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SKY & TELESCOPE

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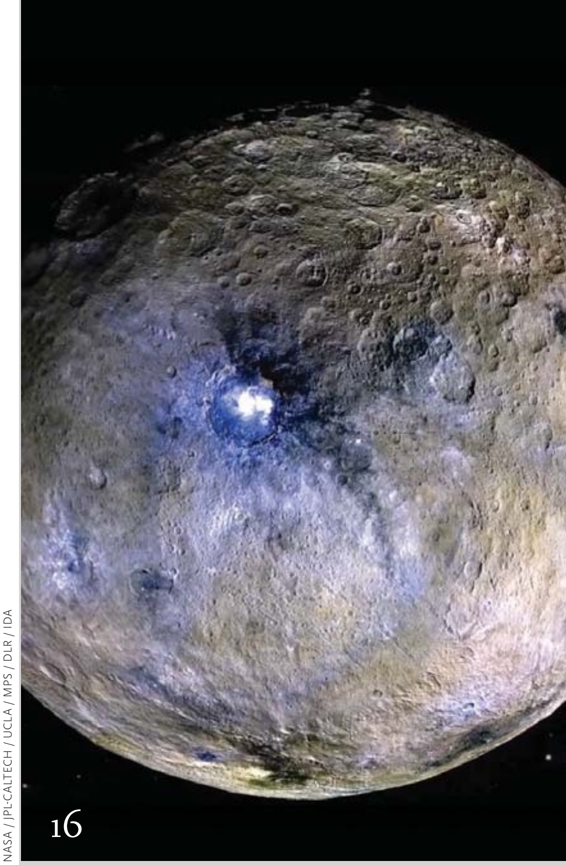

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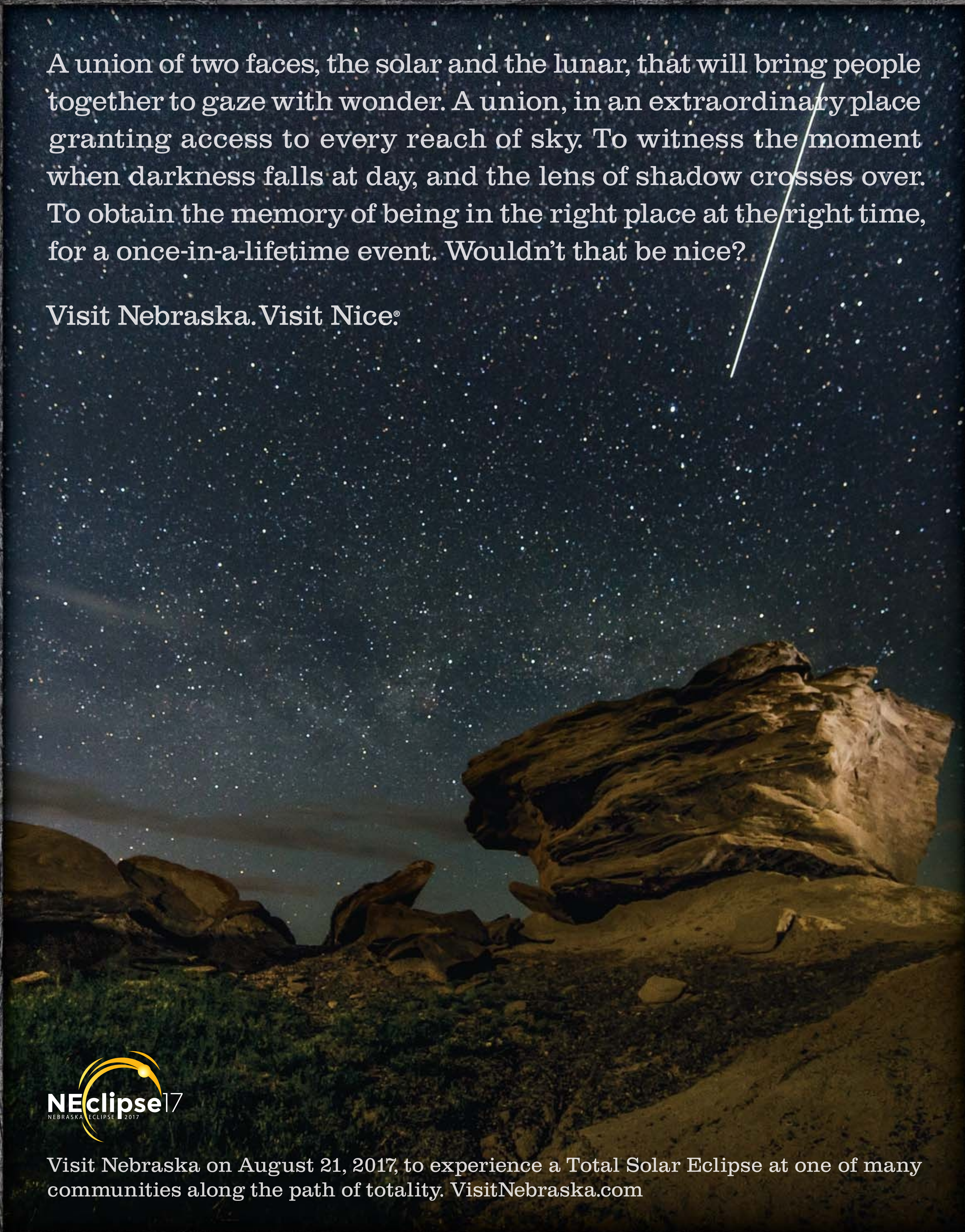
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Look-back Time

TIME CAN REALLY PLAY with your head while stargazing. On a clear evening in August, I gave my 83-year-old mother a brief tour of the heavens over the dark-sky stretch of Maine coast where she lives. The transparency and seeing were superb, and the Milky Way threw a broad, diffuse stripe down the middle of the firmament.

I was thinking what a long, interesting life she has led and how far back 1932, the year she was born, stands from us today. It was the heart of the Great Depression. Amelia Earhart flew the Atlantic solo. Mahatma Gandhi went on a hunger strike against British laws in India. For me, events like these hover in the dim mists of world history.

But 83 years is a mere instant, of course, when contemplating the look-back times of celestial objects. After we admired Mars and Saturn, which were about to set in the southwest, I pointed my 10-inch Dobsonian overhead and brought the several hundred thousand stars of M13, the Great Hercules Cluster, into view. Photons from Mars and Saturn had reflected off those planets only minutes before. But the light from the jewel-encrusted globular cluster had departed roughly 22,000 years ago, when Earth languished in the grip of the last ice age. Back then, the spot where we then stood lay hundreds of feet beneath the Laurentide Ice Sheet. (Now *that* would complicate stargazing . . .)

M13, the Great Hercules Cluster

S&T: SEAN WALKER

In the hour we observed together, we scrutinized M57, the Ring Nebula, as it looked 2,300 years ago; M11, the Wild Duck Cluster (6,200 years ago); and M31, the Andromeda Galaxy (2.5 million years ago).

To further exercise our faculties, we could ponder the estimated age of the objects on our list. The Ring Nebula began expanding around 5,000 BC, a time when humans first spun and wove clothes. The Wild Duck Cluster originated roughly 220 million years ago, during the Triassic Period. And Andromeda? About 9 billion years old, or twice the age of our solar system.

I thought keeping daily appointments in my head was a challenge, but this? A whole other ball of wax — yet worth doing nonetheless. What other hobby allows you to time-travel so easily? All you have to do is glance up or put eye to eyepiece.

Now, if only we could get a peek at the Pyramids 4,600 years ago when they were just built. Or a look at what is today eastern Montana 70 million years ago, when *T. rex* stomped through swamplands there. While we can't with our eyes, we can with our minds, as Matt Wedel does in his article on page 24, "Twelve Steps to Infinity." Join him to learn what was happening on our planet when light departed the dozen objects he describes.

Just for fun, I'd like to have shown my mother Mizar in the Big Dipper, whose rays left that double star about the time she was a baby. But Ursa Major hung behind trees to the northwest. And it was time for her to retire. She wasn't born yesterday, after all. ✦

Peter

Editor in Chief

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The Show Must Go On

I enjoyed Eden Orion's "Making It Special" (*S&T:* July 2016, p. 84). If you do public outreach, sooner or later you're going to have to improvise. When the weather, the venue, or the planets don't cooperate, and you already have people lined up for viewing through your telescope, it's just really hard to pack up and go.

Here at the Desert Foothills Astronomy Club, we've done those one-star solo performances. We've also used a single bright star at low elevation to show twinkling and dispersion effects. And we've alternated between stars (like Betelgeuse and Rigel) to emphasize color differences — people are surprised by the contrast.

Dan Heim
New River, Arizona

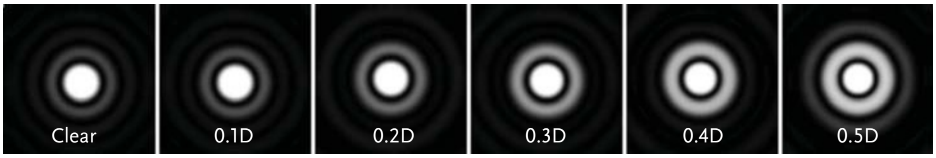
The Power of Totality

William Sheehan's article, "The Great American Eclipse of the 19th Century" (*S&T:* Aug. 2016, p. 36) calls to mind a solar eclipse of even longer duration — nearly 5 minutes — whose path of totality swept across North America from Baja California to Massachusetts on June 16, 1806. Eclipse timings in New England were collected and analyzed by Nathaniel Bowditch, the nation's foremost mathematician and expert on marine navigation.

The eclipse was also witnessed from upstate New York by 16-year-old James Fenimore Cooper, a decade before he penned *The Last of the Mohicans*. Long afterward, Cooper recalled the sublime experience in a magazine essay: "There floated the moon, distinctly apparent, to a degree that was almost fearful. . . . It looked grand, dark, majestic, and mighty."

Perhaps the most enduring impact of the 1806 eclipse on then-fledgling American science was to inspire a young clockmaker's apprentice, William Cranch Bond, to pursue a career in astronomy. In 1839, Bond became the founding director of Harvard College Observatory.

Alan Hirshfeld
North Dartmouth, Massachusetts



As this simulation shows, increasing the diameter of a telescope's central obstruction as a fraction of its aperture (*D*) causes noticeable changes in the resulting *Airy disk*, which is the diffraction pattern of a point source as seen through telescopic optics.

A Note About Airy Disks

I enjoyed "Find your Dawes Limit" (*S&T:* Sept. 2016, p. 30) so much. Let me add one minor point, however, regarding Phillip Kane's comment, "A scope with a central obstruction shows a slightly larger Airy disk . . . than an unobstructed aperture." Doesn't an obstruction make the center of the Airy disk slightly smaller?

Nozomu Muto
Sinjuku (Tokyo), Japan

Phillip Kane replies: *You are correct — as the obstruction increases, fewer photons end up in the Airy disk's central peak and more end up in the outer rings. And you're in good company to notice this. The great J. B. Sidgwick (*Amateur Astronomer's Handbook, *4th edition, 1980) notes: "For work requiring maximum resolving power, increasing the diameter of the central obstruction might profitably be tried. . . . Sir John Herschel long ago reported an improvement in a telescope's resolving power when used with a D/5 to D/6 central stop, despite the brightening of the rings." One more thing: my big table of double stars didn't include their SAO identifications. Because these are so widely used by Go To telescopes, you can download a version of the table that includes them at* ***https://is.gd/Dawes_Limit_star_list*** *(or I can send you this version if you'll just email me at icycomet1944@gmail.com).*

Two Amazing Observations

Is it possible for Mars to get bright enough at opposition to cast a shadow? I've never read about this anywhere, and I'd never noticed one, though I've seen both Venus and Jupiter cast shadows. So I decided to look for it on some good, dark nights last May, while standing outside my observatory with no artificial lighting around. By slowly rocking back and forth, I could watch my shadow jump across the observatory's outer wall. Actually I found it fairly easy to see.

