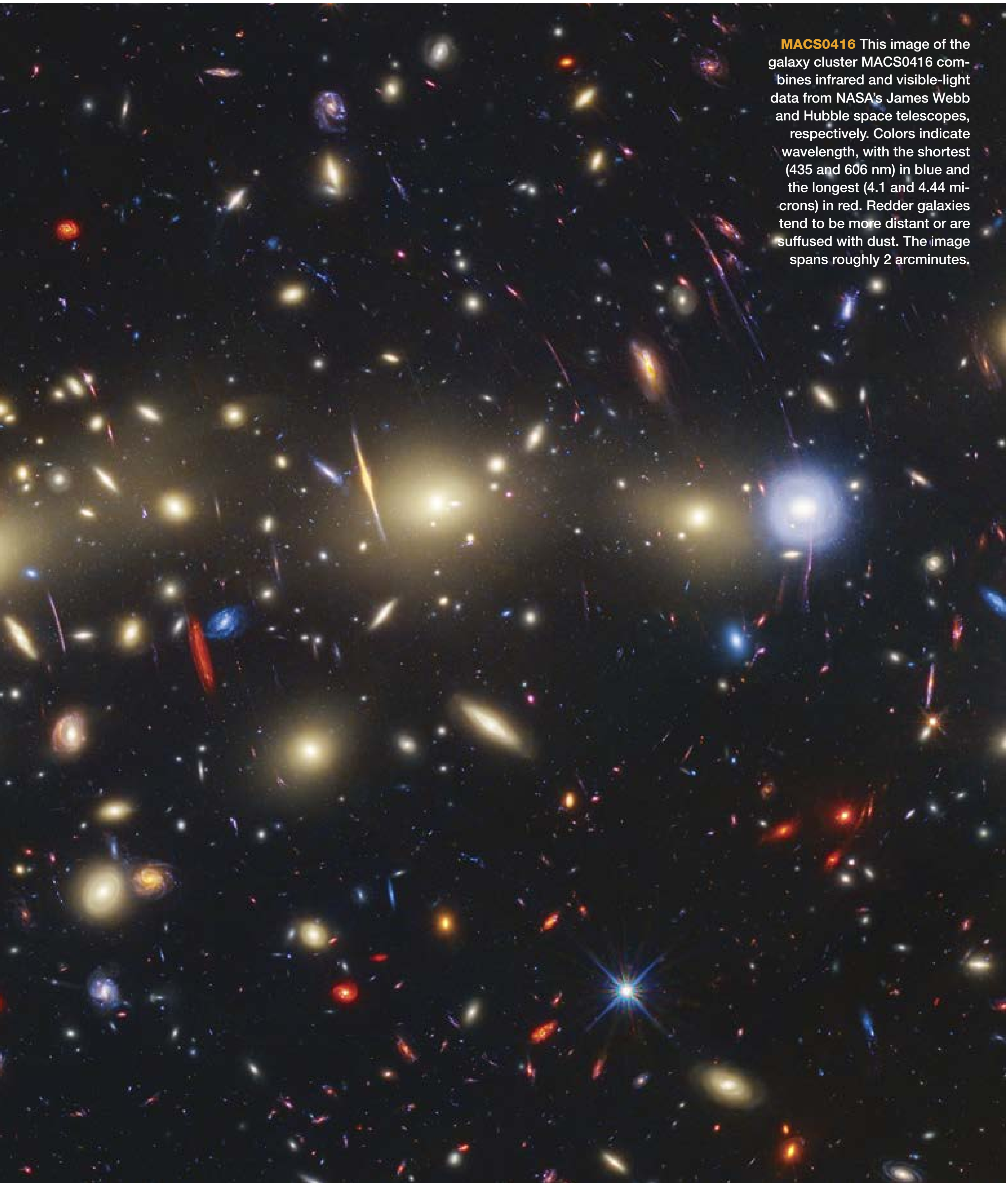
Astronomers have used the Hubble Space Telescope (HST) to examine dozens of these lensing clusters, in order to reveal unprecedented details in the distant galaxies behind them. The same magnifying power makes galaxy clusters premier targets for the James Webb Space Telescope (JWST) as well; about 10 were targeted in the first year of science observations.

One of the most interesting clusters on JWST's list is MACS0416 (officially MACS J0416.1–2403). It is a massive cluster that lies relatively nearby at a distance of "only" 5 billion light-years. (In astronomical parlance, it has a *redshift* of about 0.4; see page 76.)

MACS0416 contains several massive galaxies and hundreds of smaller ones. Fortuitously, there also happen to be many galaxies sitting directly behind it, which are magnified by the cluster into spectacular arcs. These lensed images reveal otherwise inaccessible information not only about the background galaxies but also about MACS0416 itself, including — potentially — the nature of the cluster's dark matter.

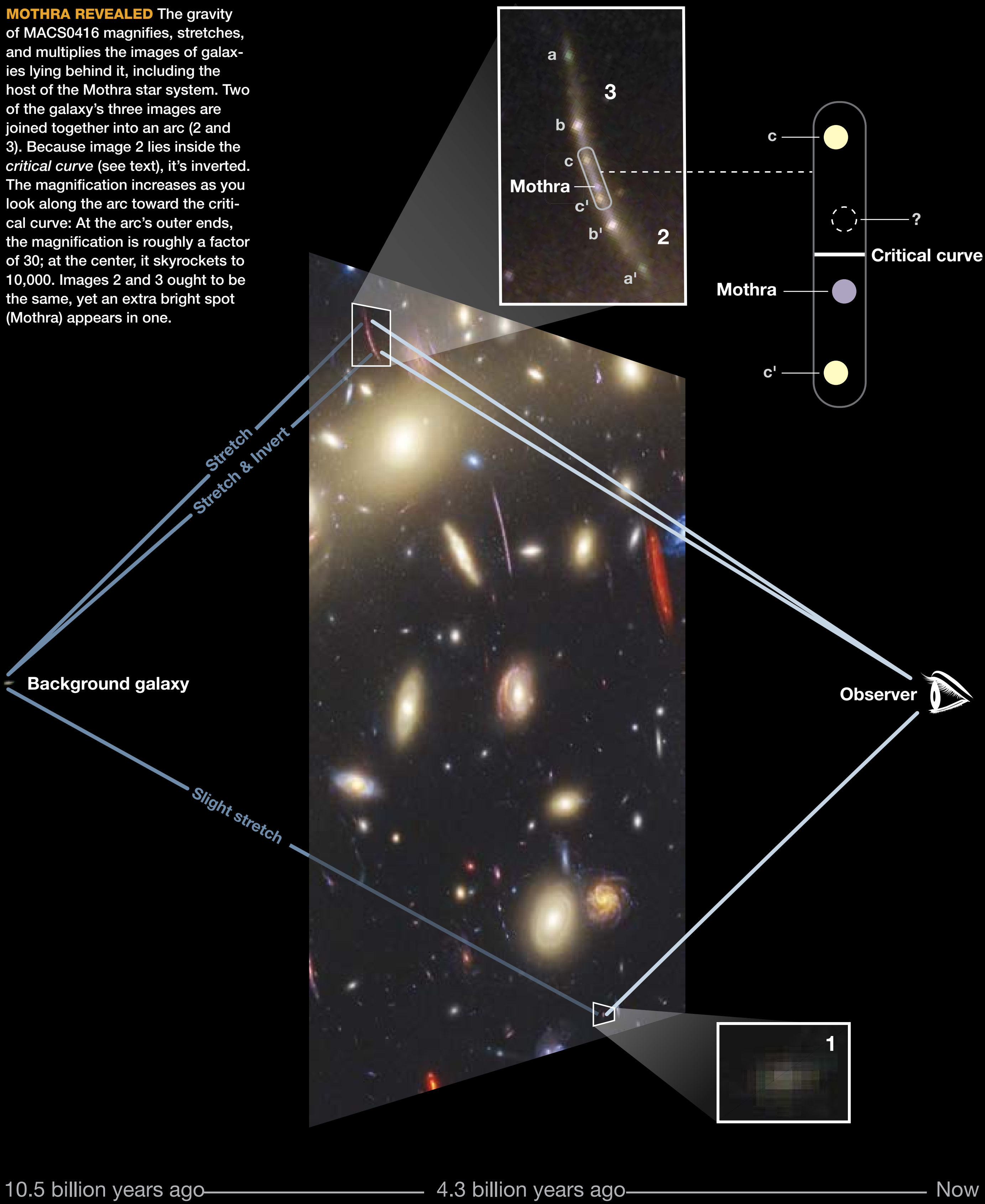
Gravitational Lensing 101

As light from distant galaxies travels through the deformed space around a cluster, the light rays bend much as they do



MACS0416 This image of the galaxy cluster MACS0416 combines infrared and visible-light data from NASA's James Webb and Hubble space telescopes, respectively. Colors indicate wavelength, with the shortest (435 and 606 nm) in blue and the longest (4.1 and 4.44 microns) in red. Redder galaxies tend to be more distant or are suffused with dust. The image spans roughly 2 arcminutes.

MOTHRA REVEALED The gravity of MACS0416 magnifies, stretches, and multiplies the images of galaxies lying behind it, including the host of the Mothra star system. Two of the galaxy's three images are joined together into an arc (2 and 3). Because image 2 lies inside the *critical curve* (see text), it's inverted. The magnification increases as you look along the arc toward the critical curve: At the arc's outer ends, the magnification is roughly a factor of 30; at the center, it skyrockets to 10,000. Images 2 and 3 ought to be the same, yet an extra bright spot (Mothra) appears in one.



BEATRIZ INGLESSIS / *S&T*, SOURCE: J. DIEGO, IMAGE: NASA / ESA / CSA / STSCI / JOSÉ M. DIEGO (IFCA), JORDAN C. J. D'SILVA (UWA), ANTON M. KOEKEMOER (STSCI), JAKE SUMMERS (ASU), ROGIER WINDHORST (ASU), HAOJING YAN (UNIV. OF MISSOURI) when traveling through a glass lens. But galaxy clusters are imperfect lenses: They have lumpy mass distributions, and therefore their lensing usually produces distorted, irregular images, the same way deformations in a glass lens would produce imperfect images.

Depending on the mass distribution within the cluster, there may be multiple paths that light from a background object takes through the gravitational lens to our telescopes. When this happens, the same object appears in multiple locations on the sky around the cluster. In most of these images, the galaxy appears magnified and stretched.

Multiple images aren't perfect clones of one another; each image can look different. For example, in most cases, the magnification is modest, just a factor of a few, but in special locations — near a so-called *critical curve* that surrounds the cluster's central region — the magnification factor can be thousands. A key property for studying lenses is that at small separations from the critical curve, the magnification is approximately the same on both sides of the curve.

The most extreme magnification near the critical curve affects only a tiny area of the background galaxy — not much bigger than a large star. In the lucky case in which a background star's light passes close to the critical curve, the resulting magnification gives a telescope such as JWST (with a 6.5-meter-wide mirror) the ability to resolve things that would normally require a telescope with a mirror hundreds of meters wide. Such telescopes cannot be built, much less launched into space, with current technology. But thanks to gravitational lensing, we can actually study individual stars in galaxies outside the local universe.

In 2018, astronomers combined a gravitational lens and HST to discover the first extremely distant star, Icarus, in a galaxy so far away that its light took 9.4 billion years to reach us. We've also discovered lensed stars exploding as supernovae, including a famous one named Supernova Refsdal in the same galaxy that hosts Icarus. After Icarus, HST observers discovered more stars at early cosmic times, culminating in 2022 with Earendel, shining at us from a breathtaking 12.9 billion years ago, less than 1 billion years after the Big Bang.

Astronomers chose the cluster MACS0416 as a target for early observations with JWST because several distant stars had already been found behind this cluster, including a few in two galaxies gleaming nearly 8 billion years in the past. These two galaxies are seen in the process of rapidly forming massive, bright stars. With so many luminous stars present, there was a good chance that a few would be magnified enough to be detectable with JWST.

We also hoped that we'd see changes in some images. Some stars vary intrinsically, as do supernovae, but the magnification of a lensed image can also vary with time. Stars in the foreground lensing cluster are constantly moving, orbiting around the centers of their galaxies. When one of these stars passes directly through the light path of a star in the distant, lensed galaxy, the cluster star itself acts as a secondary lens called a *microlens*. Microlenses alter the path of a photon by a tiny amount — on the order of 1 microarcsecond, 1 million times smaller than the arcsecond-scale lensing by the cluster.

Microlenses amplify the already large magnification caused by the cluster. Microlensing can increase a lensed star's flux by a few additional magnitudes, and the boost can last weeks to months, depending on the microlens's velocity across our line of sight.

Larger objects in the lensing cluster can also align with stars in the lensed galaxy. Globular clusters, for instance, are approximately one-thousandth the size of a galaxy but are several thousands to a million times more massive than a single star. When objects in this mass range act as lenses, they are called *millilenses*, because they can modify the path of a photon by approximately 1 milliarcsecond. Because millilenses are larger than microlenses, the alignment between a millilens and a distant star can last for decades.

Because of how long millilensing events last, directly observing the change in magnification they create is challenging. However, we can exploit the symmetry around the critical curve to bypass this problem. We expect the magnification on both sides of the critical curve to be nearly equal. If we can find instances in which the same star has an image on both sides of the critical curve, the two images should have nearly the same magnitude. If they don't, then the simplest explanation is that one image is magnified more than the other. That means a millilens or a microlens must have aligned temporarily with one of the images of the lensed star but not the other.

Because this alignment typically lasts a few months for a microlens or decades for a millilens, both images return to similar brightnesses afterward. If we find enough of these events, then we can use the statistics of how long brightness differences persist to reveal the mass distribution of small objects in the lensing cluster.

Mothra Rears Its Head

Even before JWST launched, HST observations of MACS0416 had revealed *transients* — things that changed in brightness from one observation to the next — caused by microlensing. Because of that, Rogier Windhorst (Arizona State University) and his team decided to devote almost 18 hours of JWST NIRCam observing time to this cluster, imaging it three times. Another team led by Chris Willott (Herzberg Astronomy and Astrophysics Research Centre, Canada) added 10 hours for a fourth epoch. All four fell within an interval of 126 days.

The JWST observations found 14 transients in the star-forming galaxies behind MACS0416. Two of them appear to be supernovae, but 12 look to be single- or multi-star systems, all temporarily magnified by micro- or millilensing. These 12 lensed stars make up about half of all known individual stars in distant galaxies. The many "lights" blinking on and off earned MACS0416 the nickname the Christmas Tree Cluster (not to be confused with the star-forming region NGC 2264 in the constellation Monoceros, which bears the same name).

One of the MACS0416 transients looks to be a long-duration millilensing event. The light we observe today, both from the transient and from the galaxy the transient resides in, was emitted 10.5 billion years ago. The light was bent by the intervening cluster to reach us along three paths, creating three images of the galaxy. Two of the images blend together at the critical curve, creating a single long, thin arc. The bottom half of the arc looks like an upside-down version of the top half, complete with the same individual stars — except for one extra point source. This extra point, which our team calls Mothra, appears only once and is missing its identical counterimage. The magnification of Mothra must therefore be much larger than that of its counterpart image on the other side of the critical curve.

Because of Mothra's redshift, its light is stretched by a factor of 3.1. This affects every wavelength the source emits: For example, at an infrared wavelength of 1500 nm, JWST observes light that Mothra emitted at a visible wavelength near 485 nm. JWST data also show that, in its rest frame, Mothra emits strongly over a broad range of visible wavelengths, from blue to red. This is impossible for a single star, but a double star with one red and one blue component fits Mothra's colors quite well. We even see the red component varying, as local red supergiant stars commonly do. Thanks to gravitational lensing, we're seeing light from a binary star system that lies so far away, its light has taken more than 10 billion years to reach us.

Massive, luminous red-blue binaries are common in our own galaxy. But even with two stars contributing to Mothra's glow, and assuming they're the most luminous known kind of supergiant stars, the pair must be magnified by at least a factor of 4,000 to attain Mothra's observed brightness.

Kaiju Stars

Mothra and Godzilla owe their names to their monstrous, ancient, and arcane nature, which inspired astronomers to give them nicknames from Japanese kaiju characters. Although it's not (yet?) an official definition, the term *kaiju star* could refer to any ancient, highly luminous, and incredibly magnified star (single or binary) that comes with a dose of mystery due to the invisible thing amplifying its light.

Are We Detecting Dark Matter?

One of the most intriguing aspects of Mothra is the question of what is magnifying the binary so dramatically. The magnifier cannot be a microlens, because Mothra was also seen (but not recognized) nine years earlier by the Hubble Space Telescope, and that's far too long for a microlensing event to last. The magnifier therefore must be a millilens that is too faint for JWST to observe directly.

The duration of the millilensing event requires the millilens to have a mass of at least 10,000 solar masses. In addition, it can't be more massive than 2 million solar masses, because Mothra appears as an unresolved point source, and more massive millilenses would produce a slightly resolved image, separating Mothra and the millilens into two points.

The most familiar candidate in this mass range is a globular cluster. We've seen thousands of globulars orbiting within MACS0416, and globulars are massive enough to provide a millilensing effect lasting several decades. In addition, small globular clusters are faint enough to avoid detection in the JWST images. The probability of one of the MACS0416 globulars aligning with a distant binary star like Mothra is approximately 20%, thus making this a reasonable explanation.

Another, more exotic, candidate is a clump of dark matter. We don't yet know the nature of dark matter and therefore don't know how easily it clumps together. Different models — a pessimist would say "guesses" — for the nature of dark matter predict disparate numbers of millilenses in galaxy clusters. In some models, these clumps (or "halos") are expected to be more numerous than globular clusters. Different models also predict different mass ranges for the halos.

Classic *warm dark matter* models, with relatively light particles, usually produce halos with masses of at least several million solar masses, too large to be the Mothra millilens. The mainstream *cold dark matter* model, however, predicts a wealth of dark-matter halos in the proper mass range and is therefore consistent with the observations.

Another popular model is *fuzzy dark matter*, in which the particles are incredibly light and exhibit quantum properties over scales of hundreds of light-years. These models predict small perturbations in dark matter's distribution. Normally we couldn't detect these perturbations, but if a clump of fuzzy dark matter lies near the critical curve and acts as a millilens, the combined lensing effect would produce local magnification differences that are compatible with the observations.

Mothra is not the only massive star lensed by an unknown object. We've also found Godzilla, whose light has traveled 10.9 billion years to reach us, behind the cluster PSZ1 G311.65–18.48. Godzilla may be a massive, evolved variable star in the midst of an outburst. It appears to have been magnified somewhere between 600 and 7,000 times by a millilens similar in mass to a dwarf galaxy. As is true for Mothra, Godzilla's millilens is too small for some varieties of warm dark matter, but it's fully consistent with cold dark matter.

Current data won't tell us what Mothra's and Godzilla's millilenses are. But if we gather enough examples in other clusters, we may be able to shed some light (pun intended) on the question. Observations just approved for JWST have a target list of 182 lensing clusters and may discover many more stars like these. Thanks to gravitational lensing, JWST could even observe the first stars, formed when the universe was just a few hundred millions years. The search is on.

■ **JOSÉ DIEGO** is a lens-model expert and astronomy professor at the Institute of Physics of Cantabria in Spain who has helped discover several lensed stars. **STEVEN WILLNER** is an infrared astronomer at the Center for Astrophysics, Harvard & Smithsonian, who is beginning to learn about gravitational lensing.

SKY AT A GLANCE
October 2024

1 MORNING: The soft glow of the zodiacal light should be visible from dark locations at mid-northern latitudes beginning about two hours before sunrise. In the next two weeks, look toward the east for a tall, hazy pyramid of pale light stretching from Cancer through Gemini into Taurus and beyond.

5 DUSK: Face southwest right after sunset to see the waxing crescent Moon 4° lower left of Venus — you'll need a clear and unobstructed horizon. Turn to page 46 for more on this and other events listed here.

7 DUSK: Look toward the south-southwest to spot the lunar crescent hanging some 2° left of Antares, the red supergiant in Scorpius. The view improves as twilight deepens.

10 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:12 p.m. PDT (see page 50).

13 EVENING: Algol shines at minimum brightness for roughly two hours centered at 9:00 p.m. EDT.

14 EVENING: In the southeast, the waxing gibbous Moon gleams about 3½° lower left of Saturn.

19 EVENING: The Moon, just two days past full, trails the Pleiades by 4° as they climb in the east. Jupiter and Aldebaran follow close behind.

20 EVENING: The waning gibbous Moon is about 5° upper left of Jupiter in Taurus. You'll see this sight above the east-northeastern horizon.

20–21 ALL NIGHT: The Orionid meteor shower is expected to peak. However, the waning gibbous Moon will hamper viewing. Turn to page 50 for more details.

23 MORNING: The Moon, just shy of third quarter, forms a triangle with Castor and Pollux high in the east. Mars completes the tableau below the trio.

25 DUSK: Face southwest to see Venus blazing around 3° upper right of Antares. You'll have to be quick to catch this sight as the duo rapidly sinks toward the horizon.

26 MORNING: The waning crescent Moon is in Leo with Regulus about 3° to its lower right. Enjoy this view as the pair climbs in the east-southeast before sunrise.