Mark Hays
Newbury Park, California

I am in my 32nd season as a U.S. Forest Service fire lookout. During August's Perseid meteor shower, I had a remarkable "first." Many of its shooting stars coursed across the heavens, and at one magical moment two meteor trails actually *crossed*. We all know that "X marks the spot," so I'm trying to figure out how to get up there. I've got a call in to NASA — I'll let you know how it goes.

Don Evans
Prineville, Oregon

Measuring Bent Starlight

I wish Donald Bruns the best of luck and skill for his attempt to duplicate Arthur Eddington's 1919 test of Einstein's general theory of relativity during next year's total solar eclipse (*S&T:* Aug. 2016, p. 32). Bruns mentions the inability of a 1973 eclipse expedition to measure the deflection of starlight by the Sun's gravity. However, let me note that a dust storm at its site in Mauritania brought transparency down to 10%, a major reason for the failure.

A decade ago, Carl Pennypacker (Lawrence Berkeley Laboratory) and I, with students, tried to use computerized data reduction to help Jean-Luc Dighaye pull such a stellar-deflection measure-

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ment from his observations taken in Africa before and during the 2006 total solar eclipse. The attempt failed, probably because the camera's pixels were too large — a problem overcome in Bruns's plans.

One suggestion: After completing his observations next August, Bruns might try using a comparison exposure of his eclipse-centered star field without the Sun in it, instead of using the Gaia catalog.

Jay Pasachoff
Williamstown, Massachusetts

Editor's note: *A veteran of 33 total solar eclipses and 31 more annulars and partials, Pasachoff chairs the International Astronomical Union's Working Group on Eclipses.*

Hydrogen-Alpha by Eye?

I'm curious about why hydrogen-alpha filters aren't mentioned in Rod Mollise's informative article "Visual Filters for Deep-Sky Observing" (*S&T*: Aug. 2016, p. 28). His mention of H-beta filters suggests there is some advantage to using those rather than an H-alpha filter for observing extended celestial objects containing atomic hydrogen. Why so?

Hal Heaton
Damascus, Maryland

Kelly Beatty replies: *Although many deep-sky objects emit plenty of hydrogen-alpha light, the dark-adapted eye doesn't perceive it with any kind of useful sensitivity. With a wavelength of 656 nm, it's simply too deeply red. Conversely, hydrogen-beta is blue (486 nm) and thus very obvious to the eye at night.*

Moonstruck

Many thanks for "The Moon Does That to You" (*S&T:* Oct. 2016, p. 84). I can relate to Mark Mathosian's experience, as I have been involved in similar interaction with strangers. His story also brings back the memory of another recollection that left a lasting and powerful impression on me, namely "The Mysterious Coney Island Telescope Lady" by Paul Johannsen (*S&T:* Jan. 1992, p. 97). That one, dating from the 1950s, comes awfully close to my own start in astronomy.

I have never been able to fully explain how this all works. But no matter how many spectacular Hubble images of galaxies or incredible planetary shots by Damian Peach we see, there is something magical about the view in the eyepiece that no imager can match. And that's one reason why I have remained a strictly visual observer in this age of CCD imaging.

Vahe Sahakian
Houston, Texas

For the Record

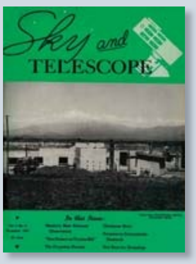
✷ *The time listed for full Moon (*S&T*: Aug. 2016, p. 42) should be 5:26 a.m. EDT.*

✷ *In the article "Processing with PixInsight" (*S&T*: Aug. 2016, p. 69), the sentence beginning on the third line should be: "Because atomic hydrogen [not Hα] also emits at blue wavelengths . . ."*

✷ *Dan Dill's Canon EOS 5D Mark III, used to record the transit of Mercury (*S&T*: Sept. 2016, p. 73), is a DSLR (not CCD) camera.*

75, 50 & 25 Years Ago

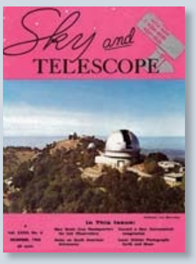
Roger W. Sinnott



December 1941
Cosmic Upheaval "Twenty years ago when the new director entered upon his duties, what were his surroundings? I don't mean the Harvard College Observatory of 20 years ago . . . I am thinking about the universe. . . . Indeed, it wasn't the same universe. . . .

"There are not many of you who can remember the time when there were, so to speak, no galaxies. I remember it very well. I remember the day Dr. Shapley said: 'My universe has been shattered.' . . . Our modern world-picture, with its galaxies, its supergalaxies, its metagalaxy, was perceived — consciously perceived — all within the last 16 years. I doubt whether any other observational science can point to a parallel expansion."

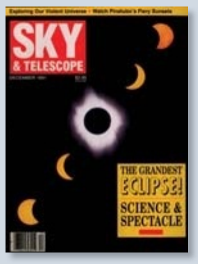
Cecilia Payne-Gaposchkin was speaking at a staff dinner celebrating Harlow Shapley's first 20 years at Harvard. He had lost the famous Shapley-Curtis debate of the early 1920s, conceding that most "nebulae" were stellar systems far beyond the Milky Way.



December 1966
No Earth Cloud "For the past seven years, data have been accumulating that suggest the earth is surrounded by a cloud of dust. . . . It now appears, says Carl Nilsson of [NASA's] Goddard Space Flight Center, that the data gathered in early satellite measurements should not be used to test the hypothesis of a dust concentration around the earth.

"Most of these satellite experiments used piezoelectric microphones as detectors. . . . But Dr. Nilsson has found from both satellite and laboratory data that the microphone crystals emit noise spontaneously when subjected to slowly varying temperatures, such as satellites traveling through the shadow of the earth may experience. The rate of occurrence of the noise pulses is consistent with flight data that have previously been interpreted as micrometeorite impacts."

Nilsson's study of detection methods knocked out the underpinnings from a key "finding" of the early Space Age.



December 1991
Halley Flare-up "Something strange happened to Comet Halley last February 12th. While slowly receding from the Sun between the orbits of Saturn and Uranus, the comet suddenly became 300 times brighter . . .

"The problem facing astronomers is explaining how so much energy might have been released from Halley's nucleus so far from the Sun's warmth. David W. Hughes (University of Sheffield) proposes that an asteroid some 2.6 to 60 meters across smacked into the comet.

"[But] Brian Marsden of the Central Bureau for Astronomical Telegrams, for example, simply disagrees . . . 'Comets are rather unstable things. It doesn't take much to make them flare — a little bit of sunlight, weak though it may be, gets into a crack and stirs up some volatiles.' . . .

"Hughes may have to wait until 2061 to be vindicated. If he's right, spacecraft visiting the comet during that return should detect a fresh crater about 2.2 kilometers across on the surface of the comet's nucleus."

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EXOPLANETS | World Found Around Proxima Centauri

Astronomers have discovered a planet orbiting the closest star to our solar system, Proxima Centauri. Proxima is a small, red *M* dwarf only about half as hot as the Sun and 14% as wide. It's member C of the Alpha Centauri triple-star system, which lies just over 4 light-years away.

Guillem Anglada-Escudé (Queen Mary University of London) and colleagues report in the August 25th *Nature* that the newly discovered world, dubbed Proxima Centauri b, has a mass at least 1.3 times that of Earth, meaning it's potentially rocky. It orbits the star every 11.2 days at a distance of only 0.05 astronomical unit, or roughly 10% Mercury's orbital distance from the Sun. That places it right in the star's putative habitable zone.

We've had our hopes raised for alien worlds in the Alpha Centauri system before. For example, in 2012 observers reported that they'd found what looked like an Earth-mass exoplanet hugging the orange Sun-like star Alpha Centauri B. But follow-up work by other researchers raised a red flag (*S&T:* Sept. 2013, p. 14). The alleged planet has since proved to be a subtle "ghost" in the data, created by how the original team sliced up the observations for analysis.

But Proxima Cen b stands on more solid ground. Astronomers suspected for some time that the star has a planet: data from two European Southern Observatory (ESO) spectrographs had found a shift in the star's light that seemed to repeat every 11.2 days. This shift might have come from a tiny wobble in the star's position toward and away from us, due to the gravitational tug of an orbiting planet.

Yet being an *M* dwarf, Proxima is a fairly active star. Astronomers didn't have enough data to tell if the planet signal was real or instead just muck in the starlight from flares and other stellar hubbub.

So Anglada-Escudé's team started the Pale Red Dot campaign to find out. The campaign took a two-pronged approach. First, the team used the renowned HARPS spectrograph on La Silla's 3.6-meter telescope in Chile to observe Proxima Centauri for 20 minutes every clear night from January 19th to March 31st this year. Second, a network of other telescopes simultaneously performed *photometry* (watched for changes in the star's brightness) to pinpoint the star's rotation period and to record if any flares went off.

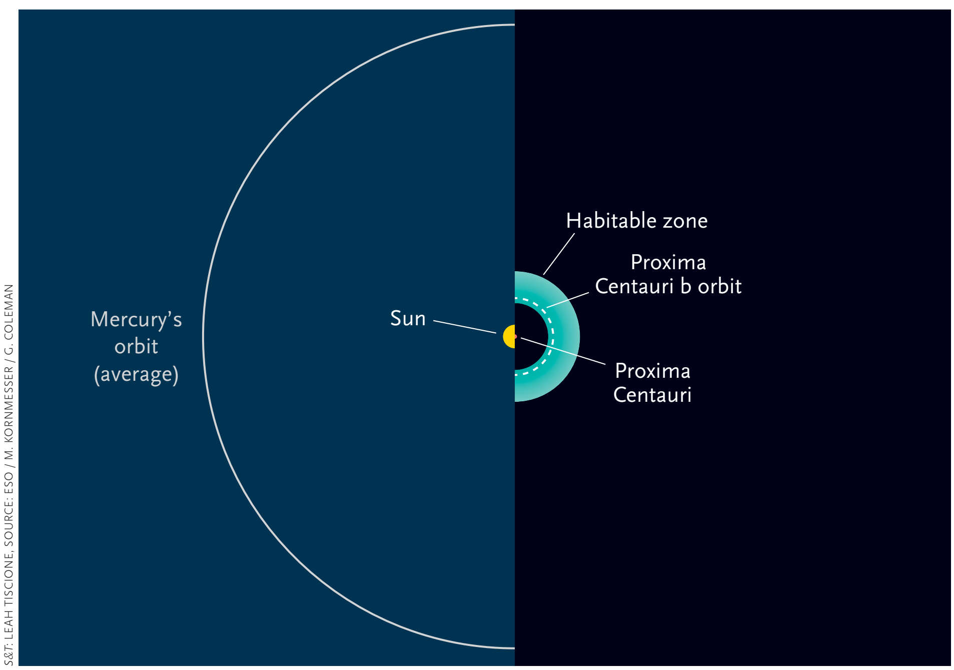
The team found that the new, 2016 HARPS data contain a periodic signal, just like the one in the archival data. And when the researchers combined both sets of data into one and analyzed the whole, 16-year-spanning shebang, the statistical significance (read: "how believable the signal is") went "sky high," Anglada-Escudé said in a press conference.

But the real kicker is the photometry. Proxima itself didn't do anything during the observations that could explain the periodic signal. Instead, the best solution is a planet.

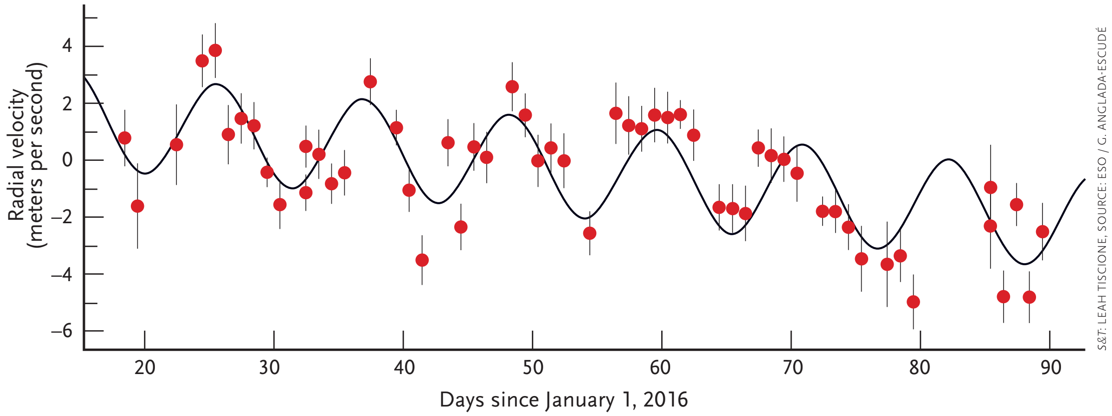
"I'm very excited about this planet, but not terribly surprised," says David Charbonneau (Harvard-Smithsonian Center for Astrophysics), who heads up the MEarth Project to look for exoplanets around *M* dwarfs. A few years ago, he and Courtney Dressing (now at Caltech) used Kepler data to estimate that one out of every four *M* dwarfs has a planet that's at most 1.5 times as wide as Earth. Expand the size to twice that of Earth, and the rate goes up to nearly one out of every two. "With those odds, it isn't at all that surprising that the closest *M* dwarf has one," he explains.

But we don't know how big Proxima Cen b is. MEarth and other projects have failed to detect a transit in front of the star, which would reveal the exoplanet's diameter. The "failure" is expected, Charbonneau says: geometrically speaking, there's only a 1.5% chance that the world passes across the face of Proxima.

The best way to follow up may be taking actual pictures. The star is so close to Earth that upcoming adaptive-optics instruments will be able to directly image the planet — assuming they can properly



This figure compares the solar system (left) with the Proxima Centauri system. Proxima is far smaller and cooler than the Sun, so even though its newfound planet orbits much closer than Mercury does to the Sun, the world lies well within the hypothetical habitable zone.



This plot shows how the motion of Proxima Centauri towards and away from Earth (y-axis) changed with time over the first months of 2016. At its max, Proxima Centauri approaches or recedes from Earth at about 1.4 meters per second — normal human walking pace. This regular pattern repeats every 11.2 days and results in tiny Doppler shifts in the star's light.

block out the star's light to see the world, which is only 0.035 arcsecond (about 1⁄100,000°) away from it. They may also be able to tease out reflected light from any atmosphere, revealing its composition.

In addition, there's the upcoming ESPRESSO spectrograph at the ESO's Very Large Telescope facility in Chile, which will begin operation in 2017. With the new spectrograph, "demonstrating the existence of Proxima Cen b should be like shooting fish in a barrel," says exoplanet researcher Debra Fischer (Yale).

A Habitable World?

Whether this planet is habitable remains a wide-open question. Technically it lies at the right distance from its star that, given the right composition and atmosphere, liquid water would be stable on its surface.

But, the discovery team stresses, astronomers only know three things about this world: its mass, orbital period, and distance from the star. It's not even clear whether Proxima Cen b is rocky — the 1.3 Earth masses is a lower limit; the team can't give an explicit, upper cutoff for how hefty it might be. Still, coauthor Ansgar Reiners (Georg-August-Universität Göttingen, Germany) says previous work has shown that massive planets generally don't form around stars this small. His gut instinct is that the world probably doesn't weigh more than a few Earths. That could still make it a mini-Neptune.

If the planet does have a solid surface, whether it has water will depend on how it formed and what happened to it soon after — did it coalesce far from the star, where ices reign, and then migrate in carrying that water with it? Did it form where it is now from dry rocks and never pick up any water? We don't know.

It's also unclear just how much the *M* dwarf's active personality would harm the planet. Proxima Cen b receives roughly 100 times more energy in X-rays from its star as Earth does from the Sun. What that means for habitability is anyone's guess. A lot will depend on what the star did in its early days, which astronomers don't know. They suspect the star is roughly 5 billion years old, on par with the Sun.

Lastly, the planet is probably tidally locked in synchronous rotation, such that the same face always points at Proxima. That's not a death knell for habitability, but it does change the kind of atmospheric circulation required.

■ **CAMILLE M. CARLISLE**

TECH | Could Spacecraft Make It to Proxima Centauri?

Last April, billionaire Yuri Milner announced a $100 million initiative to test the feasibility of sending tiny spacecraft on a 20-year journey to the Alpha Centauri system at 20% the speed of light (*S&T:* Aug. 2016, p. 12). At one-fifth lightspeed, even the micron-size dust grains and gas atoms between stars pose a real threat. But how much of a threat?

In a paper posted August 18th to the online preprint server arXiv.org, Thiem Hoang (University of Toronto) and others explored what might happen to a tiny, gram-scale probe like that proposed by Breakthrough Starshot: a mini spaceship made of a computer chip that contains sensors (composed primarily of silica) and a reflective lightsail to accelerate the craft (composed of graphite).

Because of the probe's high speed, it essentially would see any lone atom or dust mote as a relativistic projectile. The few heavy gas atoms en route would be particularly dangerous to silica-based materials, but overall dust is the main threat. While tiny and rare, every dust grain that gets in the way will both evaporate and melt material on the spacecraft, generating an impact crater and potentially damaging sensors or other key components.

The team calculated that the impact of a dust grain any bigger than 15 microns, or roughly the width of a human hair, would destroy the probe. Fortunately, cosmic dust grains of this size are rare: the authors peg the chance of running into one of them at one in 10^{50} (in other words, practically never).

To protect a spacecraft, Hoang's team thus suggests making it long and slim, like a needle. This will reduce the surface area the spacecraft presents to the onslaught of interstellar debris. Also helpful would be a protective graphite coating a few millimeters deep. Read more about the analysis at **https://is.gd/centaurishields**.

■ **MONICA YOUNG**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GALAXIES | Giant "Frankenstein" Spiral

NASA / JPL / CALTECH / SDSS / NRAO / L. HAGEN & M. SEIBERT

In optical light (left), UGC 1382 appears to be a simple elliptical galaxy. But when astronomers observed it using ultraviolet and deep optical data (middle), spiral arms emerged. When those were combined with a view of low-density hydrogen gas (seen in green at right), scientists discovered UGC 1382 is bigger than they thought.

Astronomers have taken a second look at the isolated galaxy UGC 1382 and discovered everything they thought they knew about its size, age, and formation is probably wrong.

UGC 1382 lies about 250 million light-years away in a quiet and unremarkable neighborhood, with few neighbors to bother it. Several surveys in the 2000s looked for structural features like star rings and bars but didn't find anything other than a typical elliptical galaxy. Then Lea Hagen (Penn State) noticed something interesting in ultraviolet images taken with NASA's Galaxy Evolution Explorer (GALEX): UGC 1382 actually has very extended spiral arms.

Further multiwavelength investigation showed the galaxy is roughly 10 times bigger than previously thought. At about 520,000 light-years across, UGC 1382's spiral disk is five times wider than the Milky Way's and makes it one of the largest such galaxies known. The system is so delicate that even a small nudge from a neighboring galaxy would make it disintegrate, says coauthor Mark Seibert (Observatories of the Carnegie Institution for Science).

Reporting in the August 1st *Astrophysical Journal*, the team also found that, unlike in most galaxies, UGC 1382's innermost stars appear to be younger than the stars on the outskirts. It's almost as if the galaxy had been built using spare parts — like Victor Frankenstein's creation. The researchers think the best explanation is that a group of dwarf galaxies fell into orbit around a lens-shaped galaxy a few billion years ago, eventually becoming its spiral arms and providing gas for star formation in the interior. This process would make the center of UGC 1382 younger than the spiral disk surrounding it.

But Lynn Matthews (MIT Haystack Observatory) says one has to be cautious with this scenario. It's difficult to find the precise age of a galaxy because stars form at different times, and that process doesn't always occur at a constant rate. Measuring the stars' heavy-element content, which is normally higher for younger stars, would help confirm the stars' ages.

■ **ANA V. ACEVES**

MARS | Too Much Water?

New observations reveal that dark streaks are surprisingly common on Mars. These streaks, called *recurring slope lineae* (RSL), appear and fade year after year. Last September, Lujendra Ojha (Georgia Institute of Technology) and others confirmed that these warm-season features contain water-soaked salts (*S&T:* Jan. 2016, p. 14). But scientists didn't know where the water was coming from.

Matthew Chojnacki (University of Arizona) and other members of Ojha's team investigated thousands of streaks in 41 sites of the Valles Marineris region, the largest canyon complex in the solar system. The team found that pretty much all of the canyon walls, including the sides of isolated peaks, had RSL.

Because the streaks appear on steep slopes, underground pools can't be responsible. Instead, it's more likely that the salts are pulling water from the atmosphere in a process called *deliquescence*.

Chojnacki's team estimates that about 10 to 40 Olympic-sized swimming pools of water are required to make the streaks. Based on orbiter estimates, there's enough water vapor floating above Valles Marineris for that to happen, but researchers can't think of an efficient way for the surface to extract that much water from the atmosphere. Or perhaps we've underestimated how much water is there, and some places are unexpectedly humid. Chojnacki's study appears in the July 7th *Journal of Geophysical Research: Planets*.

■ **ANA V. ACEVES**

IN BRIEF

Possible Replacement for Hitomi. The Japanese Space Agency (JAXA) and NASA are considering replacing the failed Hitomi X-ray observatory. Launched in February and originally slated for a three-year mission, Hitomi lasted just over a month, torn to pieces by an out-of-control tumble (*S&T:* July 2016, p. 11). X-ray astronomers had long awaited the chance to use this craft's instruments, especially its calorimeter, which recorded the energy of each incoming photon with unprecedented precision. Because Hitomi was an essential link between current and future X-ray observatories, JAXA and NASA are now discussing building and launching a successor, potentially a copy of the original, with a launch around 2020. Otherwise, the next chance is Europe's Athena, launching in 2028.

■ **DAVID DICKINSON**

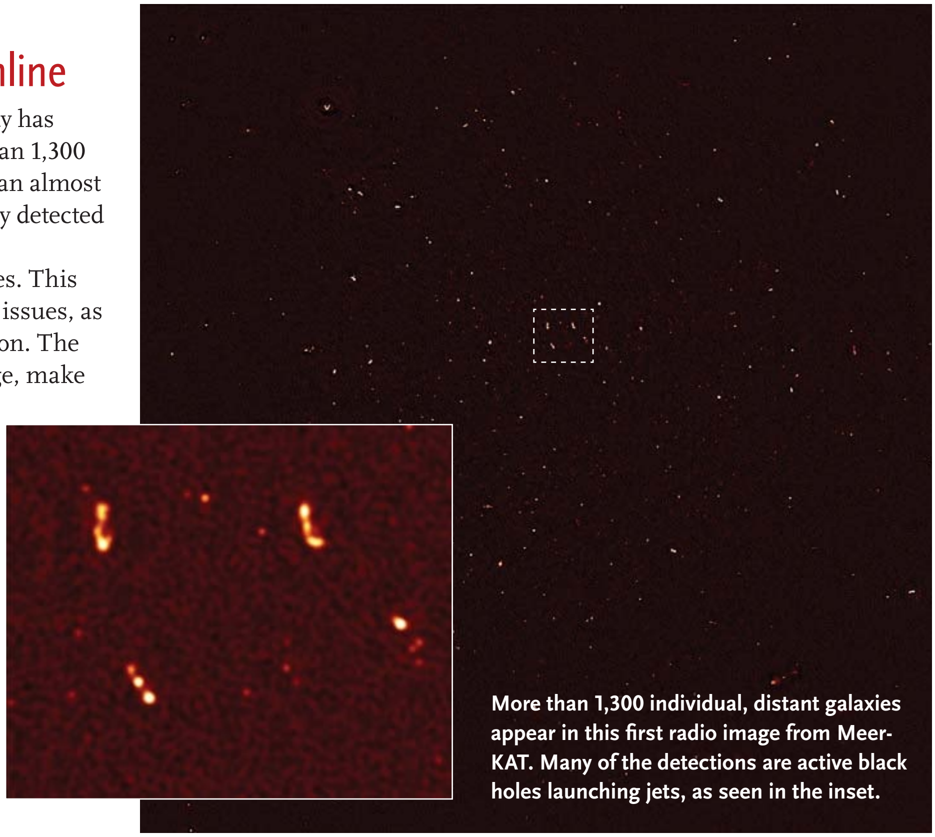
FIRST LIGHT | MeerKAT Online

South Africa's MeerKAT radio telescope array has released its first-light image, showing more than 1,300 distant galaxies in a 2°-square patch of sky — an almost 20-fold increase from the 70 galaxies previously detected in this field.