30 EVENING: Algol shines at minimum brightness for roughly two hours centered at 10:53 p.m. PDT.
—DIANA HANNIKAINEN

▲ The zodiacal light tilts to the upper right in the sky near Duluth, Minnesota, shortly before the start of morning twilight on October 3, 2016. Comet and asteroid dust in the plane of the solar system contribute to the cone of light. BOB KING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

NEW MOON
October 2
18:49 UT

FIRST QUARTER
October 10
18:55 UT

FULL MOON
October 17
11:26 UT

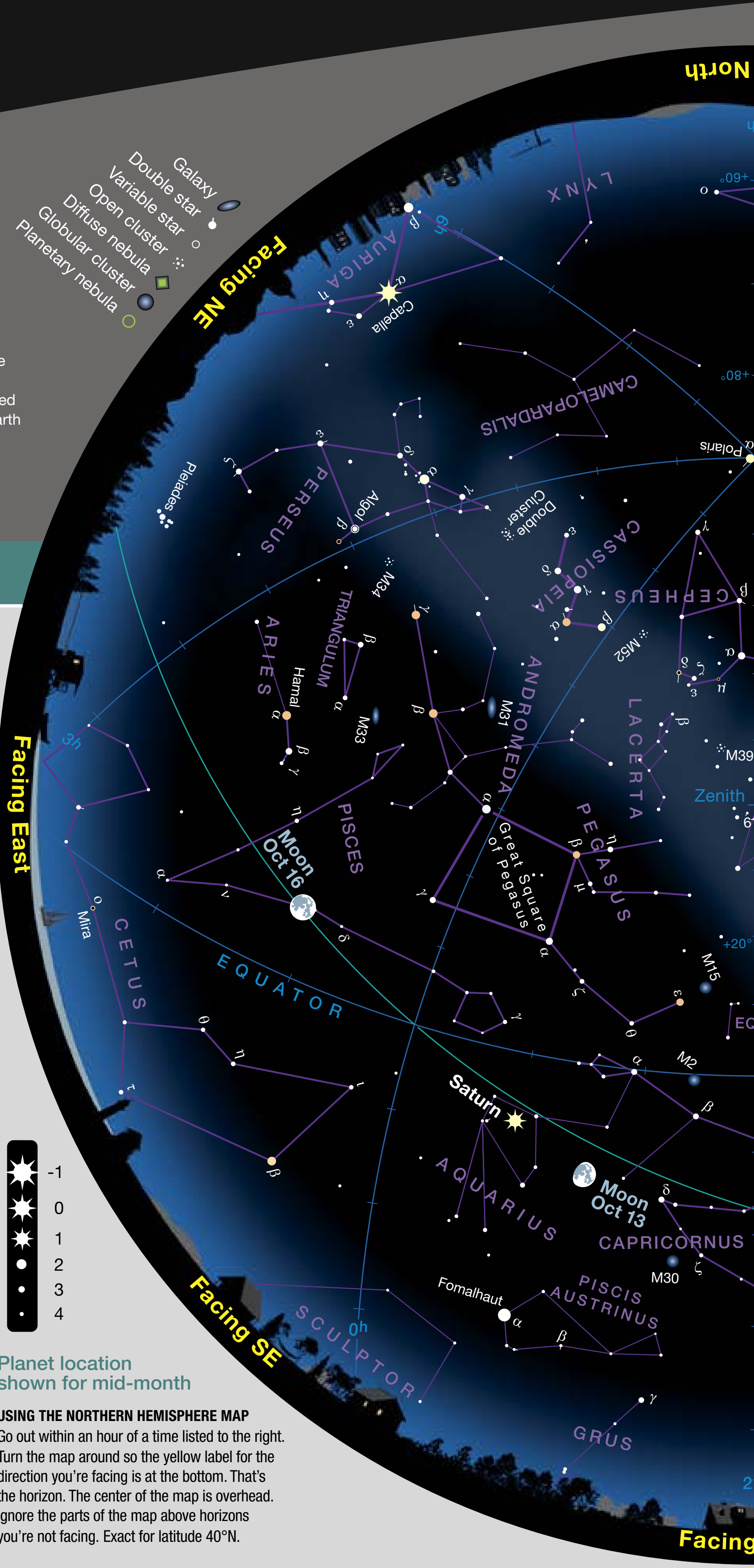
LAST QUARTER
October 24
08:03 UT

DISTANCES

Apogee	October 2, 20^h UT
406,515 km	Diameter 29′ 23″
Perigee	October 17, 01^h UT
357,176 km	Diameter 33′ 28″
Apogee	October 29, 23^h UT
406,161 km	Diameter 29′ 25″

FAVORABLE LIBRATIONS

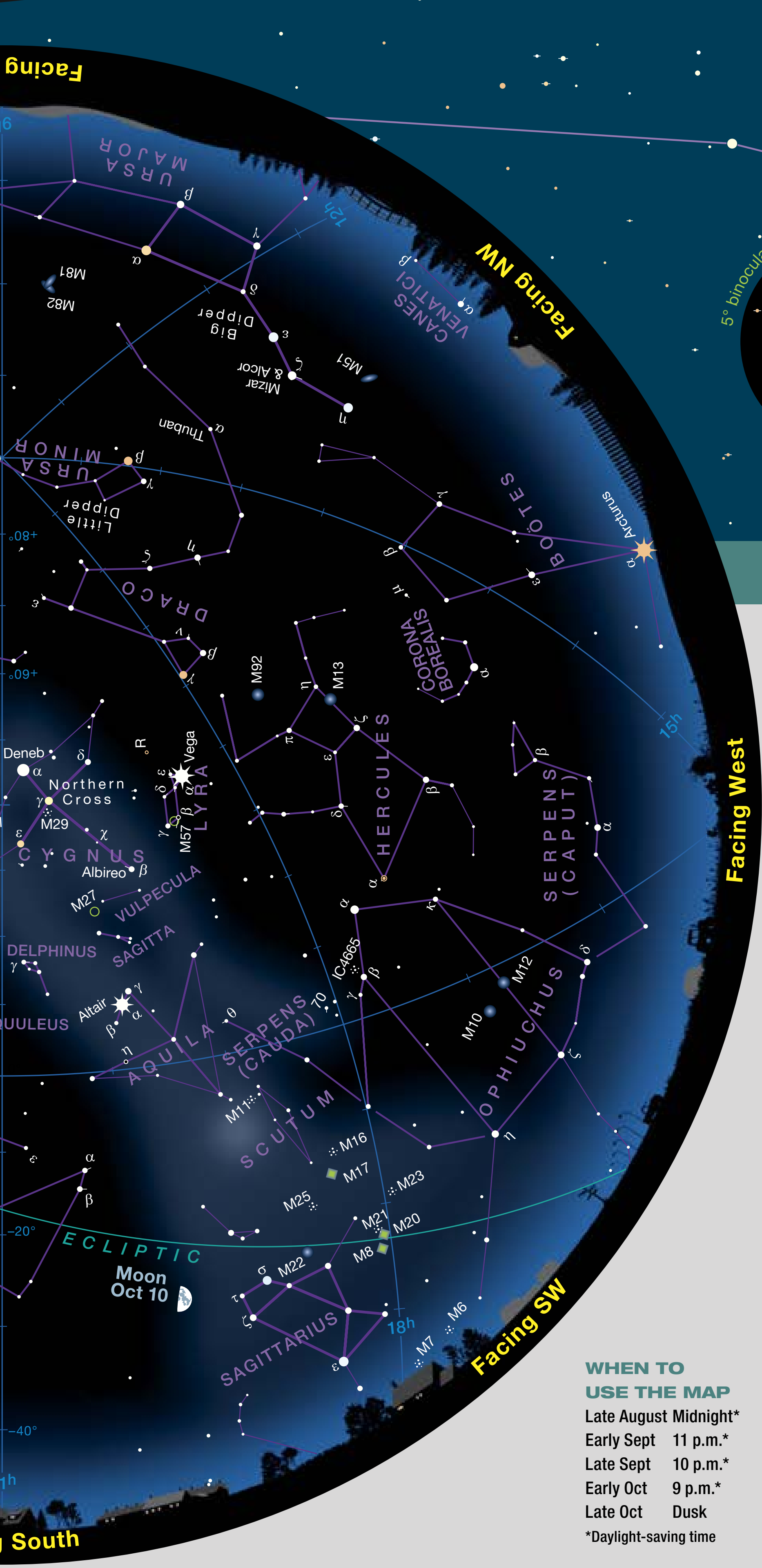
• Short Crater	October 16
• Malapert Crater	October 16
• Brisbane E Crater	October 17
• Hanno Crater	October 17

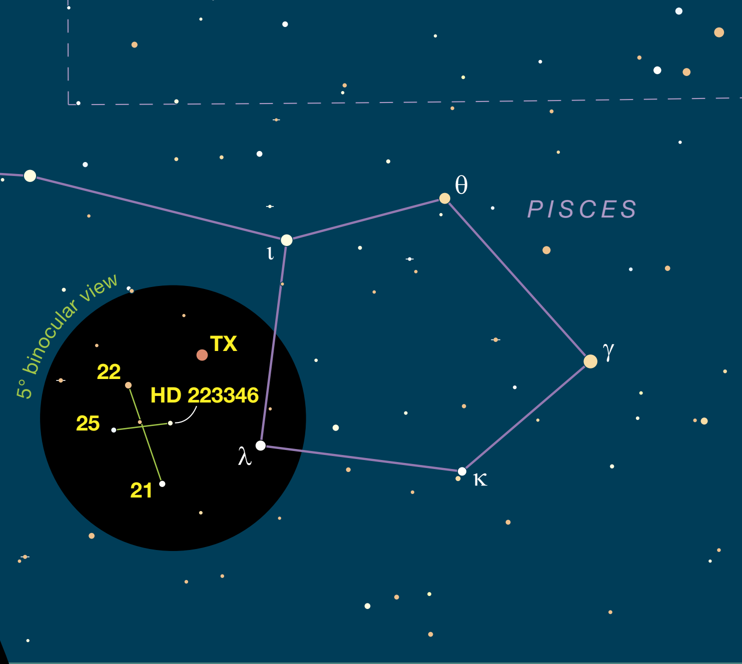


Planet location shown for mid-month

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. Exact for latitude 40°N.





WHEN TO USE THE MAP

Late August	Midnight*
Early Sept	11 p.m.*
Late Sept	10 p.m.*
Early Oct	9 p.m.*
Late Oct	Dusk

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Star Crossed

Our targets this month are the carbon star **TX Piscium**, in the constellation Pisces, the Fishes, and a nearby asterism that makes a handy comparison. Start with the famous Circlet of Pisces, south of the Great Square of Pegasus, which is a neat naked-eye asterism in its own right. TX, also known as 19 Piscium, floats just east of an imaginary line connecting Iota (ι) and Lambda (λ) Piscium.

TX Piscium is a carbon star, famous for its deep red color. The star's hue makes it challenging to get an accurate read on its brightness, and that's further exacerbated by the fact that it's a variable. It's not one of the more showy variables, but its brightness does range between 4.8 and 5.2 on a long and complicated schedule measured in months. Binoculars help make the star's red color more apparent, regardless of its brightness.

Less than 2° southeast of TX Piscium is a charming little binocular asterism in the shape of a slanted cross, formed by **21**, **22**, and **25 Piscium**, and **HD 223346**. The stars 21 and 25 Piscium are white or blue-white stars, so they make a good visual baseline for assessing the redness of TX Piscium. As with all carbon stars, I see TX Piscium's color most strongly at low magnifications. My 7×35 binos are my ride of choice here, both for showing off TX Piscium's striking red color, and for putting some elbow room around the cross asterism so it really pops. If I hop up to 15×70s, the red spark now shows distinctly orange. If you have more than one pair of binos, try each of them to see how your perception of the star's color changes with magnification.

■ **MATT WEDEL** loves comparing views through different instruments — as a serious observer, mind you, definitely not just some guy obsessed with binoculars.

OCTOBER 2024 OBSERVING

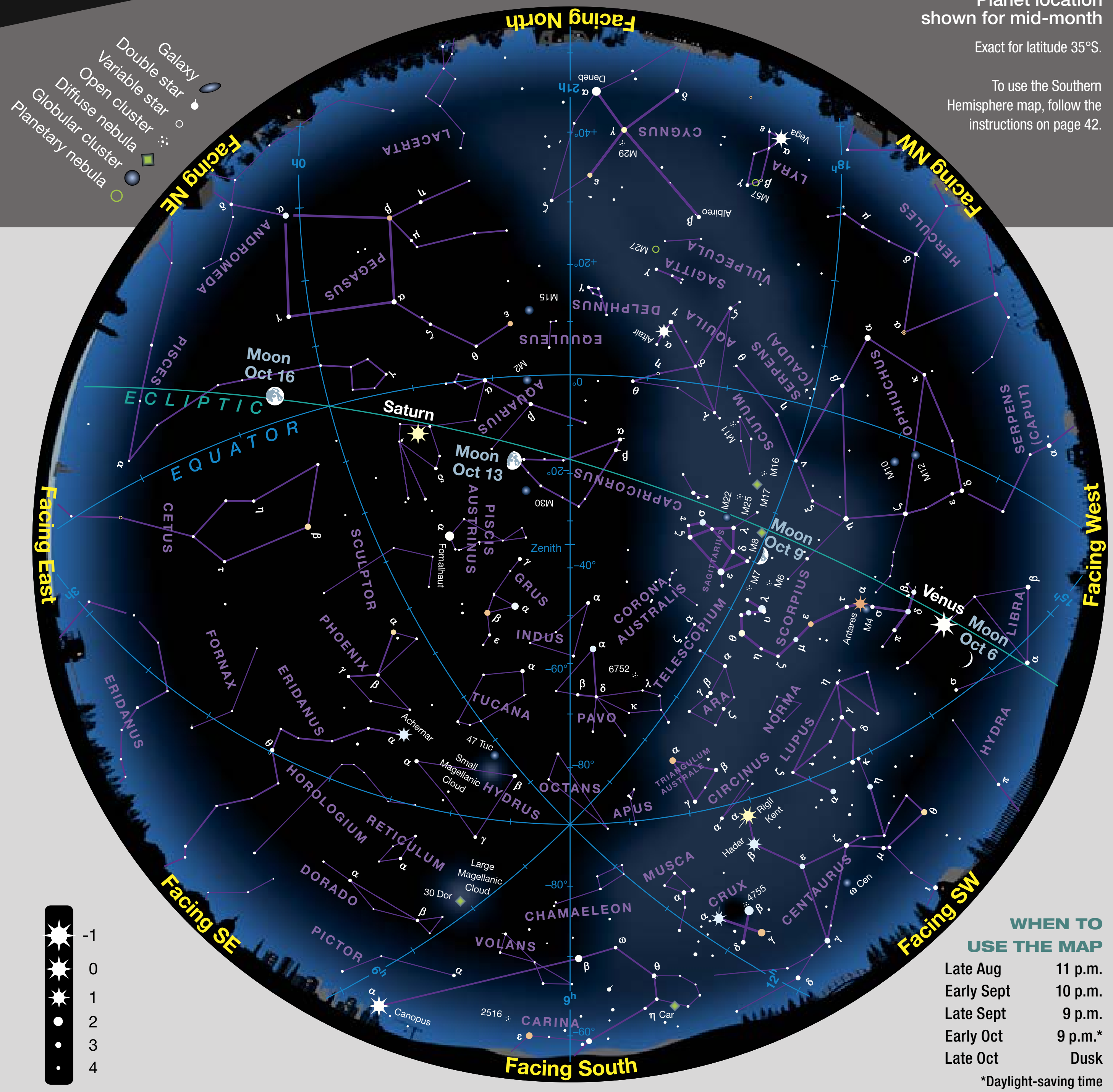
Southern Hemisphere Sky Chart

by Jonathan Nally

Planet location shown for mid-month

Exact for latitude 35°S.

To use the Southern Hemisphere map, follow the instructions on page 42.



WHEN TO USE THE MAP

Late Aug	11 p.m.
Early Sept	10 p.m.
Late Sept	9 p.m.
Early Oct	9 p.m.*
Late Oct	Dusk

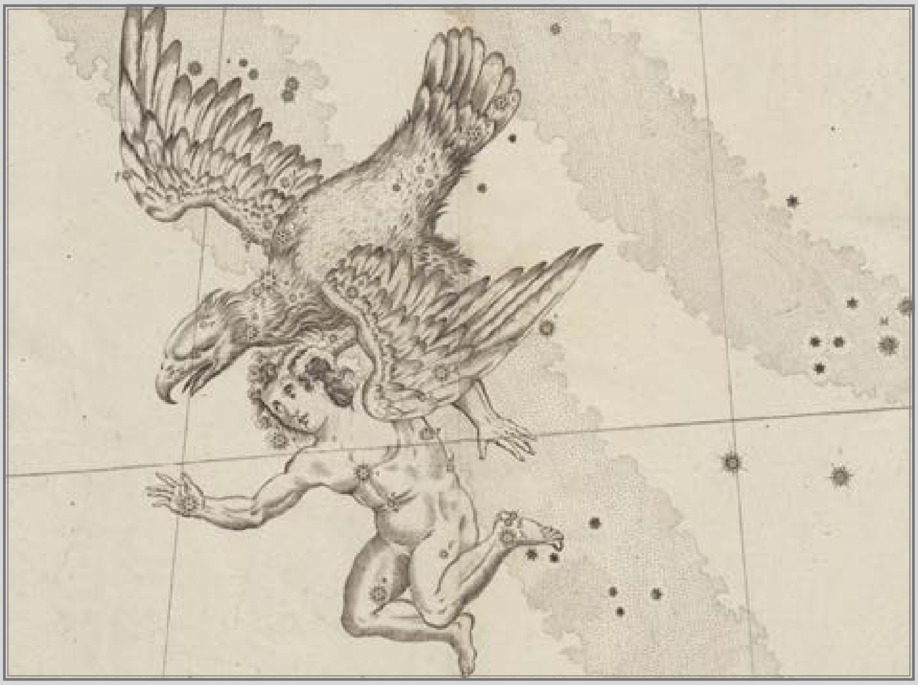
*Daylight-saving time

HIGH IN THE SKY on October evenings is **Indus,** the Indian, a seemingly nondescript constellation that first appeared on a globe of the sky produced by Dutch cartographer Petrus Plancius in 1568. Johann Bayer later incorporated it into his famous *Uranometria* star atlas in 1603.

On the chart above, Indus is presented as a crude triangle with its tips marked by the constellation's three brightest stars. Of these, only 3.1-magnitude Alpha (α) Indi is labeled. The triangle's southernmost point is marked by 3.7-magnitude Beta (β), while the western point of the triangle is occupied by 4.4-magnitude Delta (δ). Alpha is almost 60 times brighter than our Sun and about 10 times bigger. Beta, however, is a whopping 1,180 times more luminous than the Sun and roughly 60 times larger. ■

Twice-Told Tale of Ganymede

Two star patterns of the same mythical figure appear in the night sky this month.



▲ Johann Bayer's depiction of Aquila in his *Uranometria* star atlas shows the Eagle either snatching up Ganymede or transporting the spirit of Antinous into the realm of the immortal gods.

For a period of time, one mythological figure had the honor of appearing twice: Ganymede, a Trojan prince of unusual beauty. The two stellar representations of Ganymede are near each other in the autumn night sky, though only one is still recognized as a constellation today: Aquarius, the Water Bearer.

In his epic poem the *Iliad*, 8th-century BC Greek poet Homer tells us that Ganymede was "born the fairest of mortal men; wherefore the gods caught him up on high to be the cupbearer to Zeus by reason of his beauty, that he might dwell with the immortals." Later tales differ in the means by which Ganymede was transported into the sky. For instance, in the 2nd-century compendium of Greek mythology, the *Bibliotheca* of Pseudo-Apollodorus, we read that "Zeus kidnapped Ganymedes [sic] by means of an eagle, and set him as cupbearer in the sky" as Aquarius.

The 1867 *Dictionary of Greek and Roman Biography and Mythology* adds that the idea of Ganymede being the cupbearer of Zeus "subsequently gave rise to his identification with the divinity who was believed to preside over the sources of the Nile and of his being placed by astronomers among the stars under the name of Aquarius."

A different set of stars representing Ganymede initially had a second identity. The first came at the request of Roman emperor Hadrian (AD 76–138), who wanted a constellation named after Antinous, a favorite youth in his court. While on a journey with Hadrian, Antinous allegedly drowned in the Nile. In his *Roman History*, Dio Cassius (c. AD 155–229) notes that Hadrian was "in general a great dabbler in superstitions and employed divinations and incantations of all kinds." So, when Hadrian saw a new star in the heavens, he "gladly lent an ear to the fictitious tales woven by his associates to the effect that the star had really come into being from the spirit of Antinous."

Antinous ultimately made it into the heavens, but not as a constellation — at least not at first. In Ptolemy's 2nd-century *Almagest*, Antinous is merely listed as an asterism of six stars belonging to the constellation Aquila. "Ptolemy deferred to the Greek tradition, which already saw the youth Ganymede clutched in the Eagle's talons," writes John Barentine in his delightful 2016 book *The Lost Constellations*, "but perhaps in recognition of the political realities of the era included Antinoüs by way of a mention." Today, we know these stars as Delta (δ), Eta (η), Theta (θ), Iota (ι), Kappa (κ), and Lambda (λ) Aquilae.

Fast forward to the 16th century, when German cartographer Caspar Vopel rendered Antinous as an independent constellation on his 1536 celestial globe. Fellow German cartographer Johann Bayer was the first to depict Ptolemy's stars as a young man clutched in the talons of Aquila. In his 1603 *Uranometria* star atlas, he identifies the figure as Ganymede. But he also mentions that the Romans knew the stars as Antinous. So, it was Bayer who set the stage for the figure's dual identity. The shift back to Ganymede likely was due to a rising interest in the classical world during the Renaissance.

Over the next four centuries, Ganymede and Antinous shared the limelight in celestial atlases. By the mid-19th century, Ganymede clearly overshadowed Antinous. That all came to an end in 1922 when the International Astronomical Union nailed the coffin shut on both figures by relegating the duo's six stars solely to Aquila.

This month, Saturn points you to Ganymede as Aquarius. A slight shift northward to Aquila places you in the realm of the second representation of Ganymede, or, if you prefer, Antinous.

■ Contributing Editor **STEPHEN JAMES O'MEARA** has been studying the stars and their lore for more than 50 years.