MeerKAT is being commissioned in phases. This enables scientists to quickly fix any technical issues, as well as conduct some initial science exploration. The first 16 dishes, which took the first-light image, make up Array Release 1. The eventual 64 dishes are expected to be in place by late 2017.

Once complete, the array will encompass 17,651 square meters (190,000 square feet) of the region outside Carnarvon, a small town in the Northern Cape province of South Africa. Ultimately, it will be integrated into the Square Kilometer Array (SKA), which when constructed will be the world's largest radio telescope, with segments in both South Africa and Australia. SKA will be built in two phases, with early science observations projected for 2020 and full-scale operations in 2030.

■ **ANA V. ACEVES**



More than 1,300 individual, distant galaxies appear in this first radio image from MeerKAT. Many of the detections are active black holes launching jets, as seen in the inset.

MEERKAT (2)

MISSIONS | The Return of Stereo B?

Feared lost for almost two years, NASA's Solar Terrestrial Relations Observatory B (a.k.a. Stereo B) phoned home to mission control in August.

NASA lost contact with the spacecraft on October 1, 2014 (*S&T:* Mar. 2015, p. 16). At the time the team was preparing the craft for hibernation, to protect its communication antenna from overheating while it passed around the farside of the Sun as seen from Earth's vantage point. (The antenna would have had to point dangerously near the Sun in order to contact Earth during that time.) The safe mode was to last for about a year. But something went wrong during final tests, and when Stereo B turned back on, its weakened signal quickly faded to silence.

The team continued attempts to reestablish contact for the next 22 months, and on August 21st at 6:27 p.m. EDT (10:27 UT), the Deep Space Network finally reconnected with the craft. Telemetry confirmed what the team already suspected: the Inertial Measurement Unit — which tells the spacecraft if and how fast it's rotating — failed unexpectedly, feeding incorrect information into the guidance and control computer instead of merely cutting out altogether.

Further checks will assess the spacecraft's health before science operations resume.

Even if it never fully recovers, Stereo B and its mate Stereo A have exceeded expectations. Launched in 2006 to observe the Sun from Earth-like orbits, one travels ahead of our planet and one behind to provide a "stereo" view of our star. The twin craft first reached a point 180° apart in their respective orbits on February 6, 2011, affording the first full 360° view of the Sun.

■ **DAVID DICKINSON**

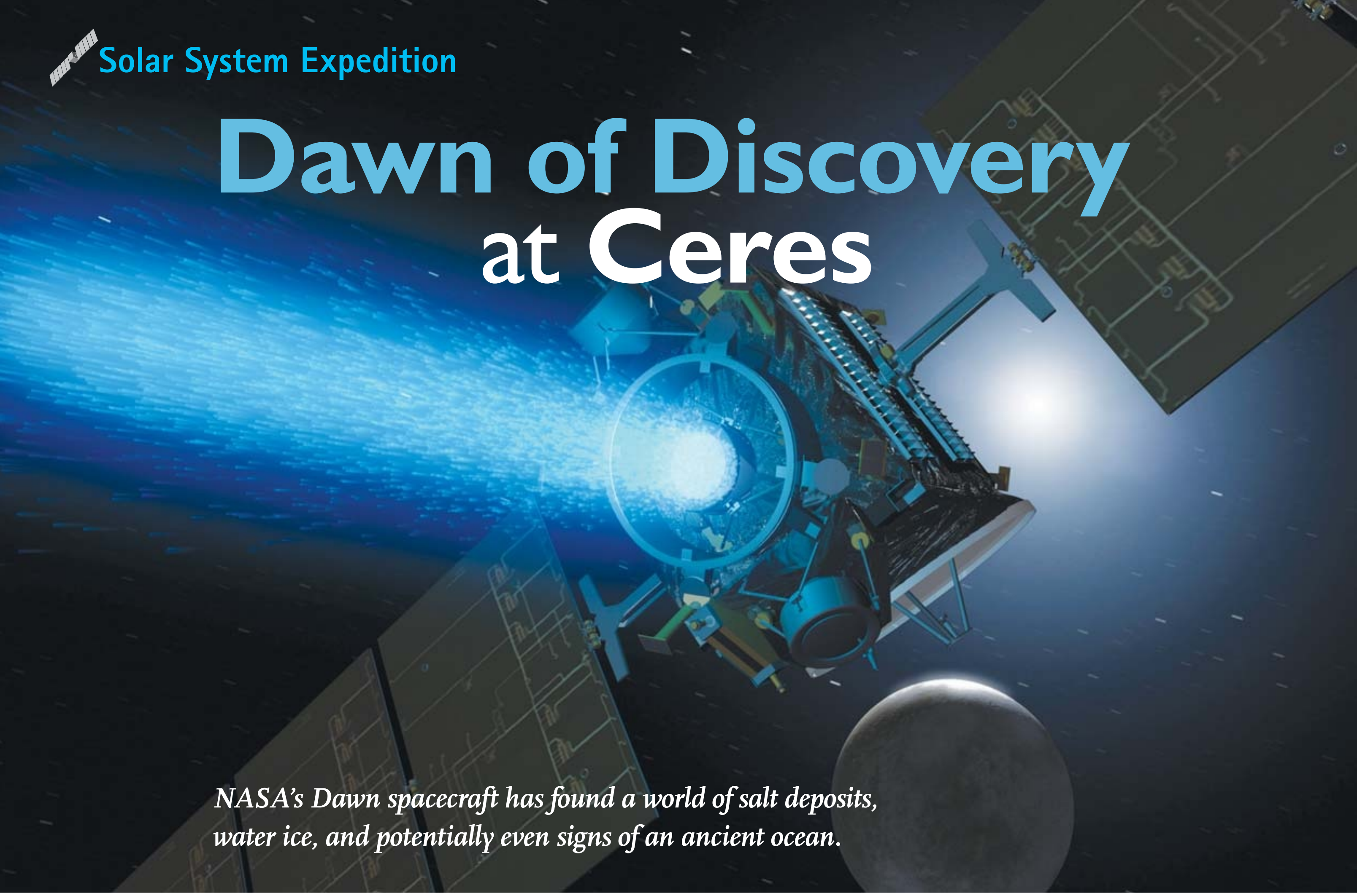
IN BRIEF

Titan Canyons are Flooded. Radar observations have revealed liquid at the bottom of a channel system on Saturn's biggest moon. Titan has seas filled with methane, ethane, and perhaps other hydrocarbons, as well as dark, sinuous channels that extend for hundreds of kilometers across its surface. But it was unclear if the channels really contain liquid. Now Valerio Poggiali (University of Rome) and colleagues have used radar images from NASA's Cassini spacecraft to catch reflections off liquid-smooth surfaces at the bottom of canyons in the drainage network Vid Flumina, which connects to Titan's second largest sea, Ligeia Mare. The data also reveal that the canyons are steep-sided (with slopes of at least 40°) and plunge up to 570 meters (1,870 feet) down. For comparison, the Freedom Tower in New York City rises 1,776 feet into the sky. The result is the first direct detection of liquid-filled channels on Titan, the team reports August 9th in *Geophysical Research Letters.* ✦

■ **CAMILLE M. CARLISLE**

Solar System Expedition

Dawn of Discovery at Ceres



NASA's Dawn spacecraft has found a world of salt deposits, water ice, and potentially even signs of an ancient ocean.

NASA / JPL-CALTECH

Marc D. Rayman

FOR MOST ASTRONOMERS, the arrival of dawn means the end of observing. Intriguing sights become more and more difficult to see, eventually disappearing entirely. Not so with dwarf planet Ceres. The arrival of NASA's Dawn spacecraft in 2015 meant the beginning of more than a year of extraordinary discoveries.

The spaceship left Earth in 2007 on an ambitious journey to explore two giants of the main asteroid belt, Vesta and Ceres. Propelled by its ion engines on a mission to boldly go where — well, you know the rest — Dawn orbited Vesta in 2011–12, revealing a complex body more closely related to Earth and the other terrestrial planets than to asteroids (*S&T:* Sept. 2012, p. 32). It then left to continue its mission to Ceres.

Dawn began approach photography on January 13, 2015, two months before it entered orbit. It was as far from the dwarf planet as the Moon is from Earth. Dawn was designed to conduct a reconnaissance of unexplored worlds from orbit, and it is not equipped with a powerful telescope. From a distance of 383,000 kilometers (238,000 miles), Ceres was only about 27 pixels in diameter. With a resolution of 36 km per pixel, these initial images were not taken to learn about Ceres itself but rather to locate it against the background of stars.

Distance: 383,000 km (238,000 mi)

46,000 km (29,000 mi)

7,200 km (4,500 mi)

NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA (3)

Navigators needed the images in order to help pin down the position of Dawn's destination accurately so that they could pilot the spacecraft into orbit.

But those very first pictures showed what has become the most famous and mysterious feature: a bright spot. A decade earlier, the Hubble Space Telescope, with resolution of about 30 km per pixel, had detected the spot as well. By the time of Dawn's next pictures, on January 25, 2015, the resolution was one-third better than Hubble's, and the bright spot only grew more salient with those and subsequent pictures. The spot seemed to glow, casting its mesmerizing light out like a cosmic beacon, guiding the way for our interplanetary ship as it sailed the solar system's seas.

Dawn continued to photograph Ceres occasionally prior to its graceful entry into orbit on March 6, 2015, using the gentle thrust of an ion engine. And it has achieved better and better resolution since then, operating in a series of four circular, polar mapping orbits. This has allowed us to progress from an overview of the entire world to an intimate portrait. The best pictures now, taken from an altitude of only 385 km, are one thousand times sharper than the first. Dawn orbits closer to Ceres than the International Space Station does to Earth. From this distance, Ceres appears as large as a soccer ball would when seen from a mere 9 cm (3.5 inches).

As the resolution improved, what initially had appeared as one bright spot became two and soon a multitude clustered together. Scientists and the public alike were captivated by them. NASA's Jet Propulsion Laboratory polled the public for their votes on what the spot was, and more than 190,000 responded. One question I often received was whether it could be the illumination from an alien city. I find such questions disappointing, and I despair of critical thinking. After all, given how little we knew about Ceres, how could we possibly know whether Cereans even live in cities? Perhaps they only live in rural areas, or only in large states. Maybe they only live underground.

Seriously, without taking advantage of the power of the scientific method and thorough consideration of all available data, it is all too easy to reach mistaken conclusions. If understanding an exotic world required only stunning pictures, the work at Ceres would be complete. To unravel Ceres' secrets, scientists integrate results from all of Dawn's measurements and combine them with three more ingredients: comparisons with other solar system bodies, comparisons with laboratory measurements of candidate minerals, and the results of extensive mathematical modeling of the physics, geology, and chemistry. It will take years to put the pieces together to understand the big picture. For now, however, we have only begun to digest the extraordinary bounty from Dawn.

A Salty Spotlight

Before Dawn brought Ceres into focus, one popular idea was that the spots could be exposed ice. This idea's appeal might have been due to a report in 2014 that the Herschel Space Observatory had detected the faint but unmistakable signal of water vapor around Ceres. From its orbit around the Sun near the second Lagrangian point, about 1.5 million km from Earth, Herschel was much too far from Ceres to see any detail. But scientists estimated that the amount of water vapor could be explained by only about 150 acres, or 0.6 square km, of ice on the surface. As ice sublimated in the cold vacuum, transforming directly from a solid to a gas, it could produce the extremely tenuous veil of water vapor Herschel detected.

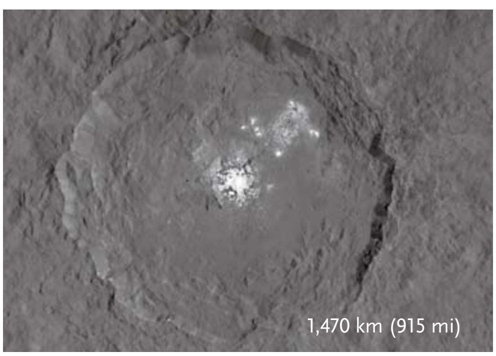
But the bright spots Dawn saw covered too much area to be the source. Even just the central bright region is 500 times larger than the area of ice scientists calculated would yield the detected water vapor. Exposed ice was not a good explanation for the spots.

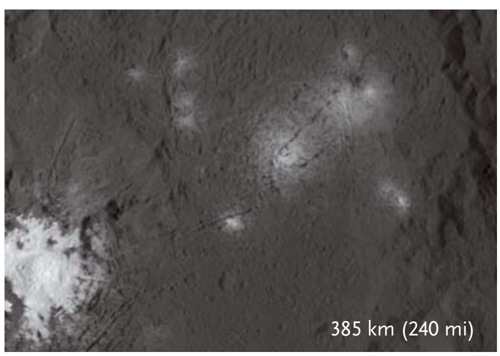
With similar reasoning, the bright region couldn't have been a cryovolcano or geyser, however exciting that might be. For such a phenomenon to be bright enough for Dawn to detect even with the early, low-resolution pictures, it would have been enormous. Once again, it would not have been consistent with Herschel's findings.

As the "spots" became better resolved, they no longer resembled discrete points but rather a complex distribution of reflective material inside a 92-km-wide crater now named Occator.

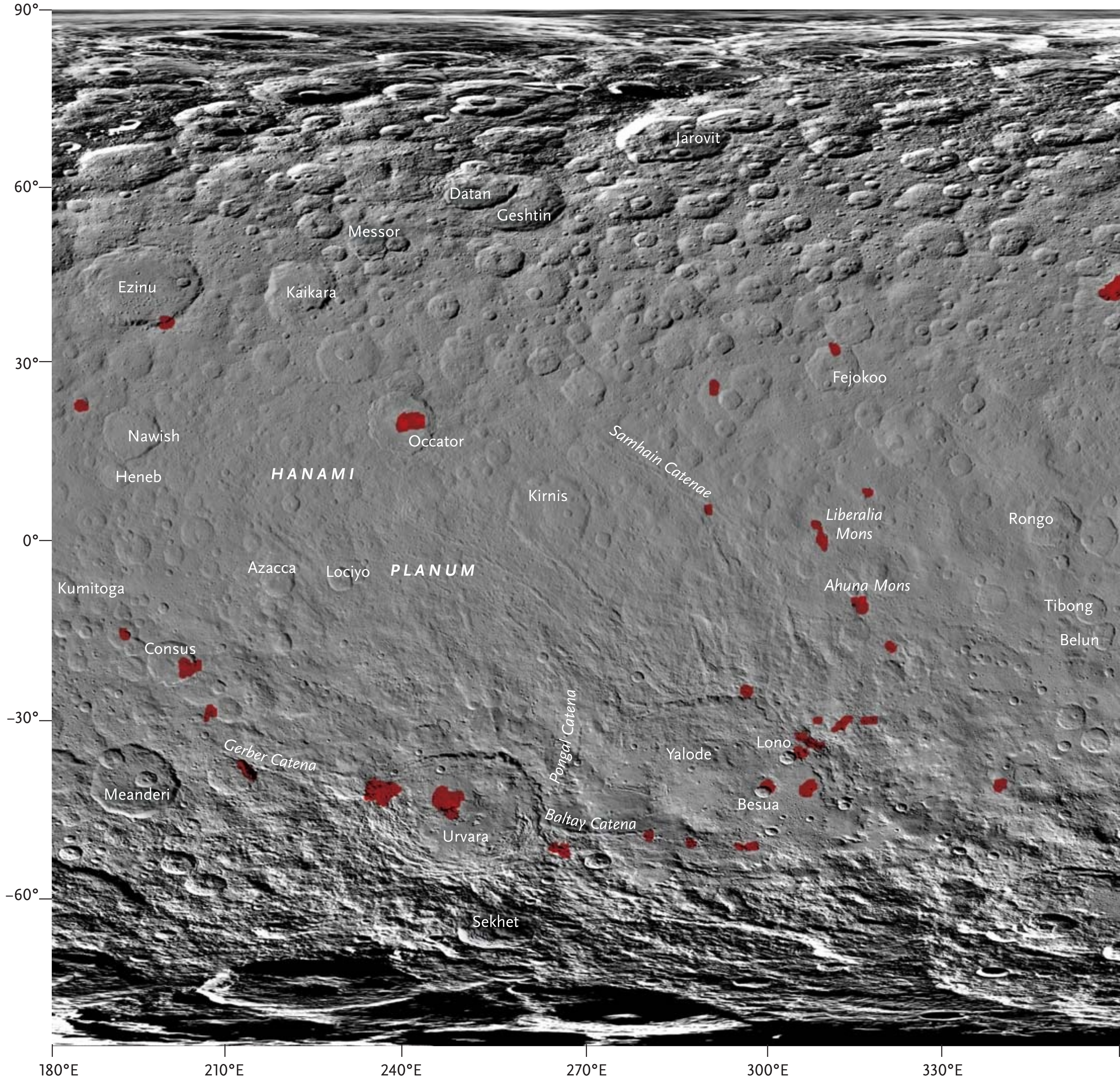
Based on all the data acquired so far, scientists consider the most likely explanation for the highly reflective ground cover in Occator to be some kind of salt. It may be that the heating from the impact that created the

NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA (2)





MYSTERIOUS SPOT **Ceres' bright beacon looks like a smudge in Dawn's first approach image *(far left)*. But as the spacecraft neared, the feature revealed itself to be a complex of reflective patches in the crater Occator. Although Occator's "spot" is the brightest, it is only one of more than 130 of these features revealed by Dawn on the dwarf planet.**



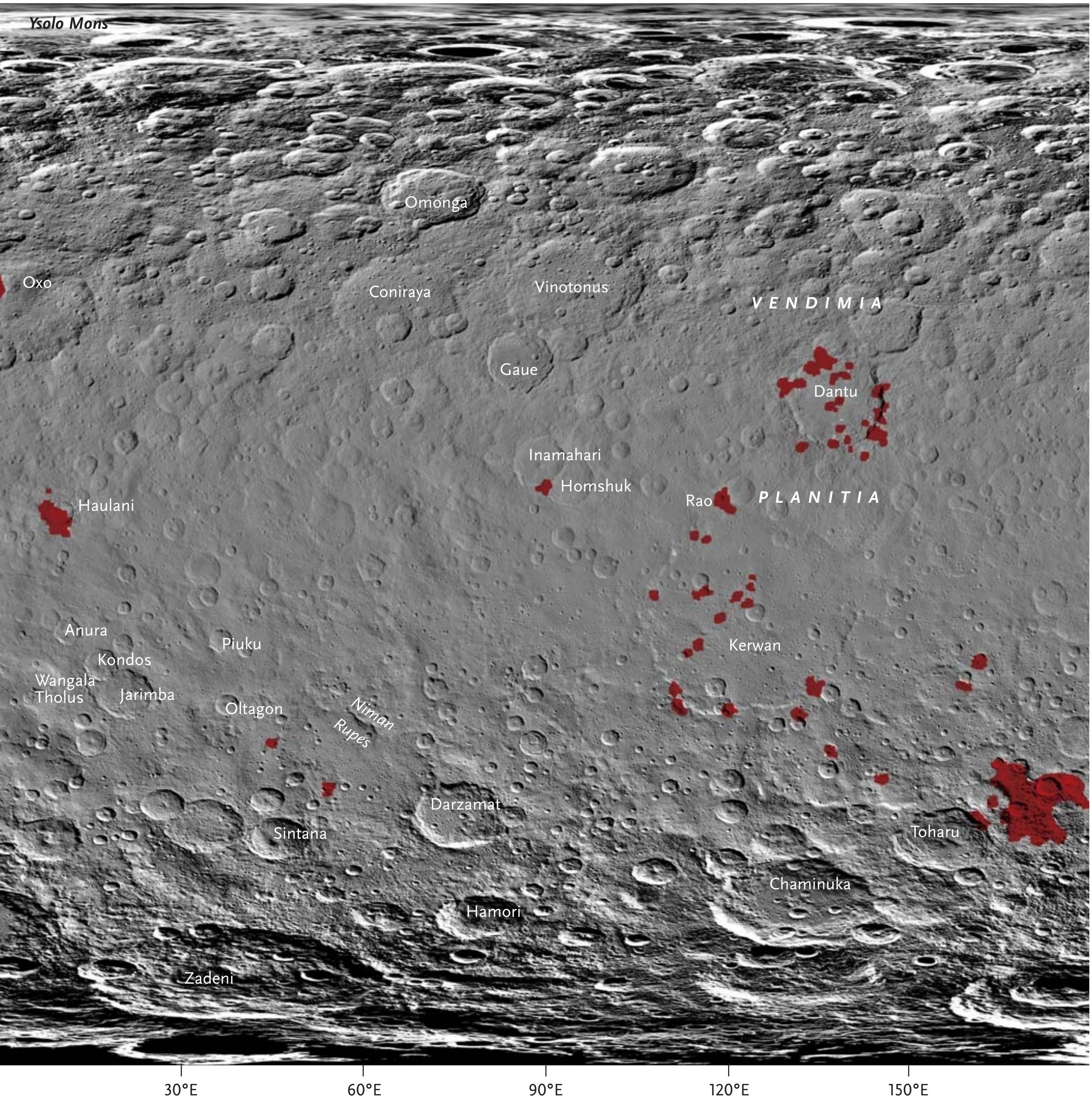
CERES' SURFACE AREA

Ceres spans 2.8 million km² (1.1 million mi²). That's about the area of Argentina, or 35% of the area of the contiguous United States.

crater 80 million years ago caused underground briny water to flow upward to the surface, perhaps through the many cracks visible to Dawn's camera. Once on the cold surface, the brine would freeze. And exposed to the vacuum of space, solid ice would sublimate, the water molecules escaping into space or settling elsewhere on Ceres. When they departed, they would have left behind the dissolved salts.

We base Occator's (tentative) age on the number and size of smaller, more recent craters both within it and on the blanket of ejected material surrounding the crater. That makes Occator young in geologic terms, given that Ceres itself is more than 4.5 billion years old.

Further evidence for the crater's youthfulness comes from it being slightly bluer than most of Ceres. Material tends to redden gradually with exposure to the



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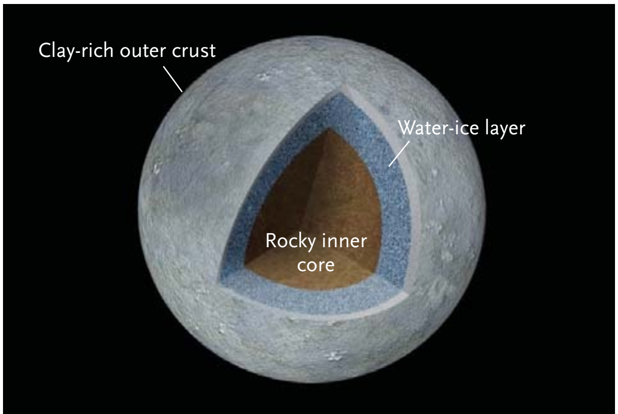
BRIGHT SPOTS GALORE Occator's spots are the most famous, but there are more than 130 other locations on Ceres that are comparatively reflective. Shown here in red are the bright spots' approximate locations, along with a selection of feature names. (For the full list, see the International Astronomical Union's Gazetteer of Planetary Nomenclature: http://planetarynames.wr.usgs.gov.)

space environment for several reasons, two of which are radiation-spurred changes in molecular structure and the breakup of microscopic grains by micrometeoroid impacts. Nevertheless, color is not a definitive indicator of age. For reasons not yet established, the central feature of Occator, the most reflective area anywhere on Ceres, is touched with red, in contrast to the rest of the crater. Occator contains the largest area of highly reflec-

Names on Ceres

The Dawn project and the International Astronomical Union have worked together to name features on Ceres. Giuseppe Piazzi named his 1801 discovery of the largest body between Mars and Jupiter for the Roman goddess of agriculture. All craters are named for deities of agriculture and vegetation from mythology around the world, and other features are named for agricultural festivals.