To find out what's visible in the sky from your location, go to skyandtelescope.org.

Venus Visits Antares

Evening twilight offers several close pairings this month.

SATURDAY, OCTOBER 5

Conjunctions between the **Moon** and **Venus** are reliably eye-catching, though some are better than others. The one occurring at dusk today is worth taking in, but a couple of factors conspire to make it tricky to view. The main problem is the Moon sits just 10° — the width of a clenched fist at arm's length — above the horizon at sunset. The Evening Star is in a slightly better position, perched 4° upper right of the waxing lunar crescent. All this means you need an unobstructed view towards the west-southwest and a sky clear of clouds, which tend to congregate near the horizon.

Although Venus is several months along in its current evening apparition, it's been picking up altitude with frustrating slowness. That begins to change in October as it gains a bit more than 4° — most of that in the latter half of the month. The planet will adorn the evening sky all the way through to March 2025, when it finally has its conjunction with the Sun and transitions into a morning sight.

MONDAY, OCTOBER 7

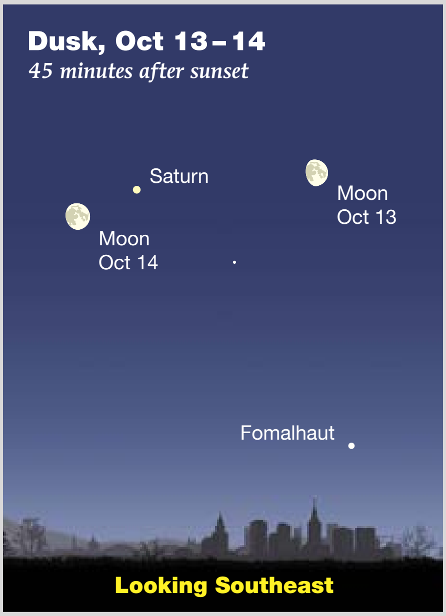
Two days after its encounter with Venus, the **Moon** meets up with **Antares**, the flickering red heart of Scorpius, the Scorpion. This is another low-lying dusk event, however. Look to the southwest as twilight begins to fade, and you'll see the star a bit more than 2° to the right of the lunar crescent. It's potentially a delightful naked-eye sight, but you might want to get your binoculars out anyway. If you do, you'll get to see that the Moon is even closer to 2.8-magnitude Tau (τ) Scorpii. Look for that star less than ¼° below the Moon. Tau is one of the two stars that neatly flank Antares — 2.9-magnitude Sigma (σ) Scorpii being the other. Your binoculars will let you see all three stars in the same field as the Moon. Be sure to look early in the evening, though, since the entire bunch loses altitude as it sets.

MONDAY, OCTOBER 14

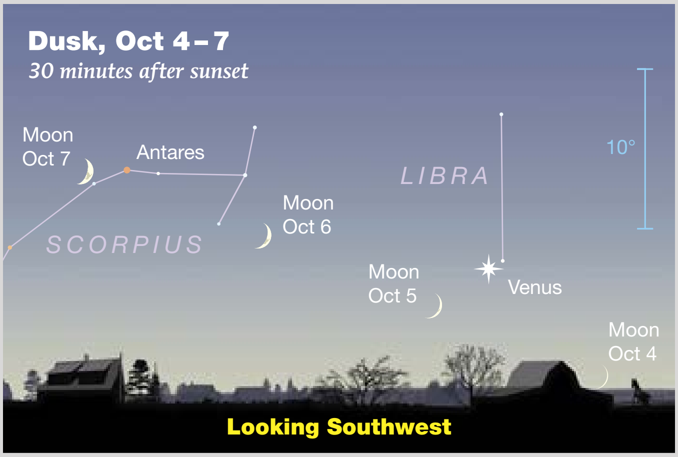
From a purely visual perspective, there's no doubt that the Moon-and-Venus pairing is the month's highlight. But it's not the closest encounter our satellite has with a planet in October. That distinction falls to this evening's conjunction with **Saturn**.

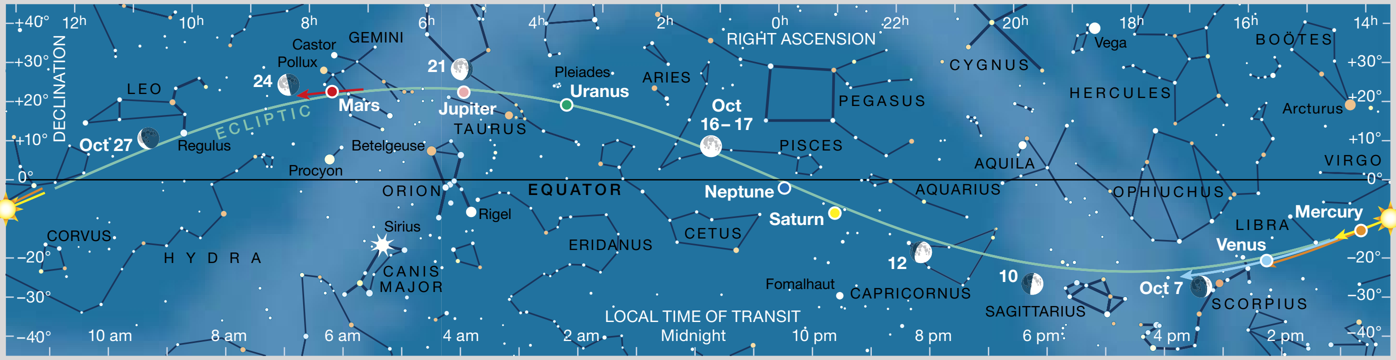
As darkness falls, look to the east-southeast to catch the 91%-illuminated waxing gibbous **Moon** some 3½° below left of Saturn. The famed Ringed Planet reached opposition last month and presently shines at magnitude +0.7. The proximity of a nearly full Moon is a clue that Saturn is only a little past opposition. With each succeeding encounter, the Moon will be less and less full as Saturn gets further from its opposition date. So, when they meet again in November — two months after Saturn's opposition — the lunar disk will be only 70% illuminated.

Similarly, by October 20th, when the Moon is next to **Jupiter**, it will be a *waning* gibbous — indicating that the planet hasn't yet reached opposition. When Jupiter hits that mark on



▶ These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). European observers should move each Moon symbol a quarter of the way toward the one for the previous date; in the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist held out at arm's length.





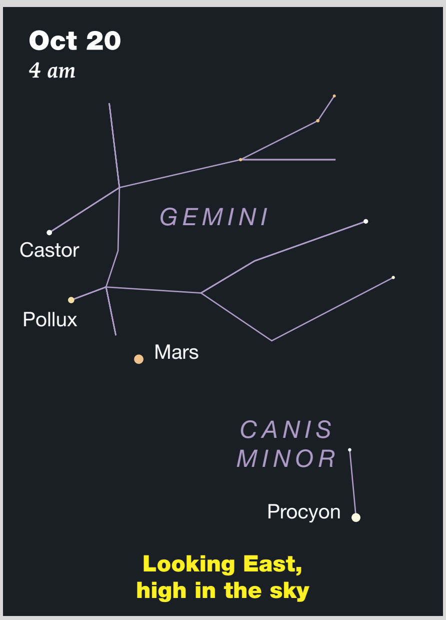
▲ The Sun and planets are positioned for mid-October; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side illuminated). "Local time of transit"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

December 7th, it will play host to the full Moon a week later.

SUNDAY, OCTOBER 20

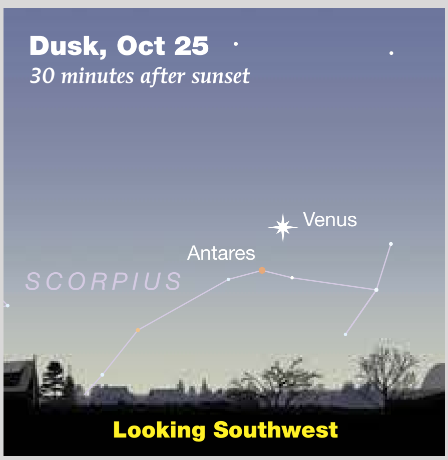
No planet sweeps across so great an expanse of night sky as swiftly as **Mars**. The Red Planet spends October racing eastward along the ecliptic through Gemini before landing in neighboring Cancer at the end of the month. You can gauge Mars's nightly progress by noting its position relative to Gemini's two brightest stars, **Castor** and **Pollux**. However, in the predawn hours of the 20th, you have an even better chance to see it in motion. That's because Mars crosses a line connecting Pollux and **Procyon**, the Alpha star of Canis Minor. The trio are of similar brightnesses, with Pollux at magnitude 1.1, Mars at +0.3, and Procyon +0.4.

You might be surprised to notice how briefly the planet sits *exactly* between Pollux and Procyon. If you look carefully, you may be able to detect Mars's motion with your naked eye over the span of just a few hours. At present it's moving slightly less than one Moon diameter (½°) per day. Don't miss this chance to watch the wheels of the celestial machinery in motion! (But if you do, you can try again on October 29th.)



FRIDAY, OCTOBER 25

Hot on the heels of the Moon, at dusk today **Venus** gleams brilliantly just 3° above right of **Antares**. That's close enough that both objects can be held in view together in a typical pair of binoculars — which is a good thing considering how low they are. Half an hour after sunset, Antares stands about 8° above the southwestern horizon.



Although it shines at 1st magnitude, the twilight sky is bright enough and the star is low enough that binoculars will definitely be a big help. Fortunately, you can key off Venus, which will be obvious even under these less-than-ideal circumstances.

TUESDAY, OCTOBER 29

How did you make out with **Mars** on the 20th? If the weather wasn't in your favor, you have a second chance to observe the Red Planet's motion. If you go out this evening just a little before midnight and face east-northeast, you'll see the trio of **Castor**, **Pollux**, and Mars in a row. Indeed, the alignment is very nearly perfect. The planet is just slightly right of a line drawn through the two stars and extended toward the horizon.

As the night of the 29th transitions into the morning of the 30th, Mars will continue to approach that line but won't quite get there by dawn. And when you look again on the night of the 30th, the planet will have traversed our imaginary line and sits to its left. Incidentally, Mars crossed the (invisible) border between Gemini and Cancer on the afternoon of the 29th. It remains in Cancer until January 11th, when its retrograde motion carries it westward back into Gemini for another alignment with Castor and Pollux later that month.

■ Consulting Editor **GARY SERONIK** always enjoys watching the celestial wheels in motion.

Comet Tsuchinshan-ATLAS Soars at Dusk

Catch this icy solar system visitor at its brightest this month.

Assuming this highly anticipated comet survived perihelion last month, Tsuchinshan-ATLAS (C/2023 A3) should be at its best during the peak of the autumn color season. On October 1st it's briefly visible at dawn just 5° above the east-southeast horizon 45 minutes before sunup from latitude 40° north. By the 5th, the comet will be even lower, but it should shine at its peak brightness, somewhere between zero and 1st magnitude.

After a week hidden in the Sun's glare, the comet practically leaps into view at dusk starting on the 11th, when observers with an unobstructed western horizon might catch it just a few degrees high in twilight. Be sure to pack binoculars. Not only will they help pluck the misty visitor from the gloaming, but they'll also reveal what may be an impressive tail.

From our Earthly perspective, the comet is nearly in line with the Sun — a favorable viewing angle that maximizes the amount of forward scattering, which enhances the tail's brightness and length. It may even be possible to photograph the appendage poking above the horizon after the coma itself has set.

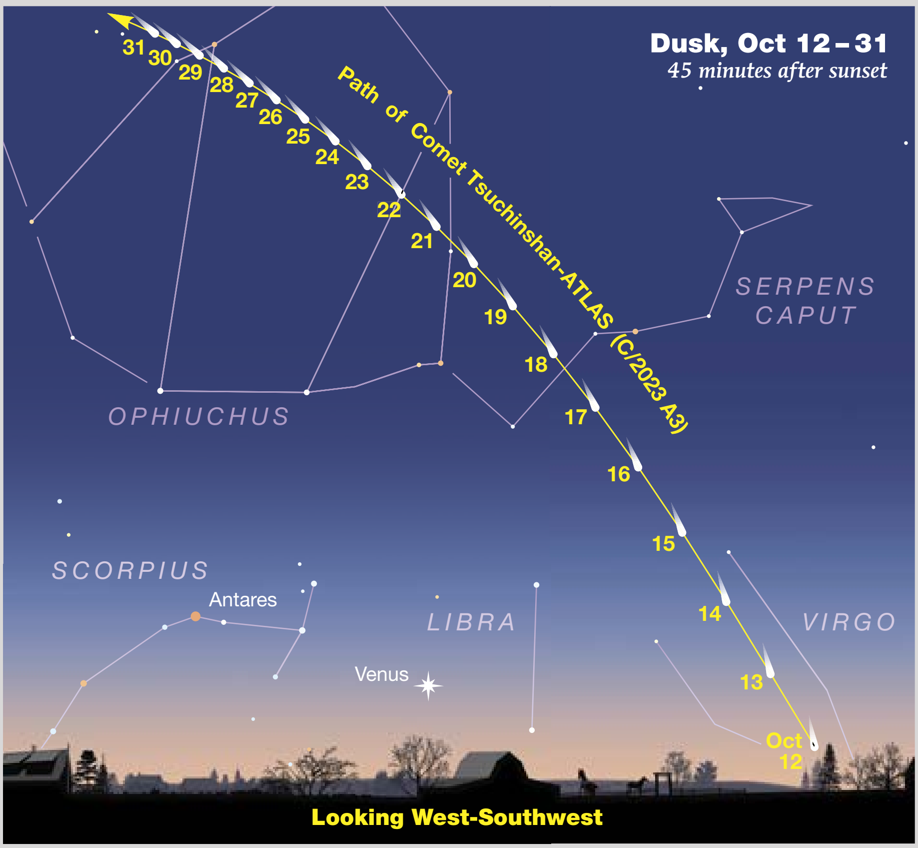
Tsuchinshan-ATLAS climbs higher as it drifts northeast at a pace of more than 5° per day around the time it has its closest approach to Earth at a distance of 70.6 million kilometers (43.9 million miles) on the 12th. Two nights later, it hangs a comfortable 6½° high at the end of evening astronomical twilight as seen from mid-northern latitudes. And it keeps climbing.

Of course, the trade-off for the comet's improved altitude is its gradual dimming as it drifts away from the Sun. It tumbles from its peak brightness at the start of the month to around 5th magnitude by Halloween. A naked-eye comet lingering for more than a month is a gift, but this one comes with a catch. Unfortunately, the Moon compromises the view until about the 20th, when it exits the evening sky.

Viewing circumstances are best at mid-northern and tropical latitudes due to both the shorter twilights and the comet's steady track to the northeast. For Southern Hemisphere skywatchers, Tsuchinshan-ATLAS clears the western horizon at twilight's end starting around October 16th and quickly climbs in the northwest.

As it makes its way across the autumn sky, on the night of October 15th (near 0h UT on the 16th) the comet coasts just 1.2° south of the 5.7-magnitude globular cluster M5, in Serpens. The pairing makes for a sumptuous sight in a wide-field telescope as well as a sweet photo opportunity. On the 28th, Tsuchinshan-ATLAS glides between the bright open cluster IC 4665 and the 11th-magnitude globular cluster NGC 6426 in Ophiuchus.

Gravitational perturbations from the planets during its visit have reworked the comet's orbit so it's now weakly hyperbolic. It may never return to the inner solar system again. And if it does, expect a *very* long wait!



▲ The comet's position is shown for 0h UT on the dates indicated.

A South Pacific Annular Eclipse

◀ Clouds can sometimes be a good thing when it comes to photographing annular or partial eclipses. Ross A. Whitley captured this partly cloudy scene from San Antonio, Texas, as the Moon departed the Sun's disk during the October 14, 2023, annular solar eclipse.

THE YEAR'S SECOND and final solar eclipse will be annular. Most of the 14,200-kilometer-long eclipse track crosses remote regions of the Pacific Ocean, with land-based viewing options limited to either Easter Island (Rapa Nui) or the mountains and pampas of Patagonia — both of which are enchanting locations.

Central annular eclipse begins on October 2nd at 16:54 UT, some 1,700 km southwest of Hawai'i. As the Moon's antumbral shadow hastens southeast, the path of annularity narrows from 332 km to 266 km at greatest eclipse, when the annular phase reaches a maximum duration of 7 minutes 25 seconds at 18:45 UT. At that time, the Moon will be less than one hour shy of apogee (farthest from Earth) and will obscure 87% of the Sun's disk. Eclipsophiles will note that this "ring of fire" will appear slightly thicker compared to last October's annular eclipse.

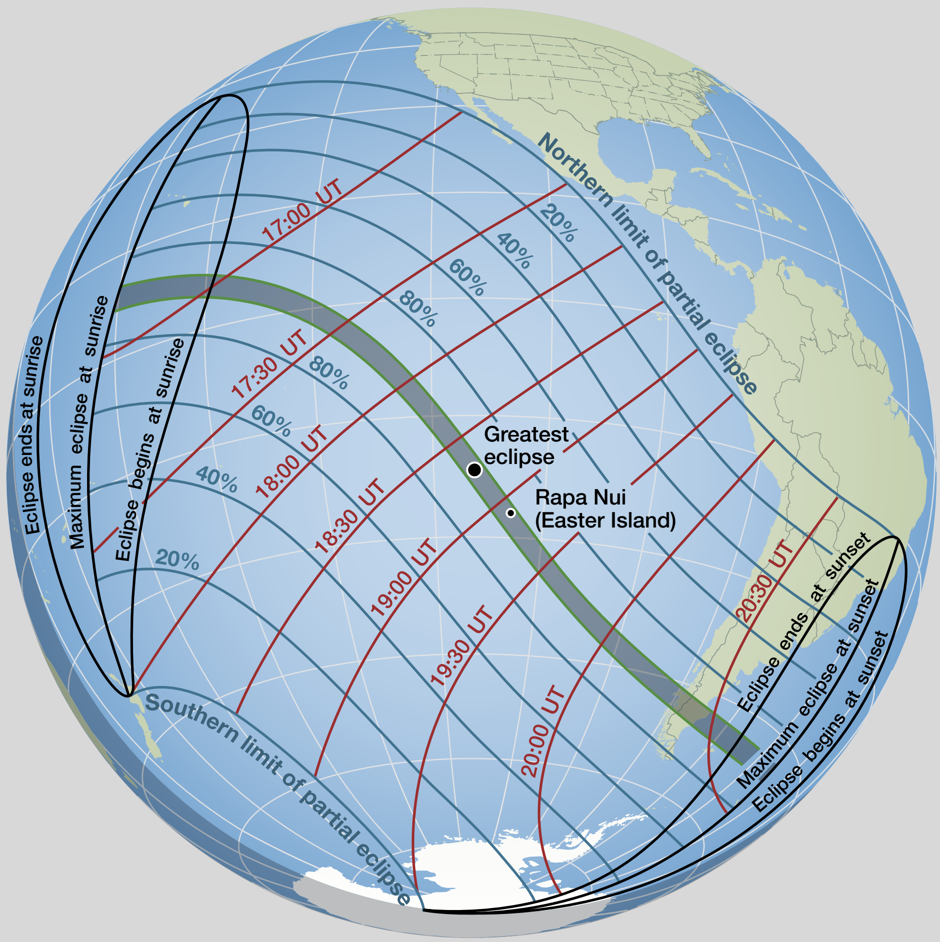
Landfall at Easter Island occurs at 19:07 UT (just after 2 p.m. local time) with the Sun high in the southwestern sky. Although the island lies northeast of the centerline, observers at Hanga Roa, the island's only town, will witness a generous 6m 22s of annularity. After racing across more than 2,000 km of open sea, the antumbra touches down again along the coast of Patagonia, Chile, where annularity lasts about 6m 26s and maximum eclipse occurs at 20:22 UT (5:22 p.m. local daylight time).

As the shadow flies east, it passes over the snowcapped Andes Mountain range before descending into the Argentine pampas. After leaving Argentina, the shadow passes north of the Falkland Islands and finishes its long journey at sunset in the South Atlantic Ocean.

Weather conditions on land along the path of annularity will be challenging. On Easter Island the mean October cloud cover is nearly 70%. Chile offers a few pockets of potentially clear skies in valleys tucked between tall peaks. Eastern Argentina, where some locales average 55% cloudiness, offers the best land-based weather prospects according to eclipse weather expert Jay Anderson. For more weather details, visit his website, **eclipsophile.com**.

Observers across the southern portion of South America, parts of Antarctica, extreme western Mexico, New Zealand's North Island, and Hawai'i will see a partial solar eclipse. In Honolulu the Moon will cover 58% of the Sun at maximum.

As always, be sure to protect your eyes when viewing this event. At no point during an annular eclipse is it safe to view the Sun without eclipse glasses!



LEAH TISCIONE / *S&T*, SOURCE: FRED ESPENAK

Two Challenging Meteor Showers

IF YOU'RE A cup-half-full sort of meteor watcher, you'll be interested in two modest displays this month: the Orionids and the Draconids.

First up is the Draconid meteor shower, which appears to radiate from the Dragon's head, at a spot midway between Beta (β) and Nu (ν) Draconis. (Both stars are labeled on our star map on pages 42 and 43.) Famous for the spectacular storms of 1933 and 1946, the shower's nominal rate is a piddling five meteors per hour. This year's peak occurs on the 8th around 13 UT, making the night of October 7–8 your best bet. At least the Moon isn't a bother — the thick waxing crescent sets around 9 p.m. local daylight time on the 7th.