NASA / JPL-CALTECH

WATER WORLD? Planetary scientists think that Ceres has a large reservoir of water ice beneath its crust.

How Dawn Measures Ceres

Dawn's camera is equipped with eight filters mounted in a wheel in front of its CCD. One admits light across the visible and near-infrared spectrum, from 450 to 920 nanometers. Each of the other seven allows a narrow range of wavelengths from deep blue at 430 nm to near-infrared at 980 nm.

To reveal Ceres' topography, Dawn mapped the dwarf planet from six angles during its third mapping orbit. One map was made by looking straight down at the scenery beneath it. Each of the other five maps was developed by holding the camera fixed at a different angle, looking ahead or behind and to the right or left. Taken together, these create stereo views, making the landscape pop into 3D.

Dawn has four spectrometers packaged in two instruments. Dawn's visible spectrometer, operating from 0.4 to 1 micron (in the near-infrared) would have a view very much like the rainbow created by a prism. The infrared spectrometer works from 1 to 5 microns. A spectrometer does more than simply disperse the light into its components, however. It measures the intensity of that light at the different wavelengths. The materials on the surface leave their signature in the sunlight they reflect, making some wavelengths relatively brighter and some dimmer. This characteristic pattern is called a spectrum. By comparing these spectra with spectra measured in laboratories, scientists can infer the nature of the minerals on the ground. The infrared measurements also yield the surface temperature.

Dawn's Gamma Ray and Neutron Detector (GRAND) consists of two spectrometers that work on the same principle, except with gamma rays and neutrons kicked up from Ceres by cosmic rays. But because the glow of Ceres' nuclear radiation is so faint, GRAND needs to collect data for a very long time, in the same way that photographing a dim object requires a long exposure.

tive material on Ceres, making it the brightest and most conspicuous place on the dwarf planet, but scientists have catalogued more than 130 other locations that also are very reflective. Nearly all of them are bluish.

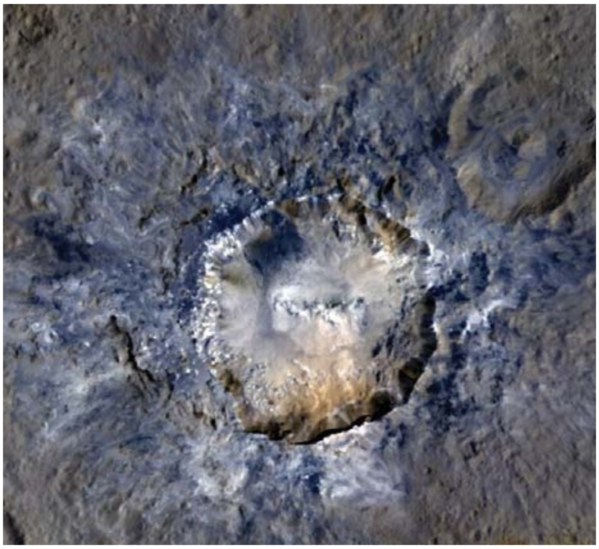
Although 80 million years is geologically brief, it seems much too long for the material in Occator to remain so reflective. Scientists expect that the constant bombardment of small interplanetary debris and cosmic radiation would darken it relatively quickly, so persistent brightness is very difficult to explain. This suggests the intriguing possibility that some geologic process replenished it not long ago. It could be that current or recent activity causes more of that underground salt water to reach the surface and then vaporize, providing fresh salt deposits. This and other explanations are being investigated now.

Water World

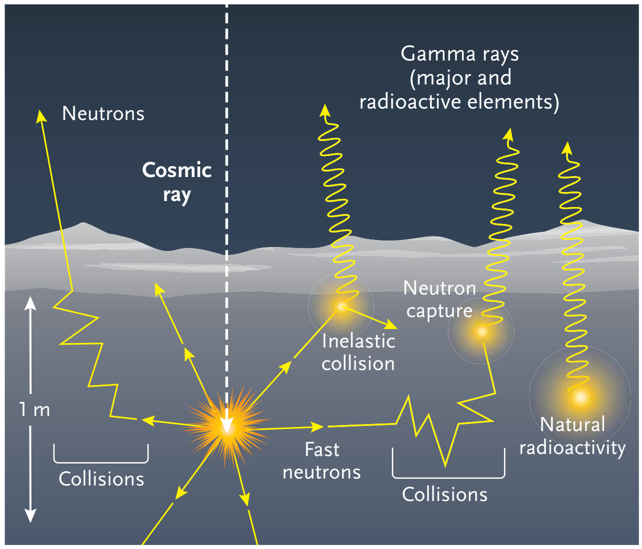
The inference of water, most likely frozen, beneath the surface is based on more than the bright areas in Occator. The overall density of Ceres is 2.2 grams per cubic centimeter (g/cm^3). This is surprisingly low, well less than half Earth's density, strongly suggesting that water is a major constituent. (The average dry rock density is 3.4 g/cm^3.) Water may account for about a quarter of the dwarf planet's mass. Ceres then would be the first rocky body with such a large inventory of water orbited by spacecraft, providing opportunities to learn about how such a world works. Other large water-rich places, including Europa and Titan, have not been studied at the level of detail Dawn has achieved from its orbital vantage point.

Dawn also has found signs of water thanks to the compound's interaction with cosmic rays, energetic particles raining down from space. Cosmic rays impinge on Ceres, slam into atomic nuclei in the crust, and produce gamma rays or neutrons that escape back into space. The spacecraft's Gamma Ray and Neutron Detector (GRAND) consists of two spectrometers that record the number and energy of these photons and particles. Measuring them tells us which atoms the cosmic rays hit, down to a depth of about a meter.

While still preliminary, the measurements of neutrons emanating from Ceres indicate that it is rich in hydrogen. The same measurements at Vesta found much less of that element. Hydrogen is a good indicator of the presence of water, which comprises two hydrogen atoms bound to one oxygen atom and is the most common hydrogen-bearing molecule that occurs on solid surfaces. Although the evidence suggests hydrogen is everywhere on Ceres, it is even more plentiful near the poles than near the equator. Researchers are investigating reasons the neutron count might vary with latitude. Their analysis of these complex data may allow them to test the hypothesis that GRAND is sensing ice extremely close to the surface. At higher latitudes, where the



NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA



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BLUISH CRATER ***Left:*** **Shown here in enhanced color, the crater Haulani has landslides along its rim, as well as a central ridge. Scientist think the bluish material here (in outlying ejecta) and elsewhere on Ceres is younger than its surroundings.** ***Right:*** **When a high-energy cosmic ray slams into a nucleus in Ceres' surface, the target nucleus "explodes," producing a spray of secondary particles, including neutrons. These particles can collide with other atoms in the regolith, creating gamma rays that escape with other neutrons from the dwarf planet and reach Dawn in orbit.**

distant Sun provides less heat, ice could have persisted throughout Ceres' lifetime, whereas at the warmer low latitudes, it would have retreated to greater depths.

In one location, however, Dawn has already directly detected water. The infrared mapping spectrometer picked up its clear signature in a crater named Oxo, 42° north of the equator. Oxo is relatively small, only 10 km in diameter, but it's the second brightest region on Ceres. (Only Occator is brighter.) We don't yet know whether the water Dawn found there is ice or is bound up in hydrated minerals. However, because exposed ice, if that's what it is, would be ephemeral, it must have arrived on the surface recently. Scientists are still scouring Dawn's infrared spectra for signs of water elsewhere.

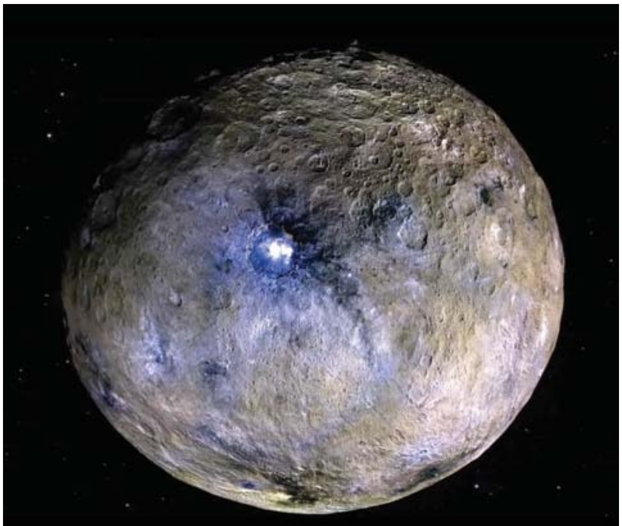
Those spectra have already revealed much more about the composition of Ceres. Most of the surface is a currently unidentified mixture of dark materials, but we now know that clay-like minerals known as *phyllosilicates* are ubiquitous on that faraway world. Many phyllosilicates are familiar on Earth, including mica. What makes their presence on Ceres particularly important is that they contain distinctive evidence of ammonia. The ammonia is bound up in minerals that form when water interacts with rock. This simple molecule, consisting of nitrogen and hydrogen, should have been common in the nebula of dust and gas from which the planets formed. But swirling around the young Sun, the material at Ceres' present location should have been too warm for ammonia to have condensed and been trapped in nascent planetesimals.

How then did it become so common on Ceres? It may be that Ceres formed much farther from the Sun, even beyond Saturn, where it was cool enough to incorporate ammonia, and the subsequent gravitational jostling of the planets pushed it to its current orbit. Another possibility is that Ceres formed close to where it is now but accreted material that originated farther away and moved in closer. That then raises the question of why so few other bodies in the vicinity display signs of ammonia. It also may be that our picture of the physical and chemical nature of the early solar system is wrong.

Carbonates, another group of minerals indicative of chemical reactions that take place in water, are common on Ceres as well. Indeed, the bright salt in Occator contains the highest concentration of carbonates known anywhere in the solar system except on Earth. And some of the minerals, such as serpentine and sodium carbonate, form only under pressure, as would occur beneath several kilometers of water.

Suppose the minerals were produced far underground and later forced to the surface by some geological process. Any mechanism for transporting the minerals from deep within Ceres should depend on the surface temperature and so should be different near the equator than near the poles, which on average diverge by more than 50K. (The surface temperature matters for what occurs inside because it affects the rate at which heat leaks out.) In that case, the distribution of minerals we see today should vary widely over the surface. But that is not what we see. Instead, the minerals show up nearly everywhere we look.

An alternative is that we may be looking at the floor of an ancient ocean! Heated by the radioactive elements incorporated when Ceres formed, the water would have been liquid, creating an ocean on the surface. But



NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

SOMETHING BLUE This false-color rendering of Ceres highlights differences in surface composition. The crater Occator and its spots appear just left of center.

exposed to the cold of space, the top would have frozen, encasing the dwarf planet in a shell of ice. Through a combination of blasting by impacts and sublimation, more than 100 km of ice could have been lost in the geologically brief span of 200 million years. As Ceres aged, it would have cooled, because radioactive elements in its interior decayed and provided less and less heat, making it more difficult for underground water to stay above the freezing point. But before it froze, the water would have provided a medium for complex chemical reactions, creating a rich inventory of minerals.

Although ice is certainly far more prevalent, could liquid water persist underground even today? Scientists don't know. The loss of heat over time depends not only on the specific supply of radioactive elements Ceres started with but also on how the heat moved. Salt, for example, conducts heat very poorly, so it could store thermal energy longer than rock. Also, the freezing point of water depends on what chemicals are dissolved in it. As one case in point, ammoniated salts make effective antifreeze. Scientists are using the extensive data from Dawn to refine mathematical models to gain insight into the interior conditions in the present and in the past.

Pockmark Pitfalls

It does not require mathematical models to see that Ceres has many craters. Or does it? To most people, the presence of craters on an ancient, airless world is not surprising. We know the solar system is replete with asteroids and comets that leave scars on the larger surfaces they strike.

But scientists did not expect to see *so many* craters on Ceres. In the darkness before Dawn, the reasoning was that if Ceres' crust were composed largely of ice (an assumption based principally on the dwarf planet's low density), then craters would disappear over geological time scales. As the ice flowed, albeit more slowly than glacial speeds, the surface would gradually relax, much as your skin relaxes after pressure from a fingernail is removed and the imprint eventually vanishes.

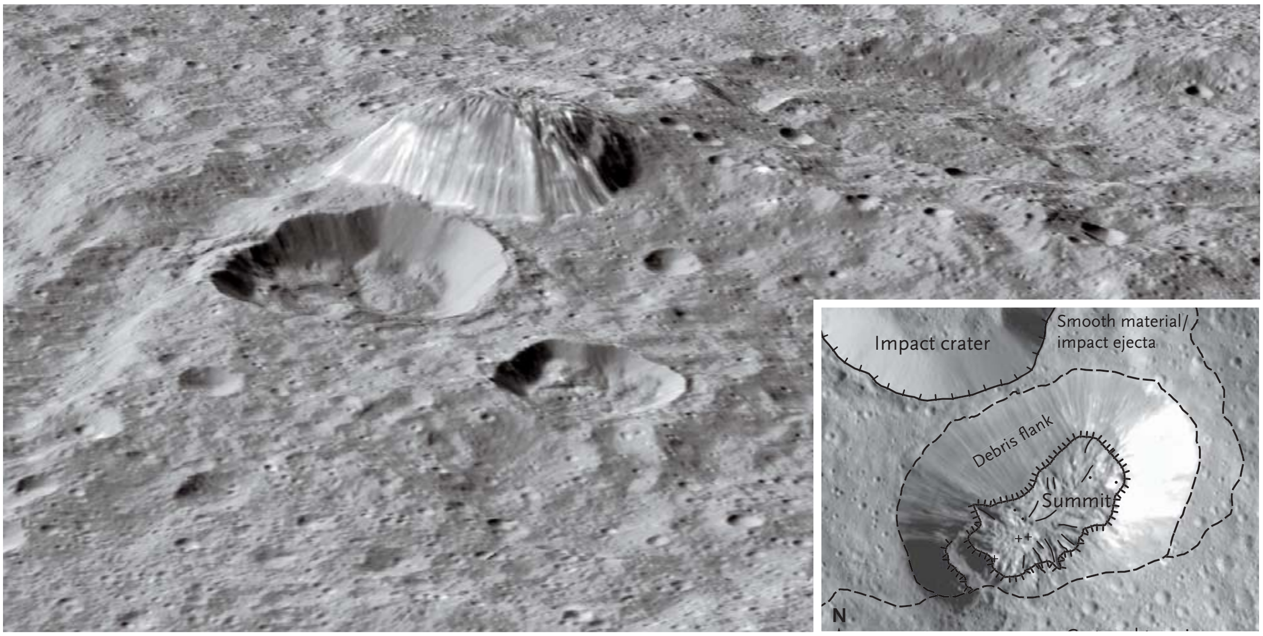
But Dawn has found areas on Ceres so heavily cratered, they are said to be saturated. That is, there are as many craters as it's possible for there to be. This may seem naïve. After all, no matter how many craters there are, if a small asteroid slams into Ceres, it will form at least one more. But a region saturated in craters has so many that any new impact is as likely to obliterate existing craters as it is to make new ones. Even in the rough-and-tumble main asteroid belt, it takes a long time to accumulate that many craters, so the process of relaxation on Ceres must be slower than expected. That is likely because of the abundance of salts and rock in that subsurface ice, making the combination stiffer than a more ice-rich layer would be.

But the mathematical models for how many craters should have formed at different sizes show there actually is a deficit of *large* ones. Based on what we found at Vesta, Ceres should have pockmarks up to sizes comparable with its diameter (roughly 900 km). Yet it has only 16 craters larger than 100 km, about 40% of the number expected. The two largest Cerean craters have diameters of 280 km (Kerwan) and 260 km (Yalode). In contrast, Dawn found a gigantic Vestan basin (Rheasilvia) more than 500 km in diameter and another (Veneneia) 400 km across overlapping at the south pole.

The absence of large Cerean craters could be the result of the loss of an exterior, icy shell or some internal processes that erase them. Scientists can use their

Dawn's Primary Mission Orbits Around Ceres

Mapping Orbit	Dates (2015)	Altitude in km (mi)	Resolution in meters (ft) per pixel	Resolution compared to Hubble
1	April 23–May 9	13,600 (8,400)	1,300 (4,200)	24×
2	June 6–30	4,400 (2,700)	410 (1,400)	73×
3	Aug 17–Oct 23	1,470 (915)	140 (450)	217×
4	Dec 16–Sept 2, 2016	385 (240)	35 (120)	830×



NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

O. RUESCH / NASA / JPL-CALTECH / UCLA / MPS / DLR / IDA

LONELY MOUNTAIN Ceres is mostly a land of craters, but there are three major mountains. The most notable is Ahuna Mons, a strangely shaped protrusion that rises about 4,000 meters (13,000 feet) high. ***Inset:*** Ahuna Mons has a wide summit and steep sides covered in debris. It's likely a cryovolcanic dome, suggesting that Ceres' interior remained melted relatively recently.

knowledge now of the size and number of craters to help sharpen their geological picture of Ceres.

A Mountain of Data

Another striking sight is a tall mountain that rises precipitously from an otherwise unremarkable area. Ahuna Mons is the tallest mountain on Ceres, reaching about 4,000 m, or comparable to Mauna Kea. Despite its proximity to a prominent crater, it's unclear whether the impact had anything to do with the mountain's formation. Given the surrounding craters, the dome and its steep slopes are less than 250 million years old.

We now think that the dome built up from one or more gooey, cryovolcanic eruptions. Nearby impacts, or perhaps shock waves from a large planetary punch elsewhere on Ceres (such as the one that formed Kerwan) might have opened the fissures the cryomagma flowed through. Based on the world's composition, this goo was potentially a briny, mineral-tainted, water-ice mix. The summit would then be the brittle carapace that formed as the material cooled, and its fracturing might have produced the younger flank debris. Ahuna Mons's apparent youth suggests that some portion of the material within Ceres was in a melt phase in geologically recent times.

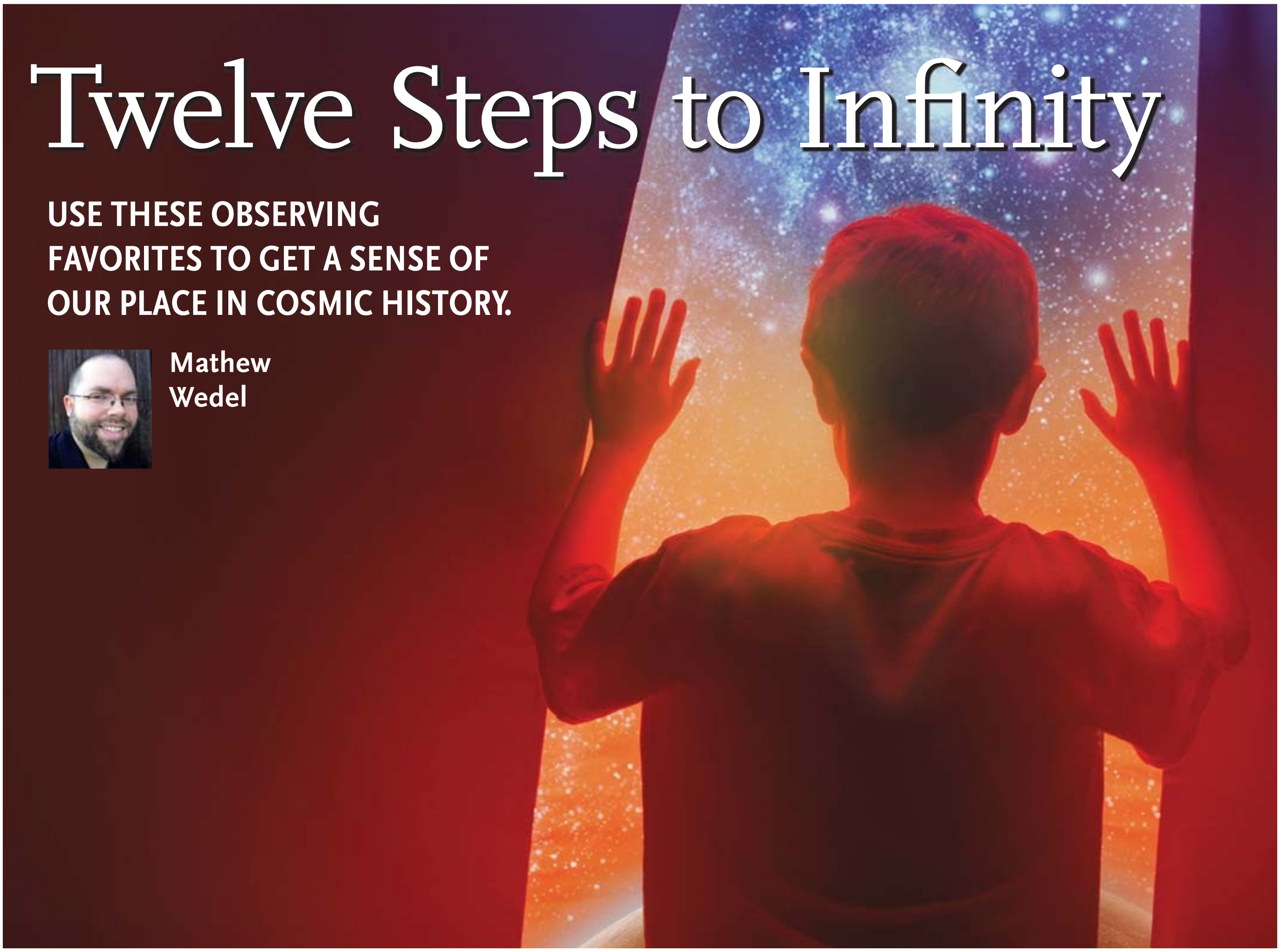
The presence of the various chemical ingredients, the retention of craters longer than originally predicted, and the profile of the interior density together show that Ceres has a crust-like exterior extending perhaps 70 to 190 km deep, or about 15% to 40% of the distance to the center. The much thicker interior must be softer and weaker. One scientist describes this world as being like crème brûlée.

Dawn's primary mission ended on June 30th, but NASA extended operations to continue investigating the fascinating world. Ongoing studies of Dawn's extensive measurements of Ceres' geology, geophysics, and chemistry will produce a great deal more new knowledge.

One of the signs of a successful scientific expedition is that it allows us to pose new questions that we could not have formulated before. By that measure, and by any other, Dawn is an outstanding success. And long, long after the mission ends, the astronomical discoveries the spacecraft enabled will continue to add to its legacy. After dawn, a new day arrives, and surely after Dawn a new mission sometime will arrive at Ceres to answer — and ask — still more questions. ✦

Orbit period	Equivalent distance of a soccer ball
15 days	3.2 meters (10 feet)
3.1 days	1.0 meter (3.4 feet)
19 hours	34 cm (14 inches)
5.4 hours	9.0 cm (3.5 inches)

Dawn Mission Director and Chief Engineer ***Marc D. Rayman*** *has been fascinated by astronomy and space exploration since the age of four. A few years later, he received his Ph.D. in physics and joined JPL. Among his most rewarding personal discoveries was* Sky & Telescope *when he was 12.*



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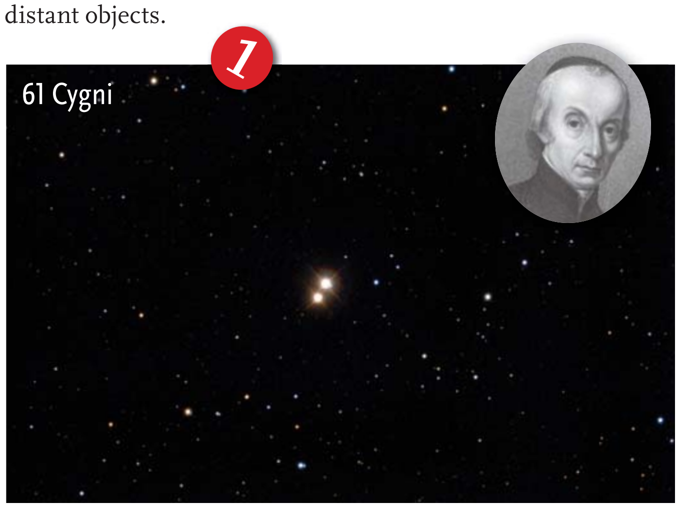
Twelve Steps to Infinity

USE THESE OBSERVING FAVORITES TO GET A SENSE OF OUR PLACE IN COSMIC HISTORY.