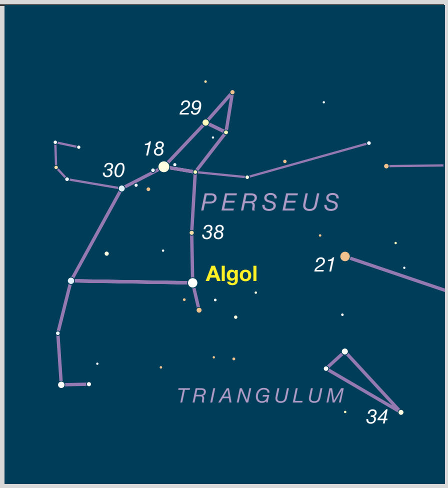
In contrast to the speedy Orionids, the Draconids are among the slowest of all meteors — a trait that aids in their identification. There's a small chance for a minor outburst arising from two dust trails laid down in 1852 and 1859 by the shower's parent, Comet 21P/Giacobini-Zinner. The dust trails approach Earth between about 6:30 and 7:00 UT (2:30 a.m. and 3:00 a.m. EDT) on the 8th. Keep an eye out for enhanced activity.

The Orionids peak during the night of October 20–21 at 6:00 UT on the 21st, but the waning gibbous Moon compromises the display. During a typical Orionid shower, you can spot up to 20 swift meteors per hour streaming from the radiant near Betelgeuse, in Orion. But conditions this year likely mean that number will be at least halved. You can make the most of the less-than-ideal circumstances by alternating between meteor watching and using your scope to gaze at the Moon and Jupiter, which happen to be in conjunction on the night of the Orionid peak.

Minima of Algol

Sept.	UT	Oct.	UT
1	0:50	2	13:45
3	21:39	5	10:34
6	18:27	8	7:23
9	15:16	11	4:12
12	12:05	14	1:00
15	8:53	16	21:49
18	5:42	19	18:38
21	2:31	22	15:27
23	23:19	25	12:16
26	20:08	28	9:04
29	16:57	31	5:53

These geocentric predictions are from the recent heliocentric elements Min. = JD 2457360.307 + 2.867351E, where E is any integer. They were derived by Roger W. Sinnott from 15 photoelectric series in the AAVSO database acquired during 2015–2020 by Wolfgang Vollmann, Gerard Samolyk, and Ivan Sergey. For a comparison-star chart and more info, see **skyandtelescope.org/algol**.



▲ Perseus reaches the zenith during predawn hours in October. Every 2.87 days, Algol (Beta Persei) dips from its usual magnitude 2.1 to 3.4 and back. Use this chart to estimate the variable star's brightness in respect to comparison stars of magnitude 2.1 (Gamma Andromedae) and 3.4 (Alpha Trianguli).

Action at Jupiter

OCTOBER IS A GOOD MONTH for Jupiter watchers this apparition. The weather can still be quite mild, and the planet — perched between the horns of Taurus, the Bull — is well placed for observers at mid-northern latitudes. Although the planet now rises in the late evening, it's still primarily a predawn telescopic target. At mid-month Jupiter transits the meridian a full hour before the start of morning astronomical twilight. It shines at magnitude –2.6 and presents a disk spanning 44″ — more than five times bigger than Mars, which sits in neighboring Gemini.

Any telescope reveals the four big Galilean moons, and binoculars usually show at least two or three. Use the diagram on the facing page to identify them by their relative positions on any given date and time. All the observable interactions between Jupiter and its satellites and their shadows are tabulated on the facing page.

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

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

October 1: 6:08, 16:04; **2**: 2:00, 11:55, 21:51; **3**: 7:47, 17:42; **4**: 3:38, 13:34, 23:29; **5**: 9:25, 19:20; **6**: 5:16, 15:12; **7**: 1:07, 11:03, 20:59; **8**: 6:54, 16:50; **9**: 2:45, 12:41, 22:37; **10**: 8:32, 18:28; **11**: 4:24, 14:19; **12**: 0:15, 10:11, 20:06; **13**: 6:02, 15:57; **14**: 1:53, 11:49, 21:44; **15**: 7:40, 17:35; **16**: 3:31, 13:27, 23:22; **17**: 9:18, 19:14; **18**: 5:09, 15:05; **19**: 1:00, 10:56, 20:52; **20**: 6:47, 16:43; **21**: 2:38, 12:34, 22:30; **22**: 8:25, 18:21; **23**: 4:17, 14:12; **24**: 0:08, 10:03, 19:59; **25**: 5:55, 15:50; **26**: 1:46, 11:41, 21:37; **27**: 7:33, 17:28; **28**: 3:24, 13:19, 23:15; **29**: 9:11, 19:06; **30**: 5:02, 14:57; **31**: 0:53, 10:48, 20:44

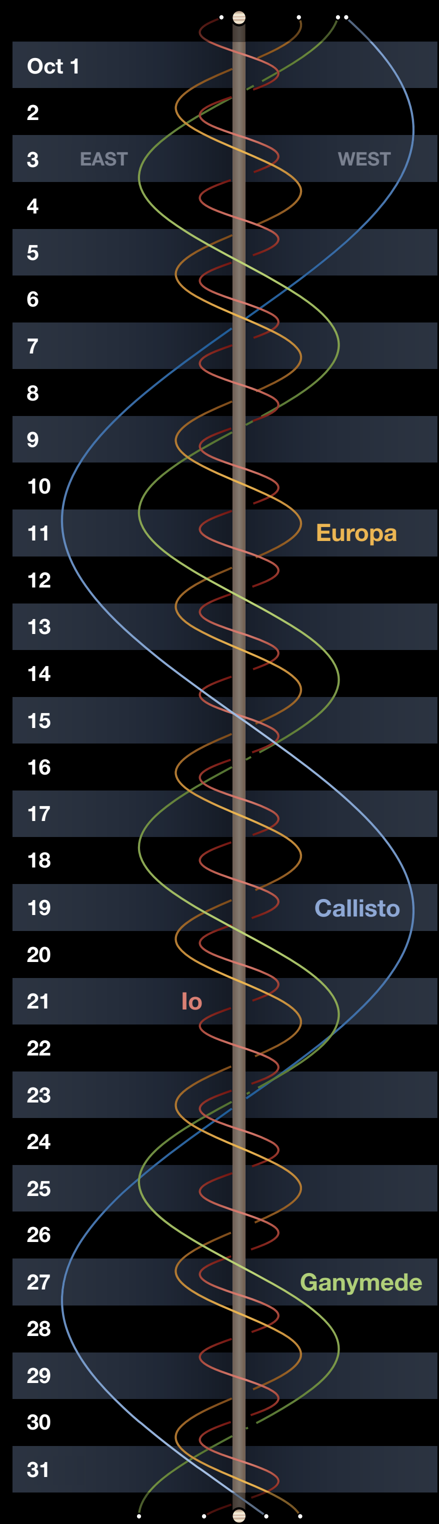
These times assume that the spot will be centered at System II longitude 66° on October 1st. If the Red Spot has moved elsewhere, it will transit 1⅔ minutes earlier for each degree less than 66° and 1⅔ minutes later for each degree more than 66°.

Phenomena of Jupiter's Moons, October 2024

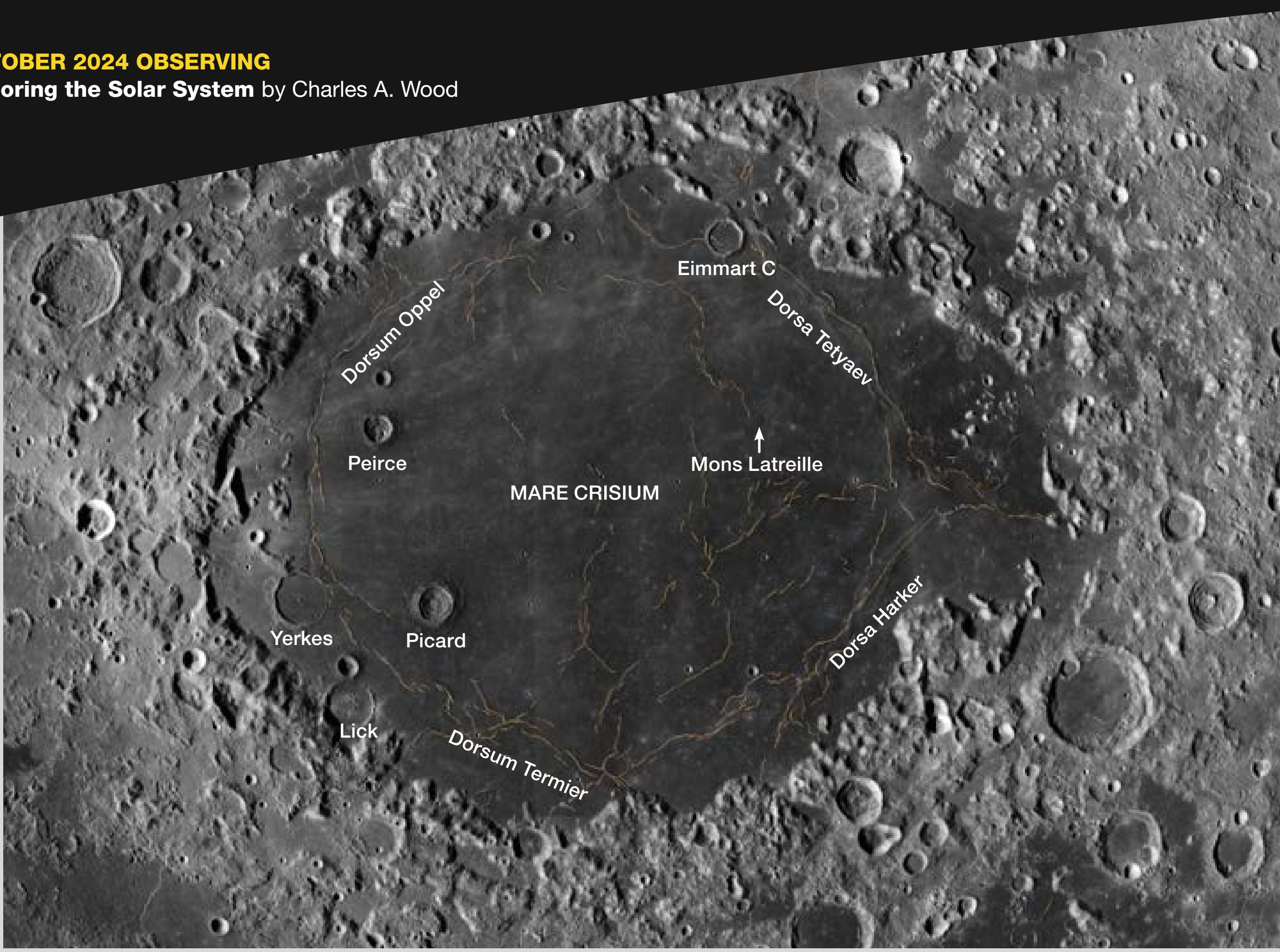
Oct. 1	3:27	I.Sh.I
	4:42	I.Tr.I
	5:36	I.Sh.E
	6:52	I.Tr.E
	8:45	II.Ec.D
	11:15	II.Ec.R
	11:17	II.Oc.D
	13:49	II.Oc.R
	20:33	III.Ec.D
	22:34	III.Ec.R
Oct. 2	0:45	I.Ec.D
	1:45	III.Oc.D
	3:45	III.Oc.R
	4:13	I.Oc.R
	21:55	I.Sh.I
	23:10	I.Tr.I
Oct. 3	0:05	I.Sh.E
	1:20	I.Tr.E
	3:48	II.Sh.I
	6:18	II.Sh.E
	6:21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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard 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.



Take a Tour of Crisium

Subtle clues reveal the story of this quasi-circular lunar mare.

Each *lunation*, or lunar month, begins with two nights of a very slim crescent low in the evening twilight sky. By night three, the progressing terminator illuminates a conspicuous, oval mare. The sight of **Mare Crisium** brings a certain joy to observers, for finally a large, identifiable lunar feature is visible. The dark surface of this mare is mostly empty and surrounded by a rugged, bright ring of unnamed mountains. But a closer look reveals several small features that tell big stories about the history of the Crisium impact basin.

Once the sunrise terminator reaches the eastern edge of the basin, the first major feature within the mare is revealed — the narrow arc of mare ridges known as **Dorsa Tetyaev** and **Dorsa Harker** spanning the northeastern and southeastern shore of the mare, respectively. A day or so later, another ridge, **Dorsum Termier**, rounds the southern edge of the basin and joins **Dorsum Oppel** near the western edge of Crisium's mountainous rim. This complete circle of ridges can't be seen at any one time, but it defines the 365-kilometer-wide (227-mile-wide) inner ring of the Crisium basin. These ridges are actually faults that step down 400 to 500 meters (1,300 to 1,600 feet) to the mostly level basin floor. These ridge faults dip down at 20° from the vertical and penetrate the thin maria surface layer and deep into the uplifted mantle that produced a large *mascon* (mass concentration anomaly) detected in NASA's Gravity Recovery and Interior Laboratory (GRAIL) data.

Basin mare ridges are faults, but most have gentle slopes, not nearly as vertical as those found in Crisium. Is this basin unique, or are there others with steep ridge faults?

Only a few craters are large enough to be easily visible on Crisium's floor. **Picard**, with a 23-km diameter, and **Peirce** (19 km) are the two most conspicuous craters on the mare. Both of these impact features are relatively fresh and formed on top of the mare lavas. The largest Crisium craters are 32-km-diameter **Yerkes** near the western rim, 32-km-wide **Lick** spilling into the southwestern basin rim, and 23-km-wide **Eimmart C** along the mare's northern rim. These three craters are located on the basin's *structural bench*

▲ Mare Crisium is a lava-flooded basin near the Moon's eastern limb best seen a few days after new Moon and again a few days following full Moon. Its mare ridges (marked in orange) are revealed by grazing sunlight over the course of two lunar days.

(a narrow strip of gently inclined land bounded by steeper slopes) and have shallow, lava-flooded crater floors with partially breeched rims — all evidence that the bench is only thinly covered by mare lavas. Similar lava-covered ghost craters are seen along the bench east of Eimmart C.

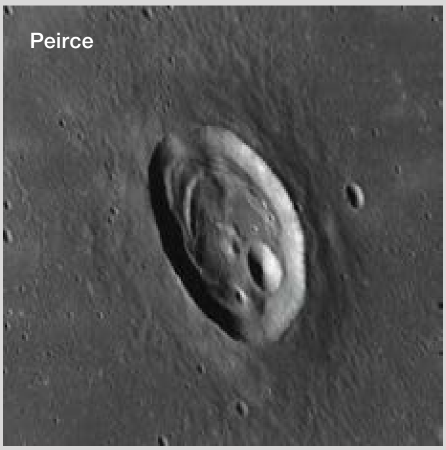
Mare Crisium contains enough small craters to allow crater-counting estimates of the ages of different parts of the mare. The most ancient lavas are 3.5 billion years old and visible along the southern edge of the maria and within a broad zone along the north. The largest part of Crisium is 3.4 billion years old and stretches entirely from east to west. The fact that the 3.5-billion-year-old lavas occur along the edges of the 3.4-billion-year ones suggests that the oldest lavas covered the entire floor of Crisium. One final patch of surprisingly young lavas (2.5 billion years old) covers a 150-km-wide area between Eimmart C and Dorsa Tetyaev. The age of 3.4 billion years is supported by samples from that part of Mare Crisium that were brought to Earth 48 years ago by the Soviet Union's robotic Luna 24 spacecraft and dated in a Russian lab.

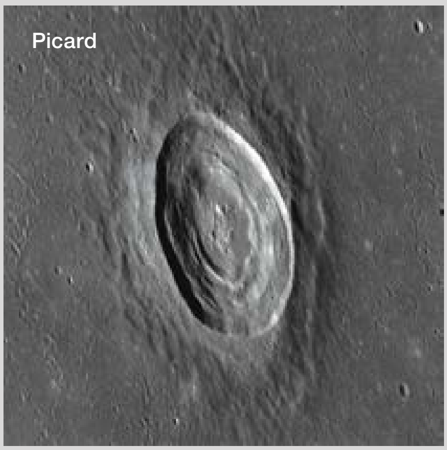
Only one volcanic cone is known on Mare Crisium. Lying about 120 km south-southeast of Eimmart C, **Mons Latreille** is a 6.4-km-wide, 125-m-high volcanic cone with a 2.6-km-wide summit crater that is breached where erupting lavas from the vent eroded through the crater wall. But why doesn't Mare Crisium have volcanic rilles or domes?

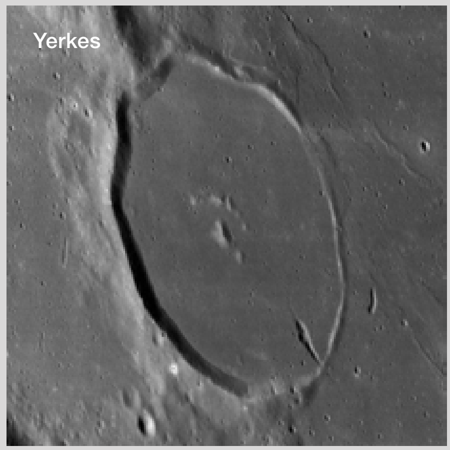
Just west of Yerkes crater on the basin bench is a series of small fractures on an uplifted hill that appears to be a portion of the Crisium basin floor. This hill and its fractures are covered by impact melt from the formation of the basin. A broad, uplifted, and fractured central zone in Lick crater and five or six other similar zones along other portions of the bench also look like exposed areas of the original impact melt. These areas imply that the entire basin floor was covered by melt and subsequently covered by mare basalts that erupted three times: 3.5 billion years ago, 100 million years later, and a third, smaller outpouring after another 700 million years.

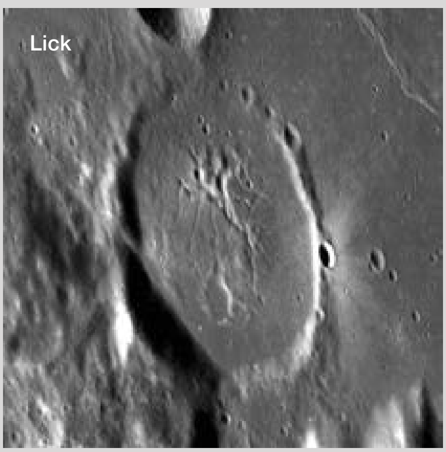
Unlike the view from Earth, which creates the illusion of an oval mare that's longer north-to-south than east-to-west, from directly above Mare Crisium resembles a puffy fish, with a slightly elongated body stretching east to west, and a split tail extending from the east end. The mascon, which defines the basin, is located entirely within the fish's body, and although the tail is covered in mare lava, it lacks a gravity anomaly. Something is fishy here. Is the irregular tail zone a small basin of its own, or did the entire Crisium basin originate from an oblique impact?

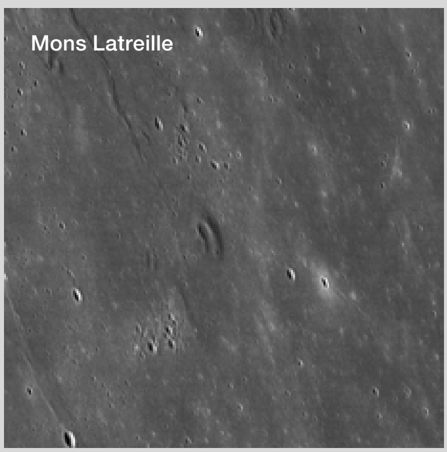
■ Contributing Editor **CHUCK WOOD** enjoys deciphering the visual clues that hint at the history of the Moon's evolution.

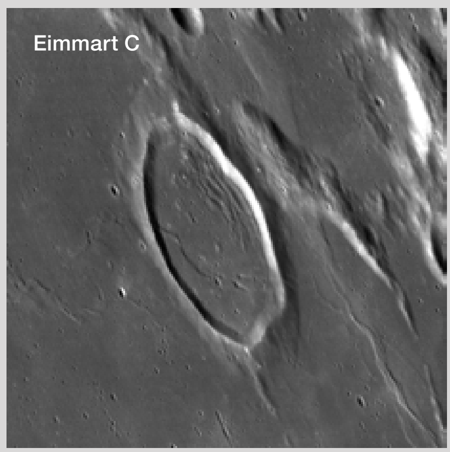




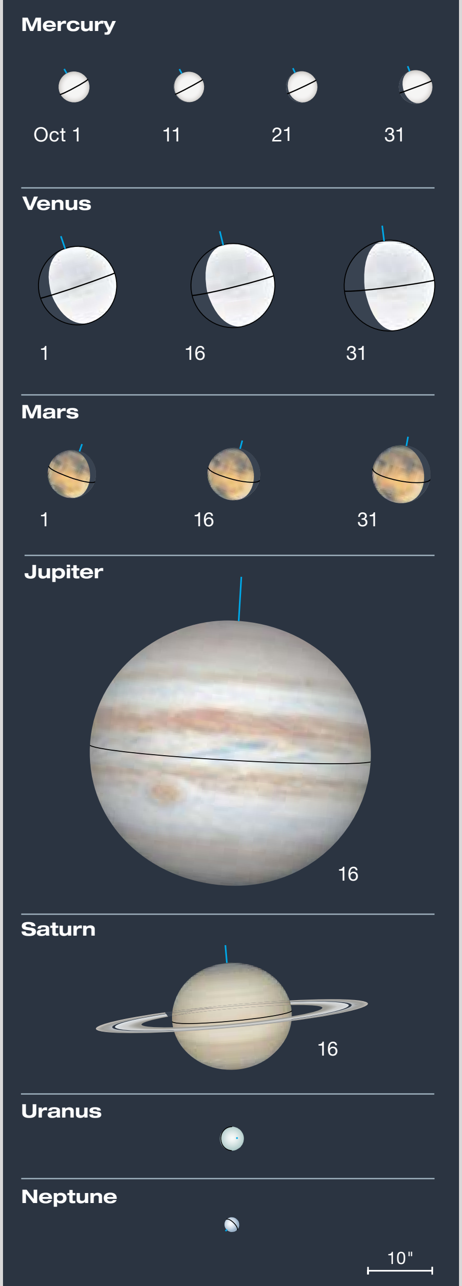








PLANET VISIBILITY (40°N, naked-eye, approximate) **Mercury** lost in Sun's glare all month • **Venus** visible at dusk all month • **Mars** rises around midnight and visible to dawn • **Jupiter** rises in the evening and transits before dawn • **Saturn** transits in the late evening and sets before dawn.



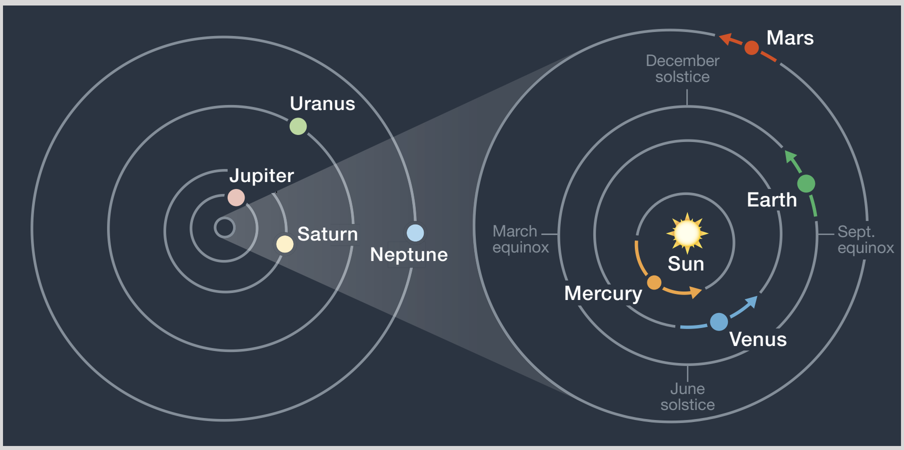
▲ **PLANET DISKS** are presented north up and with celestial west to the right. Blue ticks indicate the pole currently tilted toward Earth.

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

October Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$12^h 29.3^m$	–3° 10′	—	–26.8	31′ 57″	—	1.001
	31	$14^h 21.4^m$	–14° 05′	—	–26.8	32′ 13″	—	0.993
Mercury	1	$12^h 31.6^m$	–2° 01′	1° Ev	–1.7	4.8″	100%	1.400
	11	$13^h 33.4^m$	–9° 29′	7° Ev	–0.9	4.7″	98%	1.417
	21	$14^h 32.8^m$	–15° 56′	13° Ev	–0.5	4.9″	94%	1.376
	31	$15^h 31.6^m$	–21° 02′	18° Ev	–0.3	5.2″	87%	1.284
Venus	1	$14^h 27.1^m$	–14° 50′	31° Ev	–3.9	12.2″	85%	1.363
	11	$15^h 15.1^m$	–18° 52′	34° Ev	–3.9	12.8″	83%	1.305
	21	$16^h 04.9^m$	–22° 06′	36° Ev	–4.0	13.4″	80%	1.245
	31	$16^h 56.5^m$	–24° 23′	38° Ev	–4.0	14.1″	77%	1.182
Mars	1	$7^h 03.2^m$	+23° 10′	83° Mo	+0.5	7.5″	87%	1.241
	16	$7^h 35.3^m$	+22° 33′	91° Mo	+0.3	8.2″	88%	1.135
	31	$8^h 02.2^m$	+21° 52′	100° Mo	+0.1	9.1″	89%	1.026
Jupiter	1	$5^h 20.5^m$	+22° 25′	107° Mo	–2.5	42.2″	99%	4.668
	31	$5^h 17.6^m$	+22° 22′	138° Mo	–2.7	46.0″	100%	4.286
Saturn	1	$23^h 04.5^m$	–8° 19′	156° Ev	+0.7	19.0″	100%	8.735
	31	$22^h 59.0^m$	–8° 50′	125° Ev	+0.8	18.4″	100%	9.048
Uranus	16	$3^h 35.5^m$	+19° 01′	147° Mo	+5.6	3.8″	100%	18.726
Neptune	16	$23^h 52.9^m$	–2° 13′	155° Ev	+7.8	2.4″	100%	28.992

The table above gives each object's right ascension and declination (equinox 2000.0) at 0h 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. equals 149,597,871 kilometers, or 92,955,807 international miles.) For other timely information about the planets, visit **skyandtelescope.org**.



The Joys of RAW Image Data

Getting the most out of your astrophotos means shooting the correct file format.

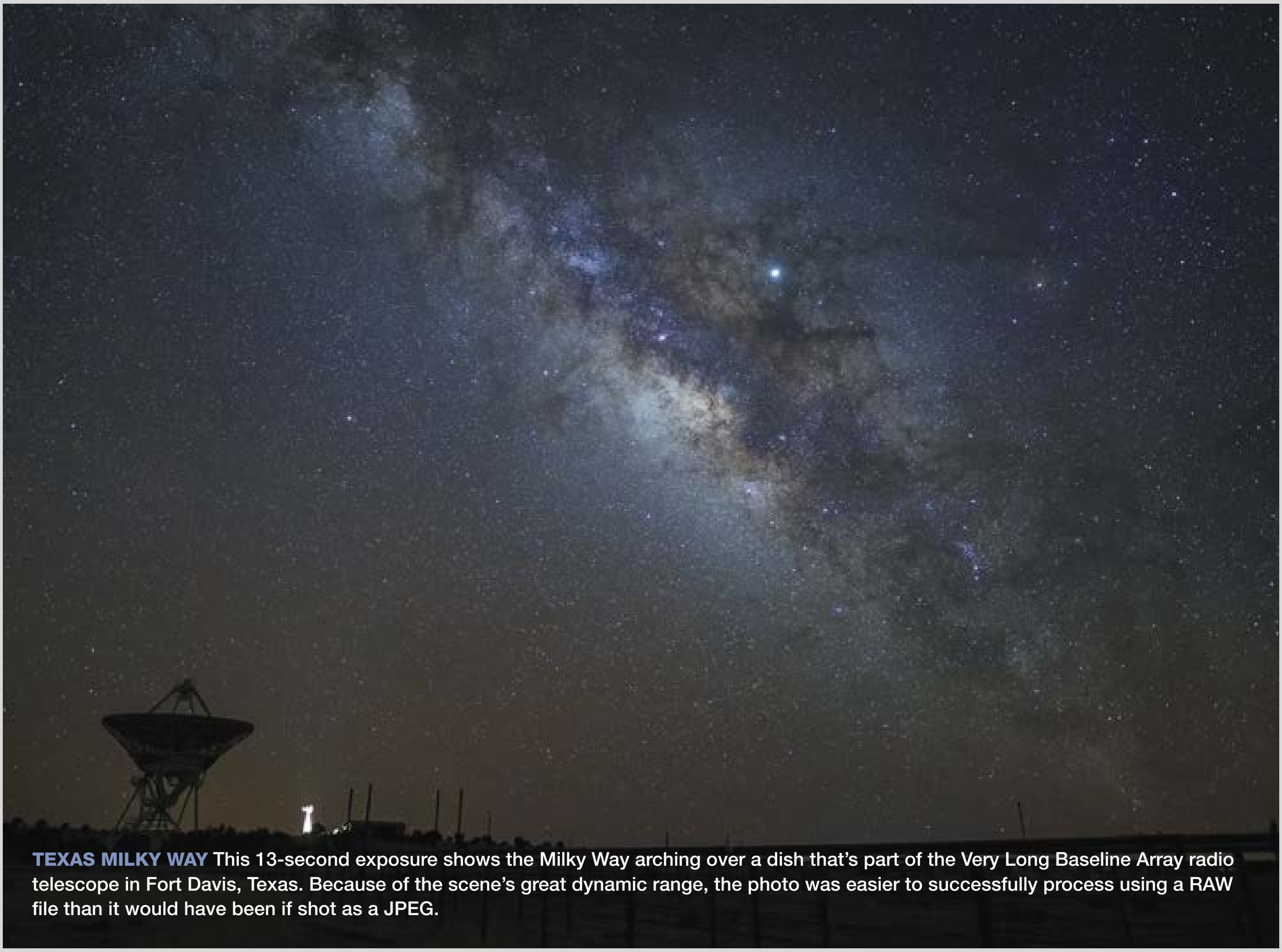
Most consumer digital cameras save images in two file formats: JPEG and RAW. And when it comes to the particular demands of astrophotography, shooting in RAW format is universally advised. Why? The quick answer is because it's better. Always. A longer (and more complete) response includes a short history lesson for context and a solid foundation.

Any kind of photography, be it capturing a distant galaxy or a backyard bird, requires you to hone two sets of skills. The first is somewhat mechanical — a mastery of the gear, an understanding of light and composition, and a sense of how to best frame a subject. The second skill set is knowing how to process the data. We could call these the "analog" and "digital" components of modern photography.

The advent of digital processing tools (and perhaps the frequent overuse of them) has led to an unfortunate stigma among neophytes about the term "processing." I often hear sentiments along the lines of "What comes out of the camera is all that should matter" — especially when it comes to comparing the work of different photographers. The truth is photos have always been processed, and this is no different today with digital cameras. Perhaps we are just less aware of it because so much of it is done inside the camera now.

How It Started and Where It's Going

I'm old enough to remember the days when we'd take a roll of film to the local drugstore and drop it off for developing. The process was largely automated



TEXAS MILKY WAY This 13-second exposure shows the Milky Way arching over a dish that's part of the Very Long Baseline Array radio telescope in Fort Davis, Texas. Because of the scene's great dynamic range, the photo was easier to successfully process using a RAW file than it would have been if shot as a JPEG.

ALL IMAGES COURTESY OF THE AUTHOR

▲ **POLLY VIEW** The unprocessed RAW image (left) is pretty lackluster but full of potential. The right-hand image is the JPEG version in which the camera optimizes the photo internally.

by the time I came along, and the best places to take your film were those where a good technician was on hand to monitor the results and tweak the process — better service than you'd get at the local mall or one of those little Fotomat booths you'd often find in suburban parking lots.

In those days, *serious* photographers had their own darkrooms equipped with all the gear and chemicals necessary to develop film. They didn't do this to save money; rather, it was to get the results they desired. Darkroom practitioners worked their enlargers to optimize the results while making their own prints. In this all-analog context, the negative was the RAW file, and the print was the final, processed result.

Why the history lesson? Because in many ways little has changed. Now, the developing process is digital rather than chemical. RAW data off the sensor of your digital camera — just like a film negative — needs to be processed before you get the "pretty picture" you want for posting online. Today, the local drugstore and Fotomat booth have been replaced by your smartphone and your digital camera.

Computer algorithms analyze your image and adjust the brightness and color balance "automagically" just like the old film-developing machine used to do. When you shoot in JPEG mode, what you get out of your camera or smartphone is analogous to the snapshot print of yesteryear. All the decisions about color balance, contrast, and so on have been made for you. But the final result might be worlds away from what you expect or desire.

That's why today's best photographers and astrophotographers understand that they need to be as skilled at image processing as they are at using their equipment. As the old saying goes, "The more things change, the more they stay the same."

Dialing in the Light

If you want to see what unprocessed RAW camera data look like, try reviewing an image file in *PixInsight* before applying any screen stretch or other enhancements. What your monitor will display is a dark scene with colors that are often pretty awful. That's why a RAW image file initially undergoes a standard treatment when it's first imported into photo-editing software such as Camera Raw in *Adobe Photoshop*. Usually, the result looks a lot like what you might have gotten by shooting in JPEG mode. So, why not just shoot JPEGs in the first place? After all, JPEG images can also be tweaked and massaged with photo-editing software. The difference is the degree to which you can make changes before the image starts to fall apart. Think of RAW files as your digital negatives — they're capable of revealing details not initially apparent.

That processing flexibility is largely due to something called *bit depth*. JPEG files are 8 bits deep while RAWs are 12, 14, or 16 bits depending on your camera model. But why is that so important for astrophotography? As a lifelong software engineer, I'm going to resist the urge to go overboard and teach you all about binary math. But in practical terms, the important thing to know is that each pixel in an 8-bit image can store up to 256 different intensity levels. Compare that to a 16-bit pixel, which can have up to 65,536 intensity levels. That's a *big* difference. Most of today's DSLR and mirrorless cameras have 14-bit sensors, which are capable of 16,384 brightness levels per pixel. Some older cameras still in use have 12-bit sensors, which can produce images with up to 4,096 intensity levels — still vastly better than what an 8-bit JPEG offers.

RAW Power

The main benefit of improved bit depth is the ability to better resolve light levels. This is a different type of resolution than most people think of when they hear that word. Normally when we talk about a high-resolution image, we're referring to the amount of fine spatial detail present. With light-level resolution, we're describing the ability to display subtle differences in light intensities when we have a greater bit depth to work with.

This parameter is especially important in astrophotography. When we start stretching our data by using Levels and Curves adjustments in *Photoshop*, we want to be able to manipulate the dynamic range of the dark areas to reveal hidden details, while also preventing the bright areas from saturating and being "blown out."

Here's a simple analogy. Let's say you go into a store with a $100 bill. The item you want to buy only costs $15, but the store doesn't give change. So, since you really need that item, you're effectively forced into throwing away $85 to get it. This is what it's like working with 8-bit data when you are trying to tease faint details out of the darkness. With

RAW data, though, it's like you have one hundred $1 bills instead.

Back to what bit depth means in the real world. Let's say that two features in your image are close to the same brightness level. In the 8-bit image, they will merge together into a single tonality. (In our analogy above, it's as if it didn't matter if the item cost $15 or $100 — it's all effectively the same price.) In the worst cases, faint details become merged with dark pattern noise and get clipped out of existence.However, with the greater bit depth of RAW files, you can often use the Curves tool to stretch out small brightness differences, so details become more apparent. Even when two tones appear distinctly different in a JPEG, if you try to increase the contrast further, you may end up with visible gaps between levels, an artifact often called *banding* or *posterization*.

It's also worth noting that modern cameras shooting at a high ISO can compromise bit depth in the form of available dynamic range (*S&T:* Dec. 2021, p. 54). Shooting in RAW means you can use a lower ISO instead and

▲ **UGLY SKY** This is what banding (or posterization) looks like. The processing used for this twilight scene is grossly exaggerated to illustrate what happens when there aren't enough bits to represent a subtle color gradient, in this case the hues found in the night sky.

achieve the desired results by stretching the data yourself after the image is captured. You are in control of your data when you shoot in RAW mode.

As imaging technology continues to evolve, we're witnessing a lot of great advances (see my article "The Next Big Thing" in the Aug. 2022 issue, p. 60). You may wonder if these improvements will eventually remove the need to access RAW image data at all. It doesn't look like it. Indeed, manufacturers are actually adding RAW capture options — even to smartphone cameras. For example, my iPhone 14 Pro can take images in RAW. The exported file format is even called DNG, which stands for Digital Negative, harkening back to the era when film was the dominant photographic medium. RAW is here to stay, and serious astrophotographers make use of its many advantages.

I wonder if photography clubs in the 1970s had members who complained that people with their own darkrooms had an unfair advantage over the Fotomat crowd? Maybe. But in the current digital era, the playing field is level — everyone has their own virtual darkroom. Take advantage of the technology and shoot RAW. I do — and recommend it highly.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** has his Canon EOS Ra set to shoot both RAW and JPEG, so his family doesn't complain about having to wait as long to see his vacation pics.

▲ **SEEING IN THE DARK** A Canon EOS Ra set to capture both RAW and JPEG images was used to show how the default JPEG looks for a low-light scene such as this nightscape taken at the Winter Star Party. *Top left:* The unprocessed image is much too dark and obviously requires adjustment to yield an acceptable photo. *Bottom left:* Attempting to process the JPEG image with the same adjustments made to the RAW file seen at right shows the limits of the JPEG's bit depth. Note the splotchy red areas on the lower left. *Main image:* The greater bit depth of the RAW file allows for a good deal more finesse and produces fewer objectional artifacts. (The yellow box indicates the crop of the photo presented in the left pair of images.)

One Night of Stellar Evolution

Witness snapshots of the birth, life, and death of stars at your eyepiece.

For generations, the serenity of the unchanging night sky has provided humankind with a comforting sense of security. However, modern astrophysics tells us the universe is anything but stable and calm! Violent explosions, maelstroms of matter swirling into black holes, and phenomena whose scale boggles the human mind are all too common.

Yet, to the visual deep-sky observer, it appears mostly static: Only a few deep-sky objects show changes over an observer's lifetime. Fortunately, we can study different examples of the same class of object at various stages of its evolution, threading them together using astrophysics — and in so doing understand the timelines of processes that take millions or billions of years. Would it not be fantastic to comprehend the dynamic universe by witnessing these snapshots with our own eyes?

Let's focus on one such timeline — the birth, life, and death of stars — and experience the billion-years-long process in a single night.

Nebulae of All Sorts

The space between stars is filled with the interstellar medium — gas and dust concentrated into clouds. The stage where we begin our stellar drama is a molecular cloud, mostly made up of hydrogen molecules. Importantly, though, there are also dust grains, thought to consist of an envelope of ice surrounding rocky matter.

Let's head to Orion to find the famed **Horsehead Nebula** about ½° south of Alnitak, or Zeta Orionis. Barnard 33, as it's also known, is a dark nebula that we can detect because the dust grains block the light of the glowing background gas. This challenging target demands a dark sky and a good eye to perceive feeble changes in contrast, though a hydrogen-beta filter helps significantly. These factors surpass aperture in importance — even a 4-inch scope can show the nebula well under the right conditions. I have noted an amorphous dark region in my 25×100 binoculars, but my 18-inch f/4.5 telescope at 150× reveals the horsehead shape nicely.

The denser regions of cold, dark nebulae can condense under gravity to form protostars. Some such stellar nurseries are embedded in bright nebulae as small cocoons known as Bok globules. The emission nebula IC 410 in Auriga located just shy of 5° north-northwest of Beta Tauri harbors two globules that look like tadpoles — **Simeis 129** and **Simeis 130**. They appear enshrouded in glowing nebulosity because ultraviolet radiation from luminous stars has ionized the outer envelope of the inner cold cloud. Whereas IC 410 is a fairly bright nebula, the tadpoles are challenging. I have only seen their "heads" in my 18-inch at 147× and a nebula filter. The easier of the pair was Simeis 130 (at left in the image on page 59), which appeared as a feeble oval glow around two stars.

Only dust-penetrating infrared light can reveal protostars forming inside

VARIABLE-TO-TERRIBLE Hind's Variable Nebula has exhibited substantial changes in brightness and has been a serious visual challenge for decades now. How will you see it?

MAKIS PALAIOLOGOU / STEFAN BINNEWIES / JOSEF PÖPSEL / CAPELLA OBSERVATORY dark nebulae. We can, however, see their imprints by way of jets of material that collide with the interstellar medium and create patches of emission called Herbig-Haro objects. Head over to the beautiful reflection nebula NGC 1999, which lies a bit more than 1° south-southeast of M42, the Orion Nebula. NGC 1999 is very interesting in its own right, but our focus here is on two tiny, faint patches of nebulosity lying a few arcminutes south of it: **HH 1** and **HH 2**. They were a challenge to spot in my 18-inch even under good conditions, but experienced observers with small apertures should not be discouraged — *S&T* Contributing Editor Howard Banich has detected them in an 8-inch telescope (*S&T:* Feb. 2022, p. 57).

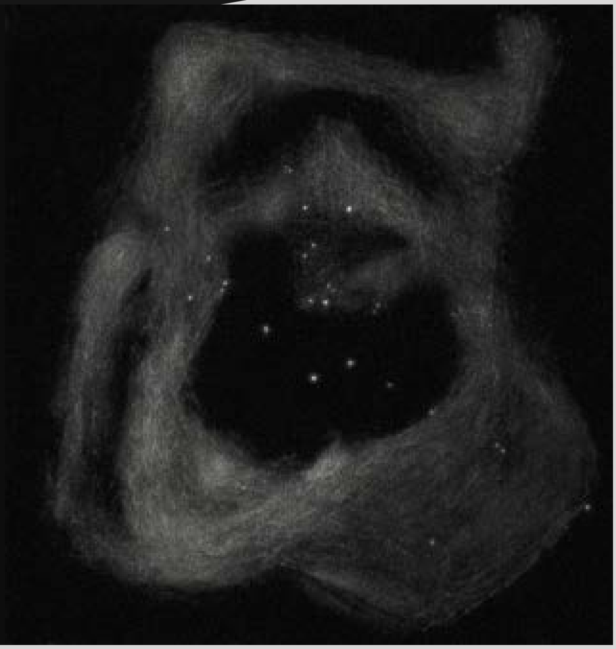
Herbig-Haro objects are variable over timescales of days, so their locations, brightnesses, and shapes may appear different to you from one observation to the next. In my first attempt from central Texas in 2016 with my 18-inch at 147×, I logged HH 1 as the brighter of the two, noting that it appeared structured. At the 2021 Okie-Tex Star Party, using 345× power on my 18-inch, I instead found HH 1 by far the fainter of the two. My most recent observation in January 2024 through a 16-inch at 180× at a star party in southern India was similar: That time, I only picked up HH 2.

Another characteristic of young stars is their variability, resulting both from the accreting star system's instabilities and the motion of surrounding obscuring clouds. The interstellar medium around them may therefore appear as variable nebulae. The best known of this class is Hubble's Variable Nebula (see the February 2020 issue for Banich's meticulous sketches). Let us instead tackle

▶ **THE TADPOLES** *Top:* Whereas these Bok globules in IC 410 (at top left) are a popular target for astrophotographers, they are overlooked in visual astronomy for good reason. Their low contrast in the eyepiece can be overcome with patience, conditions, and technique.

▶ **A HAPPENING PLACE** *Bottom:* The busy scene shows NGC 1999 and the dynamic duo HH 1 (the topmost of the pair) and HH 2. If you use this image as a guide to locate the Herbig-Haro objects, note that NGC 1999 may appear smaller in your eyepiece than it does here.

SIMEIS 129 AND SIMEIS 130: RON BRECHER; HH1 AND HH2: MAKIS PALAIOGOLOU / JOSEF PÖPSEL / STEFAN BINNEWIES / CAPELLA OBSERVATORY



ERODED CAVITY The author made this sketch of the Rosette Nebula over four hours of varying sky quality spread across three nights. He used his 18-inch and a narrowband filter at magnifications ranging from 66× to 147×. He's been inspired by Contributing Editor Howard Banich's articles.

Hind's Variable Nebula (NGC 1555), which you'll find about 1½° west-northwest of Epsilon Tauri. Illuminated by the archetypal young low-mass star T Tauri, this nebula faded out of view for about half a century after its discovery in 1852! It has exhibited substantial variation over the years. I made several failed attempts at this challenging target before finally bagging it in February 2023. My most recent observation was on a night of exceptional transparency at Death Valley National Park in November 2023: Using my 18-inch at 147× and no filter, I caught brief glimpses of a weak brightening only slightly detached from T Tauri.

Stable Stars

Massive *O*- and *B*-type stars are typically the first to evolve in a star-forming region. Intense ultraviolet emission from such stars ionizes the clouds of gas around them, causing them to glow as emission nebulae. The stellar wind and ultraviolet radiation from the stars eventually vaporize the surrounding molecular cloud, biting the very hand that fed them. For a great example, head over to **Sh 2-275**, the Rosette Nebula, in Monoceros — look for it within a triangle formed by the 4th-magnitude stars 18, 13, and Epsilon Monocerotis. The young cluster associated with the nebula, NGC 2244, includes five massive *O*-type stars, one of which is primarily responsible for blowing out a cavity in the nebula. Visually, the Rosette is one of the easier nebulae to observe in the night sky — under good conditions, even a small telescope aided by a narrowband filter should show the glowing cloud and the cavity around the cluster.

Eventually, the luminous stars eat away all the nebulosity and drift apart, forming loose OB associations, like the trio forming Orion's Belt. Looking for more challenging ones to observe? Check out **NGC 206** and **OB54** in the Andromeda Galaxy, M31 (*S&T:* Nov. 2020, p. 35). NGC 206 lies around 40′ southwest of the center of the galaxy, while OB54 is about 42′ northeast of the center. Using my 18-inch under excellent conditions, the former appeared as a mottled, elongated patch of low surface brightness at 207×, whereas the latter appeared as a slightly elongated, amorphous brightening in the spiral structure of M31.

Stellar Remnants

Stars that are "fully formed" enter the relatively stable phase of fusing hydrogen into helium in their cores when they're on the main sequence, where they'll spend millions to billions of years depending on their masses. Most main-sequence stars eventually become red giants like Betelgeuse in Orion or Aldebaran in Taurus, but it's when the red-giant phase ends that things get interesting for deep-sky observers. Stars that are more massive than about eight times the Sun will undergo a violent supernova explosion, leaving behind a nebulous remnant and a neutron star or black hole.

Arguably the best known of this class is the **Crab Nebula** (M1) in Taurus (*S&T:* Feb. 2019, p. 30), the remains of a supernova logged by stargazers in AD 1054. Look for it a bit more than 1° northwest of Zeta Tauri and try viewing it both with and without a narrowband filter. Even a small scope should do. The nebula has an emission component that comes from electrons gyrating in the strong magnetic field of the neutron star. As a result, it changes shape and dims when you pop in an O III filter!

For a true visual challenge, tackle **Simeis 147**, the Spaghetti Nebula. This extremely faint supernova remnant sprawls over 3° straddling the boundary of Taurus and Auriga some 3¼° east of Beta Tauri. Following several unsuccessful tries, at a Bortle 2 site with great transparency I finally managed to detect a few filaments of nebulosity using my 18-inch equipped with a nebula filter. The brightest part I glimpsed was a condensed patch some 1¾′ south of the 10.7-magnitude star BD+28 858.

Stars of less than about eight solar masses end their lives as white dwarfs, after having expelled their outer layers into beautiful planetary nebulae. This is a good time to resolve the white dwarf companion of Sirius, **Sirius B**, the Pup. The present separation of the binary system — 11.3″ — is close to the maximum, with the next apastron 50 years away. With the good seeing and stable temperature of Bangalore, India, I was able to split Sirius in a 17.5-inch f/5 using a 6.3-mm Plössl eyepiece, yielding about 320×.

We can also see short-lived pre-planetary nebulae. This phase occurs when the red giant's core hasn't heated up enough to ionize the ejected material, and so it simply reflects the star's light instead of glowing like a planetary nebula. A great example is **CRL 2688**, the

AKARSH SIMHA

Egg Nebula, in Cygnus 4¼° northeast of Epsilon Cygni (*S&T:* June 2021, p. 57) — catch it early on October evenings. My 18-inch at 345× showed the object's bipolar nature, with the northern lobe brighter and rounder than the southern.

As for planetary nebulae, I'll pick a couple of challenging examples here. **Abell 12** lies less than 1′ northwest of the 4th-magnitude star Mu Orionis. With my 18-inch at 200× and an O III filter, I saw a glowing disk with a raggedy brighter boundary. As a planetary nebula ages, the halo expands, resulting in large dimensions and low surface brightness, presenting a formidable visual challenge. **Sh 2-216** in Perseus is one of the largest known planetary nebulae by angular diameter, measuring 1.6° across. Look for it 3¾° due east of 4.8-magnitude d Persei. From the dark skies of the 2015 Okie-Tex Star Party, I detected the brightest (eastern) edge of the nebula in my 18-inch by scanning over it with a wide-field eyepiece equipped with a nebula filter. Examine the field for a feeble step up in the background brightness as you pan your telescope over the boundary of the nebula. To my eyes, the edge appeared more rounded in an O III filter than in an Ultra-High Contrast filter.

FAINT FILAMENTS The sprawling supernova remnant fondly called the Spaghetti Nebula is a formidable visual challenge. Use this image (or one like it) as a finder chart to map the brightest filaments.

RON BRECHER

Many of the objects in our journey here have low surface brightness and require good technique, excellent transparency, and dark skies. One doesn't have to struggle to see the stages of stellar evolution — you can still witness snapshots of this process by substituting brighter objects of your choice. But hey, some of us love challenges!

■ **AKARSH SIMHA** has been observing the deep sky for more than 18 years, starting with an 8-inch telescope in South India. He currently seeks the darkest California skies to observe with his 18-inch. You can reach him at his email address **thedeepskyadventures@gmail.com**.

Snapshots in a Star's Life

Object	Name	Type	Constellation	Size/Sep	RA	Dec.
B33	Horsehead Nebula	Dark nebula	Orion	7′ × 4.5′	$05^h\ 41.0^m$	–02° 27′
Simeis 129	Tadpoles	Bok globule	Auriga	3.5′ × 0.5′	$05^h\ 22.9^m$	+33° 32′
Simeis 130	Tadpoles	Bok globule	Auriga	4.3′ × 1.5′	$05^h\ 23.1^m$	+33° 29′
HH 1	—	Herbig-Haro object	Orion	0.2′	$05^h\ 36.3^m$	–06° 45′
HH 2	—	Herbig-Haro object	Orion	0.3′	$05^h\ 36.4^m$	–06° 47′
NGC 1555	Hind's Variable Nebula	Reflection nebula	Taurus	1.5′ × 0.7′	$04^h\ 21.9^m$	+19° 32′
Sh 2-275	Rosette Nebula	HII region	Monoceros	1.3°	$06^h\ 31.7^m$	+04° 56′
NGC 206	—	OB association	Andromeda	3.0′ × 1.3′	$00^h\ 40.5^m$	+40° 44′
OB54	—	OB association	Andromeda	3.4′ × 1.7′	$00^h\ 44.6^m$	+41° 52′
M1	Crab Nebula	Supernova remnant	Taurus	5.5′ × 4.0′	$05^h\ 34.5^m$	+22° 01′
Simeis 147	Spaghetti Nebula	Supernova remnant	Taurus	3.1°	$05^h\ 39^m$	+27° 50′
Sirius B	The Pup	White dwarf	Canis Major	—	$06^h\ 45.1^m$	–16° 43′
CRL 2688	Egg Nebula	Pre-planetary nebula	Cygnus	0.6′ × 0.2′	$21^h\ 02.3^m$	+36° 42′
Abell 12	—	Planetary nebula	Orion	0.7′	$06^h\ 02.3^m$	+09° 39′
Sh 2-216	—	Planetary nebula	Perseus	1.6°	$04^h\ 43^m$	+46° 42′

Angular sizes 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.

Travel Tips for the Astro-Adventurer

Avoid these pitfalls as you head out to a dark-sky destination.

Like many amateur astronomers, I dream of having an astro-paradise backyard, free of tall trees and light pollution, with the brilliant Milky Way overhead, but still only a short drive to my favorite coffee shop. I also realize this is fantasy, but there is an alternative — travel. Head to the dark skies of a star party or another dark-sky location. This may involve a backpack, a car packed so tight that I can't see out the back window, or perhaps a trailer loaded with my gear. It's easy to get carried away with how much to take on a dark-sky excursion, and I have on multiple occasions.

In the past, I've worked as a vendor in the astrophotography community, where I've encountered many budding astro-imagers who show up at an event and were unable to do what they came for. This article is the distillation of over two decades of the mistakes I've made with the hope that they can help you avoid making some of the same ones. It might save you some time, and it might even save your entire imaging trip.

REMOTE DARK SKIES For many of us, travel is the only way to experience extremely dark skies. What you bring and how you get it there are important considerations so that you actually get to spend your time observing or imaging the sky. Here, attendees of the Winter Star Party in the Florida Keys camp on the beach to image southern targets like Eta Carina (inset).

Do Try This at Home

The first and most important rule for the traveling astrophotographer is to test everything at home first. Who hasn't acquired a bunch of new gear, loaded it untested into the car, and headed out to a dark-sky site with visions of well-guided exposures dancing in your head? Perhaps you're just too busy at home and need the time away at the event to focus and spend some time with your new equipment. Big mistake! Taking all your brand-new gear to your favorite imaging destination is just asking to squander a good night or more learning how to use it.

You need to practice familiarizing yourself with any new piece of equipment. In order to maximize their productivity, astronauts spend months or more rehearsing their missions long before they climb into a rocket. You don't need dark skies to make sure your camera works. A light-polluted sky will still let you to determine if every new piece in your imaging train will allow your camera to reach focus, or that you have the proper spacers placed between your field flattener and camera. It will tell you if you need to add another counterweight, or if you need a more powerful battery.

Years ago, I wrote the Canon plug-in for Software Bisque's *TheSkyX* mount control program. I'd been shooting with Canon cameras for years and was updating it for the new EOS R and Ra models. I knew my plug-in worked, but I'd never actually put it on a telescope until the Sun was setting at Camp Wesumkee at the Winter Star Party. What I didn't remember is that the USB-C cable I'd been using on my desk to connect the camera to my computer was too short to reach from the camera to the USB port on the mount. I was dead in the water! I should have tried everything on a moonlit night in the backyard before heading out on an imaging excursion.

Speaking of software, it's also best to make sure you have all the drivers and software updates installed and that all your gear communicates with the computer, phone, or tablet you use to control it. Keep in mind that each time there's a software update, there are almost certainly new bugs coming along for the ride. Again, test it at home, and once everything works there, don't perform any additional updates right before a trip. If it works at home, it should work when you get where you're going.

This goes for your power supply, too. Dark skies and readily available electricity often don't go together, so you're likely bringing a battery system. Set your gear up in the living room at home and run it on your battery all night. Make sure it can power all your gear for an entire evening at least. And remember temperature affects battery life — if it's cold where you're going, your batteries may last only about half as long they do in your cozy, warm house. Be sure to fully charge your batteries before you leave.

Make a List

Confidence is a great thing, but overconfidence will get you in trouble every time. So, you've done several star parties already? You can still figuratively trip on your shoelaces.

▲ **HOME AWAY FROM HOME** Packing all your gear into the car for an excursion to dark skies is a fine idea if you plan ahead. The author brought all the equipment seen above to the 2024 Winter Star Party, tightly packed into the back of his Toyota Rav4 sports utility vehicle.

▼ **KEEP IT SIMPLE** A camera, a few lenses, and a small star tracker, such as the Sky-Watcher Star Adventurer seen below, are easy to bring along on a flight, though you'll need to check tall tripods.

▲ **CHECK IT TWICE** On any dark-sky expedition, it's crucial that you make a checklist of everything needed for your equipment to perform in a remote location. Here, the author cataloged each piece of gear packed into the Pelican travel case, ensuring no crucial component was left behind.

▲ **LOCAL ACCESS** Setting everything up ahead of time and then packing it up is a good idea and helps identify things to add to your checklist you may have overlooked. The photo above shows the packed equipment the author brought along to his favorite dark-sky site a few hours' drive from his home.

▲ **ORGANIZE** Cramming as much as you can fit in your car is a terrible idea, especially if you don't protect the gear from unexpected damage from rough roads.

An easy mistake to make is to throw everything in a case just before heading out. Having imaged with various telescopes, cameras, and mounts, I like to think I know everything I need. But, inevitably, I always end up missing something. This is why it's extremely important to make a list of things to bring along. Make a checklist, but don't make it from memory. Again, set everything up, *then* write down all the components that you require to have a trouble-free evening observing or imaging under the stars. This list is to make sure you don't forget that 6-foot-long USB-C cable or custom spacer for your field flattener that you need to make it all work. My approach is to set it all up, turn everything on, and make sure it works together, and then I catalog each component as I'm putting it in the case.

Bring Backups

"I don't understand, it worked the last time" is something I've heard on many an observing field. Everything works, and keeps working, until suddenly it doesn't. There's not really anything you can do if a major piece of your gear decides to go belly-up in transit, but fortunately, the most common point of failure is the easiest to mitigate.

There's a maxim in the astro-tech support industry: "It's always a cable until proven otherwise." Anything that moves or bends eventually breaks, particularly if it undergoes large temperature fluctuations like the extremes experienced during imaging on hot summer nights and cold winter ones. And the many cables connecting your mount, camera, autoguider, and focuser will all wear and eventually need replacement. The simplest and cheapest tip I can give you is to purchase and bring along spare cabling. I always have a little box of miscellaneous cables on hand while astro-adventuring. Often one goes to a neighboring imager on the observing field.

Perils of the Road

When you have everything packed and cataloged and ready to go, the hazards don't end there. If you're driving to an event or dark-sky location, you have the luxury of having your own vehicle or a rented one. The problem with driving on a multi-day trip is having a car full of expensive gear that is very precious to you. If you stop for the night, there is a very real possibility that you may wake up to an empty vehicle. This happened to me: some $40,000 of gear missing the next morning and broken glass everywhere. Long-distance drives can be taxing, and often I drive until I'm tired and pick a random hotel right off the road to get some rest. I got away with this for many years until I didn't.

Hotel thieves often storm its parking lot, looking for full vehicles with out-of-state license plates. They smash in, load up a truck in under a minute, and speed off. Covering your gear with blankets only alerts the thieves that there's something worth taking in the vehicle, and parking under a light makes it easier for them to see what they're doing. Most victims assume the burglars unload their haul at pawnshops, but those businesses have to report serial numbers of electronics and mechanical equipment (like cameras). But the detective working my case told me that, instead, the thieves sell their hauls in bulk, which often means your precious gear ends up getting sold at flea markets where there are no such rules.

After this painful lesson, I started putting all my astro gear into easily movable containers so I could bring them into the room with me. On one trip, we had to lug everything into a hotel room and back to the car again on three separate nights. While this was difficult, this new precaution paid off, too — my vehicle was broken into again on another long trip. This time, the car was empty, so the only thing it cost me was some time at a repair shop replacing a door window. Don't trust in chance or luck on the road.

Airline Travel

Flying to a dark-sky location presents its own set of challenges. You might be flying to a faraway star party; maybe it's a work trip to someplace exotic, or a vacation with family during which you'd like to sneak in a little nighttime photography. One carry-on and a personal item can go a long way if you check a suitcase with your clothes.

The cardinal rule of flying is that you should never check your gear, except perhaps a tripod stuffed in the middle of your clothes suitcase, and only if it's easily replaceable. There are multiple reasons for this, but the most obvious is that checked bags quite frequently get lost. They may show up eventually, though perhaps after your event or opportunity! Additionally, checked bags are required to be unlocked and subject to search. Transportation Security Administration (TSA) agents are not trained in how to handle expensive astronomy and photography gear. In fact, if you read the fine print of some travel-insurance policies, photography gear is often excluded. I also learned this the hard way.

▼▶ **CONVENIENTLY COMPACT** Keeping everything in as few containers as possible makes it easier to transport a more ambitious imaging system. Make sure your name, address, and contact information are on the outside and inside of all boxes and containers in case of theft or loss, no matter if you're driving, flying, or shipping your gear to your destination. With the exception of the battery, the entire telescope, pier, and cameras seen at right fit into the three cases shown below.

Early in my astro career, I checked luggage containing an apochromatic refractor. It turns out that that fine refractor of mine is a hollow metal tube that looks very suspicious on an X-ray machine, and it got inspected. The threaded aluminum lens cap was cross threaded when it got home. Another package containing a Software Bisque Paramount with the gears carefully disengaged showed up after the flight with the gears engaged, as this must have made it easier to lift and inspect (they probably thought it was Iron Man's boot).

And because your checked bags are unsecured, others can root through your belongings. One of my family members had a camera vanish from a checked duffel. There is little you can do when this happens.

FRUITS OF YOUR LABOR With careful planning and packing, the author was able to record this deep, colorful image of the star cluster NGC 2244 in the Rosette Nebula from his dark-sky site in southern Florida. He used the Sky-Watcher 150P setup seen at the top of page 63.

A better alternative is to carry on everything that you can in airline-compatible cases. For nightscape photography, you can easily bring a few cameras, lenses, and compact tripods with you on the flight in airline-compatible cases. Some of the smaller star-trackers and even compact equatorial strain-wave mounts (which don't require counterweights) also easily fit in a carry-on Pelican or similar case along with a small refractor.

Some things are simply too big for carry-on, so it's best in such cases to ship everything to your destination ahead of time whenever possible. Pack everything up carefully and ship to the hotel where you're staying — most hotels are helpful and will store your package until your arrival. If that isn't an option, you can also ship to a UPS store in your destination city, or perhaps you have a friend or family member where you're going. Just be sure to check the hours of your shipping company to make sure that you're not only able to retrieve your gear when you need to but can ship it back! Once, after attending the Grand Canyon star party, I almost missed closing time at the UPS store on Sunday afternoon, and I had to catch my flight early Monday morning.

The biggest challenge to shipping is if you have a large battery system. Flying with large batteries is discouraged, and shipping them is difficult as well. It can be done, but large batteries not only require a lot of paperwork (and perhaps a special license) but are very expensive to ship. In fact, I've found it easier and cheaper to simply bring a battery charger and find a department store or automotive-supply business near my destination where I can purchase a deep-cycle battery. After I'm done with it, I give it away before flying back home.

Pack Up and Go!

Travel and astronomy these days go hand in hand. Although astrophotography can mean more gear to bring along, with careful planning it can be a hassle-free experience. The main trick is to be prepared. Try everything at home first. Getting help from experienced imagers is certainly a great idea, but the right time and place to do this is at home, your local astronomy club, or an imaging workshop *before* you travel. Practice like an astronaut at home under hazy skies or a bright Moon so that you're ready to take full advantage of that amazing night under a dark, pristine sky.

■ Contributing Editor **RICHARD S. WRIGHT, JR.** loves to travel for photography and hopes you can learn ahead of time from some of his mistakes.

Smart Luck

ACCIDENTAL ASTRONOMY: *How Random Discoveries Shape the Science of Space*

Chris Lintott
Basic Books, 2024
320 pages, ISBN 9781541605411
US$30, hardcover

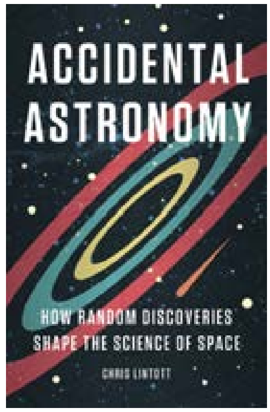
ACCIDENTS HAVE LONG played a valuable role in advancing science, and that includes astronomy. Chris Lintott, a professor of astrophysics at the University of Oxford and co-presenter of the BBC program *Sky at Night*, is an ideal guide to understanding why this is true.

Like many astronomers, Lintott retains a childlike wonder for the mysteries of the cosmos, and his writing reflects this appealing attribute. “I will never forget the shock of staring through the eyepiece at something so completely unexpected,” he recalls of seeing the aftermath of Comet Shoemaker-Levy 9’s collision with Jupiter’s cloudtops in 1994. “There was a moment of absolute surprise, disbelief that made a second look essential, and then a surge of elation that something new, something different, was visible.”

Lintott is also amusingly self-deprecating. He recounts spending a month as a PhD student trying to track down the source of a dip he’d found in the spectra of a star-forming region, only to realize that he’d “made a completely independent discovery of oxygen in the Earth’s atmosphere . . .”

> We have to at least consider the possibility of aliens, otherwise we might miss something.

But Lintott is dead serious when describing how accidental discoveries, unexpected results, and inspired guesses can lead astronomers in entirely novel and fruitful directions. As he notes, “The lesson from the stories in this book is that whenever we have looked longer, deeper, farther, or in new ways at the Universe, it has surprised us.”



Take the Hubble Deep Field image. After acknowledging his bafflement that “the best idea anyone since Galileo has had about how to use a telescope” was initially rejected, he goes on to say that, once it was approved, the Hubble Space Telescope’s 100 hours of observation in 1995 of one tiny spot in the sky changed how astronomy is done. Today, taking a deep look at the cosmos is *de rigueur* for any new instrument. The James Webb Space Telescope specializes in just that, picking out the earliest galaxies; it might even detect the very earliest stars, he says. If it does so, it will be because those in charge of Hubble a quarter century ago “decided to be brave and risk seeing nothing at all.”

Another fortuitous discovery that shook things up was that of 1I/‘Oumuamua, the first confirmed interstellar object. Lintott mentions two colleagues who now posit that such an object might have been the very thing to jump-start the formation of Earth itself. Debris in the protoplanetary disk surrounding our newly born Sun might not have grown big enough fast enough to “seed” a planet before the disk dissipated. But a huge rock hurtling in from far away might have served the purpose. Study of future interstellar visitors may or may not support the hypothesis, but regardless, “[t]he passage of a tiny rock that no one expected can upend all our ideas,” Lintott observes, about how our own world began its existence.

Other serendipitous finds that he relates in detail include the accidental (and Nobel Prize-winning) discovery of the cosmic microwave background; the salty water spewing from Saturn’s moon Enceladus, which supports the notion of a possibly habitable ocean beneath the moon’s icy surface; and the debated identification of phosphine in the atmosphere of Venus, another hint that life might exist beyond Earth.

When it comes to identifying life elsewhere, particularly intelligent life, being open to accidental revelation is crucial, he reminds us, especially since we’ve really only begun the search. He cites the words of astronomer Jill Tarter, who has devoted her career to the search for extraterrestrial intelligence (SETI). At Oxford in 2011, Tarter told a gathering of astronomers that all we’ve achieved so far in our search for ET intelligence amounts to trying to determine the chances for life in our oceans by “examining a bathtub full of water and finding no fish.”

Lintott holds that whenever we turn up something unexpected in the universe, we have to at least consider the possibility of aliens, otherwise we might miss something. It’s a notion that undergirds many of the stories he relates in *Accidental Astronomy*.

Altogether, Lintott is a gifted storyteller who offers an entertaining and insightful look at the role happenstance has played — and continues to play — in furthering our ken of the cosmos.

■ **PETER TYSON** would welcome the discovery of ET life by hook or by crook.

Optolong's L-Quad Enhance Filter

This filter helps reduce the impact of light pollution in your images.

◀ The L-Quad Enhance Filter (L-QEF) blocks light pollution while passing wavelengths emitted by stars, nebulae, and galaxies. This deep, colorful image of IC 1396 in Cepheus was captured with the author's Takahashi FS-60CB apochromatic refractor and QHY367C Pro camera equipped with the L-QEF from his light-polluted backyard in Guelph, Ontario.

ALL IMAGES COURTESY OF THE AUTHOR

Optolong L-Quad Enhance Filter

U.S. Price: $199
optolong.com

What We Like

Produces high-contrast, natural-color images

Works well in some light pollution and moonlight

Minimal color cast that is easy to correct

What We Don't Like

Only available in 2-inch format

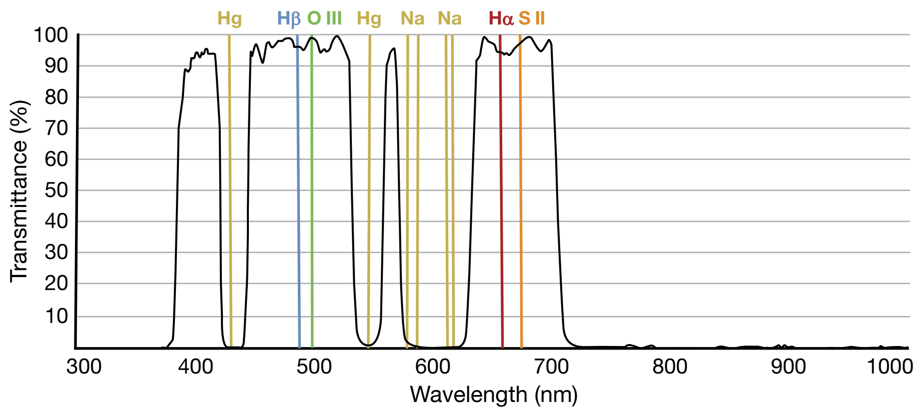
MOST EVERY astrophotographer has to deal with light pollution to some extent. While my skies are fairly dark, I'm most affected by lights from an automotive dealership nearby to the south as well as the yellowish glow of streetlamps from denser neighborhoods to the east. This light pollution causes gradients in my image data that require careful attention to correct in post-processing. Fortunately, there are light-pollution-suppression filters that can help mitigate the problem.

Light-pollution-suppression filters have been around for a long time. They work by blocking specific wavelengths produced by the mercury-vapor and sodium lamps used for street lighting while allowing other wavelengths to pass through unimpeded. The filters work best when paired with color cameras equipped with a Bayer-filter matrix, such as DSLRs, mirrorless cameras, and some astronomical cameras.

Optolong's L-Quad Enhance Filter (L-QEF) is one of the newest in its ever-expanding inventory of deep-sky imaging filters. According to the manufacturer, the L-QEF passes more than 90% of the four most prevalent emission lines that nebulae emit. These are hydrogen beta (486.1 nanometers), oxygen III (495.9 and 500.7 nm), hydrogen alpha (656.28 nm), and sulphur II residing at 672.4 nm in the visible spectrum. At the same time, the filter blocks the majority of wavelengths produced by mercury-vapor lighting (435.8, 546.1, 577, and 578.1 nm) as well as sodium-vapor light wavelengths (589.6, 598, 615.4, and 616.1 nm). The filter also blocks natural skyglow as well as near-infrared wavelengths up to 1,000 nm. Holding the filter up to my eye while examining a daylight scene reveals a fairly natural-looking color palette, with perhaps a slight warm bias. The filter is available in a 2-inch format with 48-mm threads. Other sizes are not yet available.

I tested the L-QEF by comparing similar exposures taken both with and without the filter in a QHY367C Pro color camera fitted to a Takahashi FS-60CB refractor. I made comparison images using the same equipment, replacing the L-QEF with a UV/IR blocking filter. My first target on a clear, moonless night was the large emission nebula IC 1396 in Cepheus.

From the very first comparison with unprocessed, single 5-minute frames, the filtered image showed more nebulosity than the version made without it. Even with minimal processing, the L-QEF yielded brighter nebulosity and a more



▲ *Left:* The L-QEF blocks three sections of the visible spectrum where mercury- and sodium-vapor lights emit light, while transmitting more than 90% of visible wavelengths between about 400 and 700 nanometers. *Right:* The L-QEF filter works well on all kinds of objects, including reflection nebulosity like that found around the stars in the Pleiades, M45.

contrasty result overall, making it easier to bring out details than in the unfiltered image. The L-QEF also revealed faint nebulosity that wasn't evident in the other image. The photos displayed a slight color bias that made the nebula appear a little too red, likely due to the suppression of some blue wavelengths. I've seen this effect in all the other light-pollution filters that I've tried over the years, some with a stronger cast than others. However, the color from the L-QEF was easy to fix with processing.

Star colors were also pleasing through the filter. To test this aspect, under the light of a full Moon I targeted NGC 884 and NGC 869, the Double Cluster in Perseus. The resulting image showed a good range of star colors, including blue, yellow, and red that were virtually indistinguishable from results I've obtained without the use of special filters (other than a UV/IR blocking filter).

The L-QEF blocks some wavelengths in the blue and green regions of the spectrum where mercury emission wavelengths reside. I was curious to see how the filter would perform on blue-dominant targets like galaxies and reflection nebulae — poor blue transmission is an issue I've experienced with other LPS filters that I've used. For my final tests, I imaged the Pleiades, M45, with and without the L-QEF filter on consecutive clear, moonless nights while the cluster was relatively low in my sky, where the light pollution is worst. In nearly identically processed images, the L-QEF made a big difference in the results, allowing more faint nebulosity around the star cluster than my non-filtered picture. The blue hues in the filtered image were slightly more cyan than in the unfiltered version, but this was easily adjusted with a single processing step.

The L-QEF also rendered an appealing image of M31, the Andromeda Galaxy, without any special processing steps. Even under favorable conditions the L-QEF boosts image contrast by blocking natural skyglow.

While imaging under dark skies produces the best results, urban astronomers will find the L-Quad Enhance Filter to be an excellent option to improve color astrophotography under moderately light-polluted skies, particularly those dominated by orangish sodium and bluish mercury-vapor lamps. Note that this filter is less effective at mitigating light pollution from LED sources, as these emit light across the entire visible spectrum. But for most imagers, the L-QEF is a powerful tool I'd recommend.

■ Contributing Editor **RON BRECHER** welcomes any product that reduces the effects of light pollution in his images.

▶ These images compare views of IC 1396 captured on similar moonless nights from the author's backyard sky, which rates 5 on the Bortle scale. With identical basic processing, the L-QEF image has better overall color and contrast than the unfiltered version.

Celestron SkyMaster Pro ED 15×70 Binoculars

This bino offers enough magnification and light grasp to satisfy many astronomical observers.

SkyMaster Pro ED 15x70 Porro Binoculars

U.S. Price: $329.95
celestron.com

What We Like

Excellent optical and mechanical performance

Solid construction

Eyepieces threaded to accept 1¼-inch filters

What We Don't Like

Eye relief not long enough to show full field of view for some glasses wearers

I BEGAN MY LIFELONG love of astronomy as a pre-teen with a WWII-vintage Galilean field glass and a copy of the Golden Nature Guide *Stars*. I'd terrify my mother by climbing with those primitive binoculars to the roof of our house for a more expansive view of the constellations. But like most beginners, I longed for a telescope. Within months an early birthday present had me observing the heavens with a 60-mm refractor and, to my mother's relief, from the safety of ground level.

▲ Celestron's top-of-the-line SkyMaster Pro ED 15×70 Porro Binoculars have the hallmarks of premium astronomical binoculars, including porro prisms made of high-quality BaK-4 glass, fully multi-coated optics, and rugged rubber armor coating.

If anything, my path to becoming an amateur astronomer was noteworthy for being unremarkable. Like countless others before and after me, it was natural to progress from binoculars to telescopes — a path that's universally recommended in observing guides and by seasoned observers. But graduating to a telescope doesn't mean leaving binoculars behind. In the past 60-plus years, it's impossible to tally the number of hours I've spent gazing at the heavens, let alone the equipment I've used most often. But it wouldn't surprise me if, apart from the naked eye, binoculars came out on top. Really.

Lately the model I've been using the most is the Celestron SkyMaster Pro ED 15×70 Porro Binoculars on loan from Celestron for this review. (For the sake of brevity, I'll refer to them as the Pro

◀ The author found the binoculars' center-focusing assembly to be especially rigid, preventing rocking that would affect focus during use. He measured the binoculars' close-focusing distance to be 63 feet (19 meters).

ALL IMAGES COURTESY OF THE AUTHOR

ED 15×70s going forward.) They're very nice both optically and mechanically.

I've not had a lot of experience with the SkyMaster line, but I know that some of the less expensive models have received mixed reviews from observers. Because of that, I certainly feel it would be a mistake to paint the Pro ED 15×70s with a similar brush based simply on the SkyMaster name. For example, there are two other models of SkyMaster 15×70 binoculars. While the all-important magnification (15×) and objective diameter (70 mm) are the same for all three glasses, the Pro ED 15×70s tip the scales at 2 kilograms (4.6 pounds), making them a substantial 0.6 kilos heavier than the heavier of the other two, suggesting from the get-go that they're built very differently.

The Pro ED 15×70s are also different in that their eyepieces are threaded to accept standard 1¼-inch filters. The retractable eyecups extend to the top of the filters I tried, keeping the edge of the filter cells from pressing against your eyes. However, keeping your eyes this far back from the eyepiece can prevent some observers from seeing the binoculars' full 4.4° field of view due to the relatively modest 15.7 mm of eye relief. This is especially true for those who wear eyeglasses when observing.

On the plus side, the binoculars' center-focusing assembly is notably robust and prevents the eyepieces from rocking or affecting the focus when you press your eyes tight to the eyepieces. I also found the twin thumb tabs on the right eyepiece particularly nice for making focus adjustments to compensate for the differences between my eyes.

The relatively large diameters of the eyepieces (52 mm) means the spacing between the eyepieces was a little tight for me as I squeezed my generously sized nose between them. People with a larger eye separation (or a smaller nose) will find this to be less of a problem.

On the optical bench, I measured the Pro ED 15×70s eyepieces' apparent field of view to be almost 66°, which is quite generous for binoculars. It renders a very pleasing, immersive view of the night sky. This was particularly noticeable when I compared the view to 7×50 binoculars that have a 54° apparent field and a pair of 8×60s with a 42° apparent field, even though both of these offer larger true fields than the Celestrons. The joy of observing with a wide apparent field is what fueled the popularity of modern wide-field telescope eyepieces, and it's just as desirable for binoculars.

▲ The SkyMaster Pro binoculars have eyepieces threaded to accept standard 1¼-inch astronomical filters, such as the dual-band nebula filter seen here with the eyecup retracted (left) and fully extended (right). The extended position may keep your eyes too far back to allow seeing the full field of view, especially if you need to wear eyeglasses when observing.

Another aspect of the Pro ED 15×70s that becomes quickly apparent when looking through them is the need for some kind of solid support. In a pinch you might get away with a quick handheld look, but even when leaning against a wall or propping the binoculars on a fence post, the view isn't very satisfying — it simply jiggles too much. But that still didn't stop me from using them this way to quickly check for an outburst of the recurrent nova T Coronae Borealis (*S&T:* March 2024, p. 34) on scores of nights last winter and throughout the spring.

The Pro ED 15×70s have a ¼-20 threaded socket on the pivot bar so that they can be used with virtually any conventional binocular tripod adapter. I find that using a sturdy photo tripod with binoculars is comfortable when viewing the sky up to altitudes of about 45°. A reclining chair works well for higher altitudes but typically requires a special support for the binoculars. Try Googling "binocular mounts for astronomy" if you want to peruse the seemingly endless contraptions that amateurs have devised to mount binoculars for use with reclining chairs.

For more than 20 years I've often used the Sky Window pictured on page 72 when

◀ The binoculars' objectives are made with ED (extra-low dispersion) glass, which provides views free from color fringes at the edges of bright objects and color halos around bright stars. The rubber lens caps are easily removable.

scanning the sky at high altitudes. This novel binocular mount, which I reviewed in this magazine's January 2002 issue, page 57, became available as a commercial product in the early 2000s and may be available today at **skywindow.com**. The device offers very comfortable observing at the expense of showing the sky upside down and mirror-reversed, making it difficult to use with printed star atlases. Today, however, digital star charts made for computers, tablets, and smartphones can often be displayed to match the Sky Window's orientation.

Thanks to the ED (extra-low dispersion) glass used in the objective lenses, the Pro ED 15×70s deliver a beautifully color-corrected view. Even white objects illuminated by brilliant sunshine and seen against a dark background show no sign of color fringes. And there was no sign of color halos around bright stars. Indeed, to my eyes, the subtle contrasts in star colors seen with these binoculars were particularly impressive.

▲ The SkyMaster Pro ED 15×70 binoculars come with lens caps for the objectives and eyepieces, a soft carrying case, neck straps for the binocular and case, and a lens-cleaning cloth.

For people like me who evaluate binoculars by their specifications, there's a number for the Pro ED 15×70s that may catch your attention. The exit pupil is listed as 4.4 mm. This is the diameter of the light bundle emerging from the binocular eyepiece, and it's often considered a waste of binocular aperture if the exit pupil exceeds the diameter of your eye's pupil. The Celestron's 4.4 mm is a nice diameter even for those of us with aging eyes who have lost the maximum 7-mm- or 8-mm-pupil diameter of our youth, or simply prefer better contrast with the background sky. But the exit pupil of binoculars (or a telescope) is calculated by dividing the objective diameter by the instrument's magnification, and simple math for the Pro ED 15×70s says the exit pupil should be almost 4.7 mm, not 4.4 mm. So, what gives?

To make a rather long story short, after careful measurements on the optical bench I found that 4.4 mm is correct because the effective diameter of the objectives is 67 mm even though the front of the lenses measure 70 mm across. This slightly reduced aperture is insignificant at 15× and thus has no perceptible impact on the binoculars' performance. But it does explain why the specification table for the Pro ED 15×70s lists the exit pupil as 4.4 mm rather than the expected 4.7 mm.

For almost 30 years my go-to binoculars for serious high-magnification astronomical viewing have been a pair of Fujinon 16×70s, which today retail for about $1,050 (almost twice what I paid in the mid-1990s). I could go on at length making a comparison between the Celestron and Fujinon binos, but here's the bottom line: The Celestron binos have a slightly larger apparent field of view (66° vs 62°), almost a ½° larger true field of view, and better color correction, especially at the very edge of the field. And in a world where dollars and cents make a difference, there's no question that the Pro ED 15×70s are a winner. Choosing between the two today, I'd pick the Celestron binoculars. I highly recommend them.

▲ As detailed in the accompanying text, the author used the Sky Window binocular mount when observing celestial objects at high altitudes. This device provides comfortable viewing at the expense of views that are upside down and mirror-reversed.

■ When autoguiding freed **DENNIS DI CICCO** from staring into an illuminated-reticle eyepiece, binoculars became his preferred method for scanning the sky while babysitting his astrophotography equipment.

◀ EYEPIECE TURRET

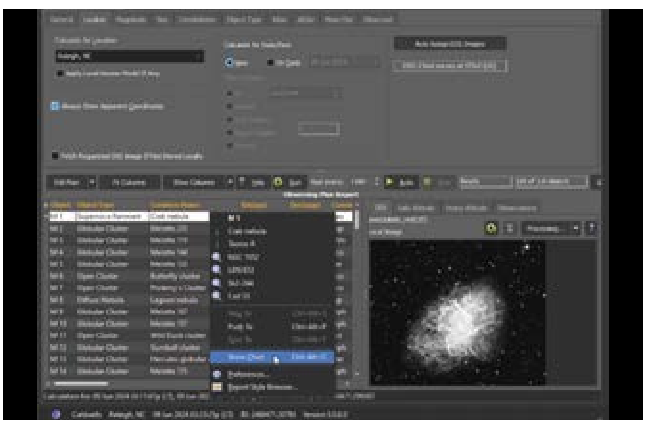
British manufacturer nPAE Precision Astro Engineering now offers a new eyepiece turret for observers and imagers alike. The Rotating 6 × 2 inch Flip Turret (£2,400) holds up to six individual 2-inch eyepieces, enabling you to swap magnification in seconds. The unit weighs 2.3 kg (5.3 lb) and is manufactured from CNC-machined, aircraft-grade aluminum. Each eyepiece is secured with a brass compression ring, and users can set the precise focus for each installed ocular. The turret uses a 1⁄10-wave aluminized mirror to provide crisp, unvignetted views. The mirror flips out of the way to permit astrophotography through the rear port of the unit, which includes an M68 thread to attach your camera. The 2-inch-format nosepiece also contains an nPAE filter drawer that holds 48-mm-threaded filters. Requires 152 mm of back-focus travel.

nPAE Precision Astro Engineering
Northgate House, Northgate, Nottingham, UK NG7 7BQ
+44-7360-725-179; npae.net

▼ OBSERVING PLANNER

Knightware announces the release of *Deep-Sky Planner 9* ($85 for digital download). This PC software operates on Windows 11 and lets you take advantage of cloudy nights and daylight hours to plan your evening observing sessions. Users can search through more than 1.6 million objects in the software's extensive database, which provides accurate positions for each object and computes the best time to observe it from your location. This latest revision includes numerous improvements to the user interface and support for 4k monitors. *Deep-Sky Planner 9* allows you to create and export customized observing plans directly into most popular Go To navigation systems and imaging automation software on PCs and smart devices. The program can also directly command any ASCOM-compatible Go To telescopes and mounts.

Knightware
305 Evans Estates Dr., Cary, NC 27513
knightware.biz



▼ ROLL-OFF ROOF

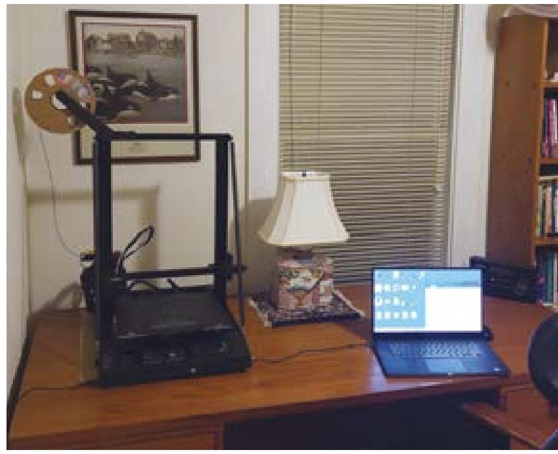
Canadian observatory manufacturer Nexdome unveils its latest offering in its growing line of telescope shelters. The NexROR-2 kit (starting at $4,595) is a 2-by-2.3-meter (7.5-by-6.5-foot) roll-off roof designed for maximum protection of your instruments in wind, snow, and other harsh weather. It's constructed of stainless steel and aluminum and designed to withstand windspeeds of up to 160 kilometers-per-hour (110 mph) and snow loads of 122 kilograms per square meter (25 pounds per square foot). The roof can be anchored to any type of floor with its custom anchoring system. The roof is sold separately to attach to a building of your own design, though kits are available that include wall frames. The NexROR-2 can be shipped using a standard LTL carrier. Custom sizes and automation accessories are also available.

NexDome
3430 Brighton Ave., Burnaby, BC, Canada V5A 3H4
604-336-3821; nexdome.com

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

3D Printing and the Future of Telescope Making

Shop space is so retro!



▲ Avner's workshop is considerably neater than mine.

▶ Avner designed the tube rings in *FreeCAD*, then printed them out. They were a perfect fit and could probably hold up a Volkswagen.

I'VE WRITTEN ABOUT 3D printing before, most recently Robert Asumendi's "Magic" binoculars (*S&T:* June 2024, p. 74) and Jonathan Kissner's "Hadley" telescope (*S&T:* Jan. 2023, p. 70). But those columns were mostly about the telescopes, not their method of construction. In this column, I want to talk more about 3D printing in general. Why? Because 3D printing has come of age, and it's a technology that's changing the face of Amateur Telescope Making.

Until recently, building a telescope has nearly always required machining some parts. Most ATMs use wood, because that's what we have tools for and it's relatively easy to handle. Some of us use metal, often cut with hacksaws and shaped with files, while the more advanced builders have machine shops with lathes, drill presses, etc.

3D printing makes most of that unnecessary anymore. If you need an adapter ring to mate your focuser to the optical tube, you can design it with computer-aided design (CAD) software on your computer and print it out on a desktop 3D printer. You need no shop space, and you generate no dust, debris, metal filings, noise, or marital discord.

I've long assumed that 3D printing was mostly for minor parts, but Boston ATM Avner Butnaru recently set me straight about that. He built a 9-inch refractor (!) for which he 3D printed practically everything but the lens and the tube. He even printed the tube rings, the parts that hold the telescope to the mount. Those rings have to withstand the weight of the telescope tugging sideways on the bolts. I assumed the plastic would simply snap under the strain, but Avner tested his rings with a 39-pound car battery and couldn't get them to break, nor even pull out the ¼ × 20 threaded inserts he'd epoxied into place.

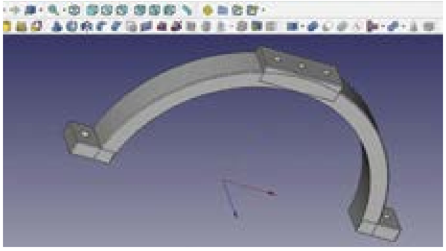
The key to such strength is in the design. 3D printers lay down a tiny little tube of molten plastic, snaking it around on a flat bed, then they raise the print head upward the width of the filament and print the next layer, and so on upward until the part is complete. That leaves the piece with a noticeable grain to it, just like in wood. And as with wood, the printed part is strongest along the grain. You wouldn't saw a one-inch strip off the end of a 1-by-6 board and expect that strip to hold much, and you shouldn't expect it from a vertically 3D-printed piece of the same dimensions, either. But along the direction of printing, the stuff is amazingly strong. So with tube rings, for instance, you print them flat, so the grain runs around the rings.

There's also the matter of infill. Most 3D-printed parts aren't solid plastic. They have an airy structure inside, which saves a lot of material and allows you to dial in the degree of strength you need. Infill can be as little as 10% of the density for extremely lightweight parts, or denser for more strength. The infill pattern can also vary from six-sided honeycombs to four-sided cubes to three-sided triangles, even spirals. Avner used a 60% honeycomb infill for his tube rings and figures he'd need an industrial test facility to safely gauge their breaking strength.

There are also different types of filament. Avner used PLA (polylactic acid), which is popular for its versatility,

Avner Butnaru poses with his 9-inch refractor, for which he 3D printed most of the parts. He's holding just about the only hand tool required: a caliper for accurate size measurements.

AVNER BUTNARU (2)



but there are many different materials, even some with carbon fiber in them for additional strength. You can also choose from dozens of different colors.

There are dozens of models of printers, too. Avner has two: a Sunlu S9 and a BIQU B1 SE Plus. Both have a print area of 310 × 310 millimeters (12.2 × 12.2 inches), essentially large enough to print anything that fits inside a cubic foot.

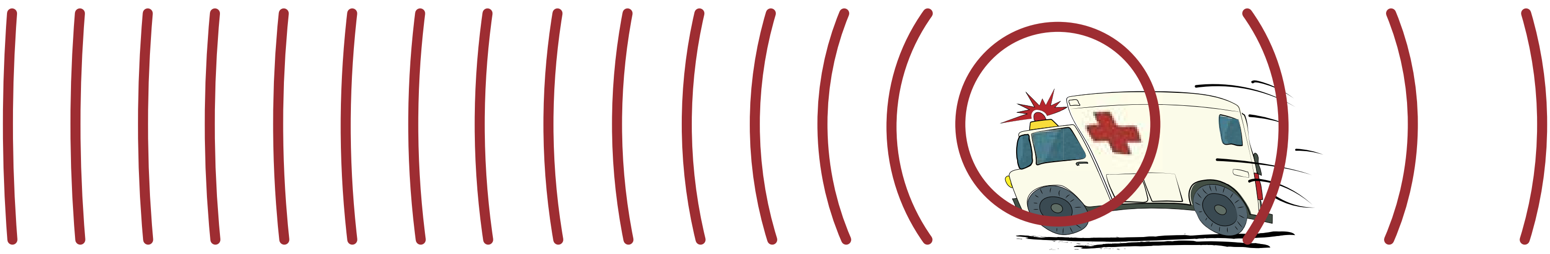
There are dozens of CAD programs, too. Avner uses *FreeCAD*, which, as its name implies, is free. The software allows you to build parts on screen, rotate them, X-ray them, etc., so you know exactly what you're going to get when they're printed.

3D printing isn't for everything. As Jonathan Kissner points out, there's no point in 3D printing a plastic replacement for a slab of plywood. It's a waste of plastic, time, and money. But a helical focuser can be printed for a couple of dollars.

Avner's final word on the subject says it all: "Happiness is the ability to make any part you want, anytime, on your desk, in your home office. And all this for 'short money.'"

AVNER BUTNARU

■ Contributing Editor **JERRY OLTION** is holding out for a 4D printer, so he can have parts printed before he knows he needs them.



What Is Redshift?

WITH THE ADVENT OF far-seeing observatories like the James Webb Space Telescope, the word *redshift* comes up regularly in reference to objects in the distant universe. For galaxies, quasars, or other remote celestial wonders, redshift represents their distance.

But really, redshift is a measure of *velocity*. Yes, velocity — bear with me for a moment!

The term redshift originates from the term *Doppler shift*, which describes the change in frequency an observer detects in a signal coming from a moving source. Just as a passing ambulance siren seems to decrease in pitch as it zooms by, the light from a star that's moving away from us decreases in frequency — which means its wavelength increases. Longer wavelengths are redder than shorter ones, so a shift toward the red (lower-frequency) end of the spectrum is known as redshift. Likewise, the light from a star moving toward us would be blueshifted to shorter wavelengths.

All the light from a source shifts redward or blueward by the same fraction. But to gauge the size of that shift, we need precise measurements of specific, known wavelengths of absorption or emission in the source's spectrum. For example, hydrogen gas can emit light at 121.6 nanometers. If a star's hydrogen emits that light but observers see it shifted redward to 150 nanometers, then the star is moving away from us at 20% the speed of light.

Redshift came to mean more than an object's velocity in the early 20th century, when astronomers realized the universe is expanding.

It turns out that every distant galaxy we see appears to be speeding away from us, with more distant ones having a faster *recession velocity* than closer ones. But these galaxies aren't flying through space — it's the space between us and them that's expanding. So a more distant galaxy has a higher recession velocity, and thus a higher *cosmological redshift*.

Yet, while a galaxy with a larger recession velocity surely lies at a greater distance, it's more difficult to say exactly what that distance is. To make the translation between redshift and

BEATRIZ INGLESSIS / S&T (2); EDWIN HUBBLE / *PROCEEDINGS OF THE NATIONAL ACADEMY OF SCIENCES* 1929

Equation for Redshift

The equation to calculate redshift (z) is:

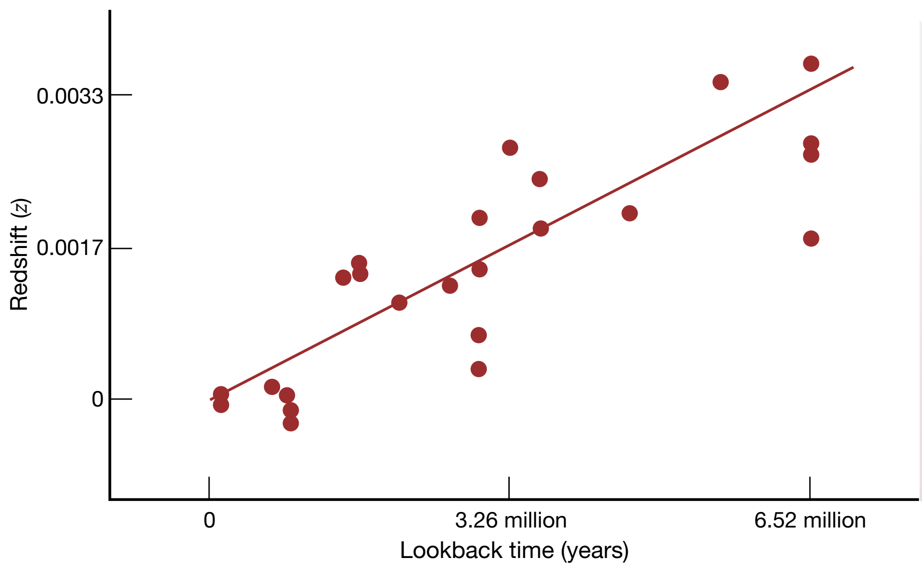
$$z = \sqrt{\frac{1+\frac{v_r}{c}}{1-\frac{v_r}{c}}} - 1 = \frac{\lambda_{observed}}{\lambda_{emitted}} - 1$$

where:

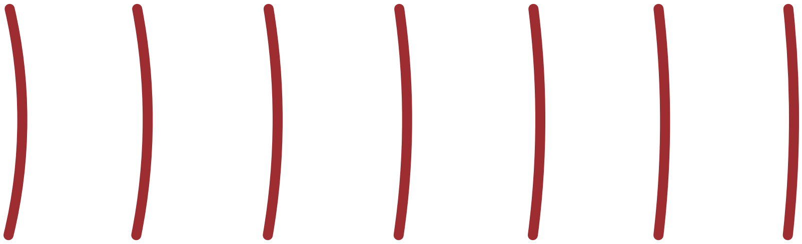
v_r is the object's velocity toward or away from us

$\lambda_{emitted}$ is the wavelength the object emits

$\lambda_{observed}$ is the wavelength astronomers observe



▲ **THE EXPANDING (NEARBY) UNIVERSE** In 1929, Edwin Hubble showed that galaxies' recessional velocities increase with their distances (determined via standard candles). The velocities and distances of the original plot have been converted to redshift and lookback times, respectively.



PRINCIPLE FOUNDER
Austrian physicist Christian Doppler first described the effect named for him in 1842. He used it to explain the colors of binary stars in terms of their motion around each other — but erred in his assumption that the intrinsic color of all stars is white!

▲ **DOPPLER SHIFT** A bystander can hear the pitch of the siren first rise, then drop, as an ambulance zooms by. In an analogous way, the color of light (described by its frequency or wavelength) changes depending on whether the source is moving toward or away from us.

distance requires understanding the entire history of cosmic expansion.

The universe hasn't always expanded at the same rate it does now. To understand how the expansion rate has evolved, we can do one of two things: Go backward in time using observations of stars, supernovae, or other *standard candles*, or move forward in time starting with the universe's first light, the Big Bang's afterglow that is now seen as the *cosmic microwave background* (CMB).

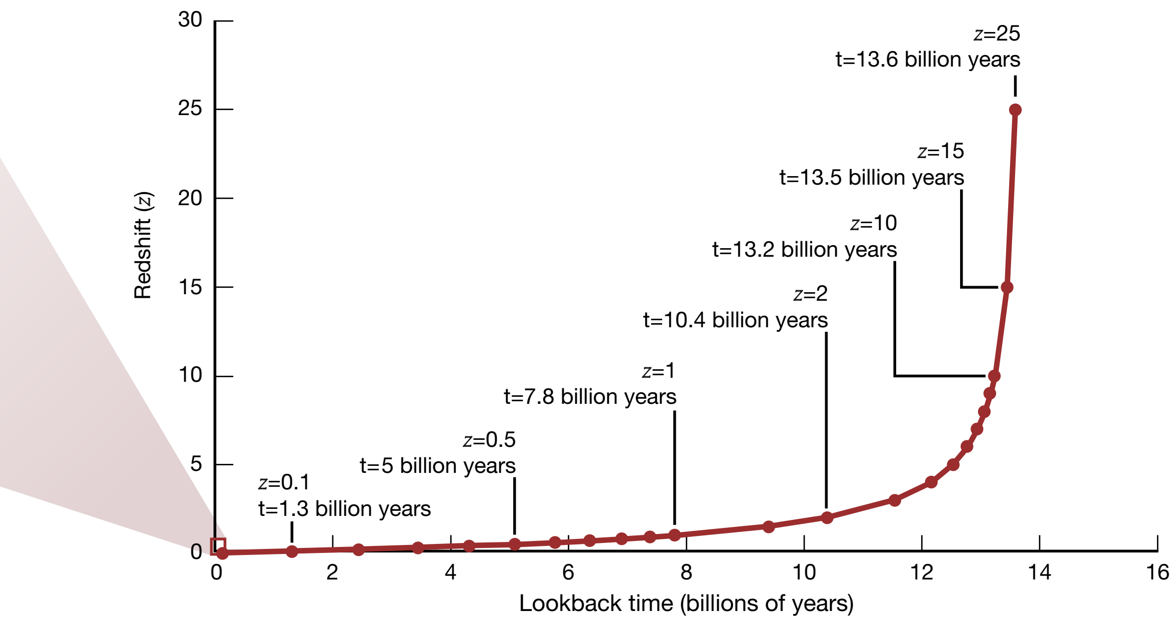
Astronomers who turn to standard candles may, for example, observe the brightness of certain supernovae in distant galaxies. They know how bright these supernovae are intrinsically, so they can determine how far away they must be in order to look as faint as they do. We can then connect their distances with their measured redshifts.

Alternatively, astronomers who look to the CMB are quantifying the subtly uneven glow of microwaves that suffuses every direction we look in the sky. Variations in this background reveal the sloshing that happened in the primordial plasma of the very early universe. Studying these patterns, in turn, enables scientists to measure the handful of fundamental parameters that describe cosmic expansion over time (*S&T:* July 2015, p. 28).

Using one or often multiple methods to calibrate our understanding of cosmic expansion, astronomers can map out a relationship between redshift and distance. However, the expansion of space makes distance a tricky notion to define. (See the October 2022 issue, page 12, for multiple definitions of cosmic distance.) In the pages of *S&T*, we use *lookback time* as a proxy for distance: It tells us how old the universe was when the light we're seeing was emitted.

However, even lookback time requires translating from redshift in a way that depends on our observations of the universe. Simply put, the relationship between redshift and any measure of distance or time relies on a complete understanding of cosmic history that we'll never quite have.

That ambiguity is the reason professional astronomers generally prefer to use redshifts rather than distances or lookback times, even if the numbers involved are less intuitive to understand. Redshift is a quantity we can obtain straight from a galaxy's spectrum — it's a physical measurement that remains valid even if our cosmological theories need to be changed. ■



◀ **LOOKING FURTHER BACK** While redshift and lookback time increase in lockstep for nearby objects, when we look farther out into the universe, changes in redshift correlate to smaller and smaller jumps in lookback time. To see the universe's first light (the cosmic microwave background, emitted 380,000 years after the Big Bang) would require seeing to a redshift of about 1,100. This plot shows the relationship between redshift and lookback time based on the following cosmological parameters: Hubble constant (H_0) = 69.6 km/s/Mpc, matter density (Ω_m) = 28.6%, and dark energy density (Ω_{vac}) = 71.4%. (Note: The inset square at the origin is not to scale.)

RIBBON OF GAS

Gerald Rhemann

Comet 12P/Pons-Brooks sported a long, rippling ion tail as it passed through Aries earlier this year on April 2nd. Its coma glows a distinct teal color due to the presence of diatomic carbon.

DETAILS: *Astrosysteme Austria ASA 8N f/3.6 astrograph and Moravian C3-61000 camera. Total exposure: 33 minutes through LRGB filters.*

◁ THE EYE OF THE BEHOLDER

Drew Evans

The Helix Nebula, NGC 7293, is one of the nearest planetary nebulae, located 650 light-years away in Aquarius. The nebula formed when the aging central star shed its outer layers, producing the colorful, eye-shaped nebula we see today.

DETAILS: *Sharpstar SCA260 V2 Aspherical Cassegrain and ZWO ASI6200MM Pro camera. Total exposure: 24 hours through narrowband filters.*

▽ CRATER LAKE

Dave Horton

The largest solar storm in the last 20 years impacted Earth on May 10th. The event produced vibrant aurorae that lit up the skies over Crater Lake in Oregon, painting the landscape and sky in vivid pink, red, and green hues.

DETAILS: *Sony α7S III camera and 20-mm lens. Panorama of six panels, each a 6-second exposure recorded at f/1.8, ISO 1250.*

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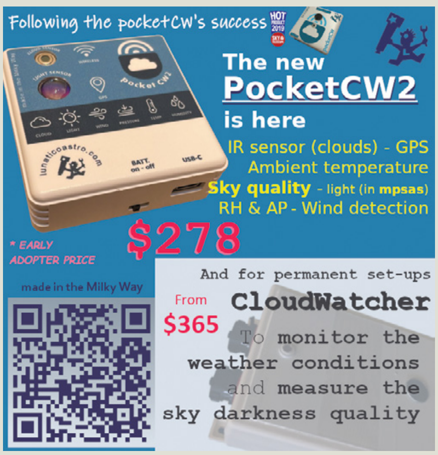

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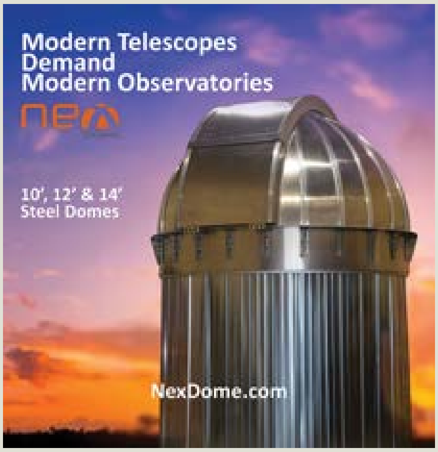

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The Gift of Stargazing

How observing and imagining helps the author forget, for a time, the hardships he faces as an adult with disabilities.

AS SOMEONE WHO IS deaf-autistic and wears a hearing aid and cochlear implant, I've always greatly enjoyed stargazing. Beyond relishing the beauty and mystery of the night sky, it allows me to temporarily escape the challenges I've faced ever since I was a child.

When I was young, my parents owned a colonial home in rural New Hampshire. There was little street traffic or light pollution, and on clear nights the sky was absolutely alluring. For my seventh birthday, my parents gave me a Meade Polaris 60AZ 60-mm refractor. The telescope wasn't anything particularly special, but it was good enough to see Mars and Jupiter with. Altogether, the two things I enjoyed most in those early years were astronomy and transition-period railroads, when steam locomotives gave way to first-generation diesel-electric engines. I still treasure both hobbies as an adult.

Being deaf-autistic, finding acceptance among my childhood peers was always an issue. To get them to look past my social differences was impossible. Though I tried hard to be included, my peers would always bully me.

Sadly, due to a lack of awareness toward adults on the autism spectrum, bullying is still a constant problem for me, even at 28 years old. I struggle with anxiety and depression because of it. It feels like society is still decades behind being truly informed about how autism works. The lack of empathy toward adults with autism has made life extremely difficult for me.

But I've always found going outside and looking at the stars to be a therapeutic reprieve. I love the universe so much. It's a beautiful display of natural art that we humans should be more grateful for.

I love to imagine visiting celestial objects. If I could travel anywhere in our Milky Way Galaxy, it would be to NGC 3372, the Carina Nebula. I think it's one of the most beautiful sights in the night sky. I'm also very curious to know what the Trappist-1 exoplanet system is actually like. I look forward to future discoveries about its multiplanet system. I'm fascinated by planets and exoplanets everywhere as well as by moons, nebulae, and spiral galaxies.

Ever since second grade, I've enjoyed watching *Star Trek*, which greatly contributed to my interest in astronomy growing up. Beyond the show's depiction of human space exploration, what I appreciate most about it are the fantastic examples of friendship, teamwork, family, and acceptance of people from different cultures. I wish I could experience those values more often in life.

I also wish humankind had the ability to explore beyond our solar system. If Starfleet were real, I'd join in a heartbeat. The truth, though, is that adults like me don't receive the same opportunities as others. As someone who supports space exploration, I'd highly encourage space industries to figure out how deaf and/or autistic people can contribute to the development of space technology or anything related to the exploration of outer space.

I always try to stay informed on current night-sky events. I frequently read astronomy articles, watch SkyTour Livestream (**skytourlive.com**), and browse Stellarium. One day I hope to go stargazing at southwestern natural wonders like Zion National Park, Bryce Canyon, and Monument Valley. Those look to me like some of the most majestic places in the world to observe the night sky. One shouldn't go through life without visiting them!

■ **COREY BURRELL** loves to explore the outdoors, particularly the White Mountains region in his home state of New Hampshire.

LEAH TISCIONE / *S&T*

The image on the right is the famous Pillars of Creation (M16) taken with the Wide Field Planetary Camera of the Hubble Space Telescope. The image on the left is taken with a QHY600M-PH Camera through a 7-inch refractor from the author's backyard in Buenos Aires. Courtesy Ignacio Diaz Bobillo. To see the original composition, resolution and acquisition details, visit the author's Astrobin gallery at https://www.astrobin.com/users/ignacio_db/

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