Mathew Wedel

WHEN I WAS A KID growing up out in the country, I loved the stars. I knew that the night sky was not just a dome overhead but an effectively endless space, with celestial lights distributed at many different distances. To enhance that perception, I would lie down on the front lawn to stargaze. I'd point my head north and my feet south and imagine that I was hanging on the edge of the planet, like a refrigerator magnet, looking out horizontally into infinity. I'd even dig my fingers and toes into the grass to keep from falling off into the sky.

Three decades later, I'm still on a quest to shatter the bowl of the sky, to see space as space. It helps to know the distances to celestial objects, but the numbers are so large that they can become overwhelming. To tie them to something I can understand, I like to think about objects in terms of their look-back times. The speed of light is fast but finite, and we cannot look out into space without also looking back into time. In this tour of the late autumn and early winter sky, we'll visit a series of celestial objects ranged at different distances, from one of the closest stars to one of the more distant Messier galaxies. At each stop, we'll pause to contemplate what was happening here on Earth at the time that the light we see now left those distant objects.



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DENNIS DI CICCO

THE FLYING STAR Giuseppe Piazzi *(inset)* noted the high proper motion of double star 61 Cygni in 1804. If you sketch 61 Cygni with its surrounding starfield, you'll be able to detect its motion in relation to the background stars in just a couple of years.

Most of the objects we'll visit are familiar favorites. Almost all can be seen with binoculars or small telescopes even in suburban skies. You've probably seen many or all of them before, but perhaps not in the same way. Grab your favorite instrument, and let's get going.

Our first stop is **61 Cygni**, a double star in the constellation Cygnus, the Swan. Giuseppe Piazzi noted the star's rapid motion across the sky in 1804; to this day, it's also known as "Piazzi's Flying Star." It was also the first star to have its distance reliably measured via parallax. Starting in the 1830s, Friedrich Wilhelm Bessel obtained a series of measurements that he eventually refined to almost the modern value of 11.4 light-years. That means that the light we see now left 61 Cygni in mid-2005. It was a busy year for astronomy: the Huygens probe reached Saturn's moon, Titan, in January. In April, amateur astronomers detected a second exoplanet by gravitational microlensing. And in July, the discoveries of dwarf planets Haumea, Makemake, and Eris made the news.

I encourage you to sketch the Flying Star with its surrounding starfield. If you revisit it in just a few years, you should be able to see that 61 Cygni has moved against the background stars.

From 61 Cygni we'll take a long step out to the open star cluster known as the **Hyades** (Caldwell 41) in Taurus. The cluster's central V-shape spans about 5°, anchored on the orange giant Aldebaran. The Hyades cluster appears large because it's close, only 151 light-years away. We see the light that left the cluster in the mid-1860s. Amidst the chaos of the Civil War, American astronomers were still making impressive discoveries. Lewis Swift and Horace Tuttle independently discovered Comet 109P/Swift-Tuttle in July 1862. In the same year, famous telescope-maker Alvan Clark discovered Sirius B, the dim "pup" that accompanies the brightest star of winter. Across the pond, British astronomer William Huggins took the first spectrum of a planetary nebula, that of the Cat's Eye Nebula, NGC 6543, in 1864. And closer to home, Maria Mitchell became the director of the observatory at Vassar College in 1865.

Aldebaran means "the follower" in Arabic, because it follows **M45**, an open star cluster popularly known as the Pleiades or the Seven Sisters, across the night sky. That's our next step as well, 10° northwest and 230 light-years farther out. At 380 light-years away, the Pleiades cluster takes us back to the mid-1630s. Telescopic astronomy was only two decades old, and the solar system was still a big, strange place. Giovanni Batista Zupi discovered in 1639 that the planet Mercury has orbital phases. That same year, the British astronomers Jeremiah Horrocks and William Crabtree became the first people in history to observe a transit of Venus. And Galileo was under house arrest, victim and symbol of the uneasy relationship between tradition and change.

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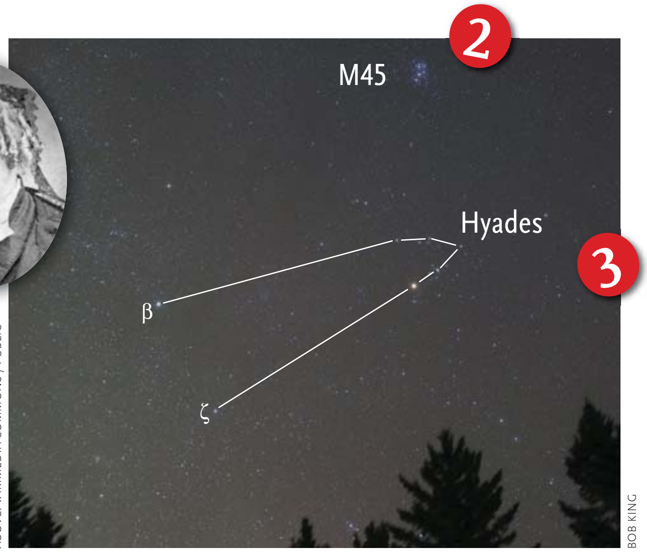
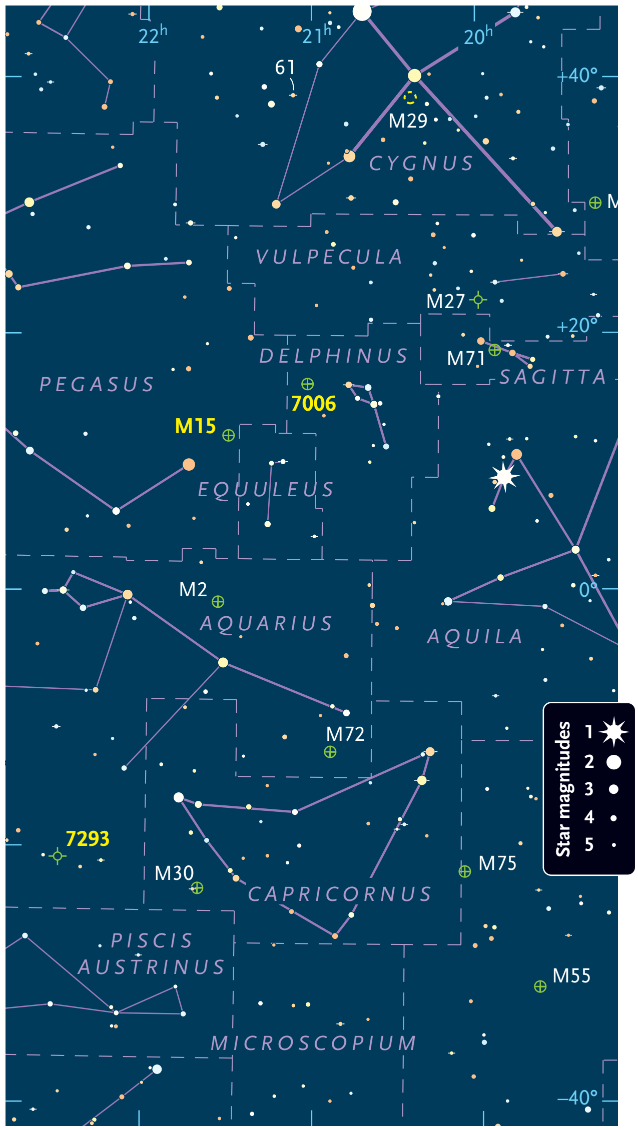


BOB KING

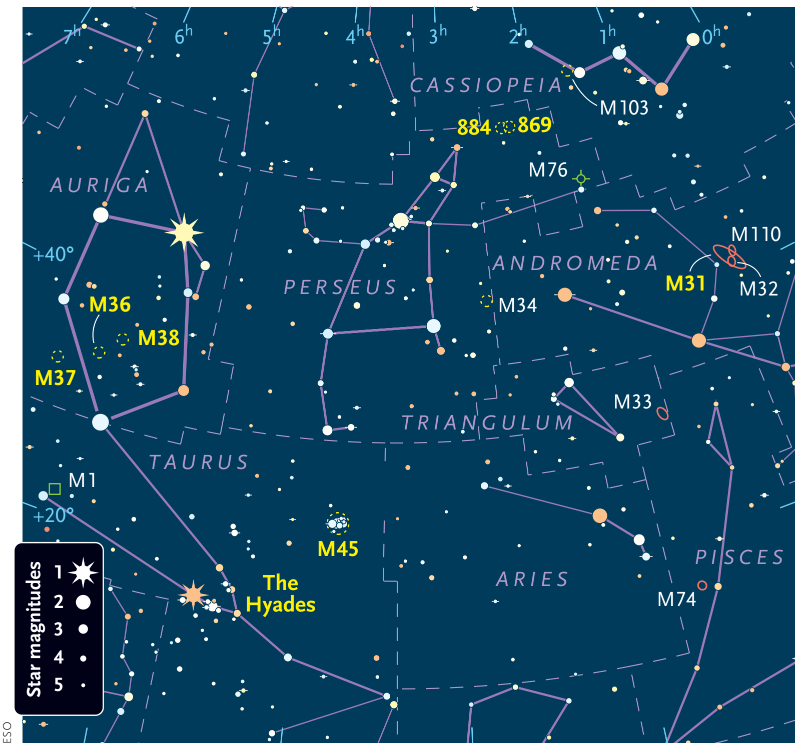
TIME TRAVEL The light we see left the Hyades 151 years ago, the year Maria Mitchell *(inset)* became director of Vassar College Observatory. The Pleiades takes us back to the mid-1630s.



Twelve Steps to Infinity

Object	Type	Distance (l-y)	Mag(v)	Size	RA	Dec.
61 Cygni	Double star	11.4	5,2, 6.0	31.6′	$21^h\ 06.9^m$	+38° 45′
Hyades	Open cluster	151	0.5	330.0′	$04^h\ 26.9^m$	+15° 52′
M45	Open cluster	380	1.5	120.0′	$03^h\ 47.0^m$	+24° 10′
NGC 7293	Planetary nebula	700	7.6	14.7′	$22^h\ 29.6^m$	–20° 50′
M42	Emission nebula	1,344	4.0	85.0′	$05^h\ 35.3^m$	–05° 26′
M36	Open cluster	4,100	6.0	10.0′	$05^h\ 36.2^m$	+34° 08′
M38	Open cluster	4,200	6.4	20.0′	$05^h\ 28.7^m$	+35° 51′
M37	Open cluster	4,500	5.6	14.0′	$05^h\ 52.3^m$	+32° 33′
NGC 869	Open cluster	7,600	5.3	18.0′	$02^h\ 20.2^m$	+57° 11′
NGC 884	Open cluster	7,600	6.1	18.0′	$02^h\ 23.5^m$	+57° 11′
M15	Globular cluster	33,000	6.2	18.0′	$21^h\ 30.8^m$	+12° 10′
NGC 7006	Globular cluster	137,000	10.6	3.6′	$21^h\ 01.5^m$	+16° 11′
M31	Spiral Galaxy	2,500,000	3.4	177.8′	$00^h\ 43.7^m$	+41° 16′
M81	Spiral Galaxy	11,800,000	6.8	21.4′	$09^h\ 55.5^m$	+69° 04′
M82	Starburst Galaxy	11,900,000	8.1	11.0′	$09^h\ 57.2^m$	+69° 41′
M77	Barred Spiral Galaxy	47,000,000	9.0	5.2′	$02^h\ 42.6^m$	+00° 01′

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.



OLD LIGHT *Left:* The light captured in this composite image of NGC 7293, the Helix Nebula, is some 700 years old. It left its source in the early 1300s, around the time Dante was describing the universe as nested crystalline spheres in his *Divine Comedy*.

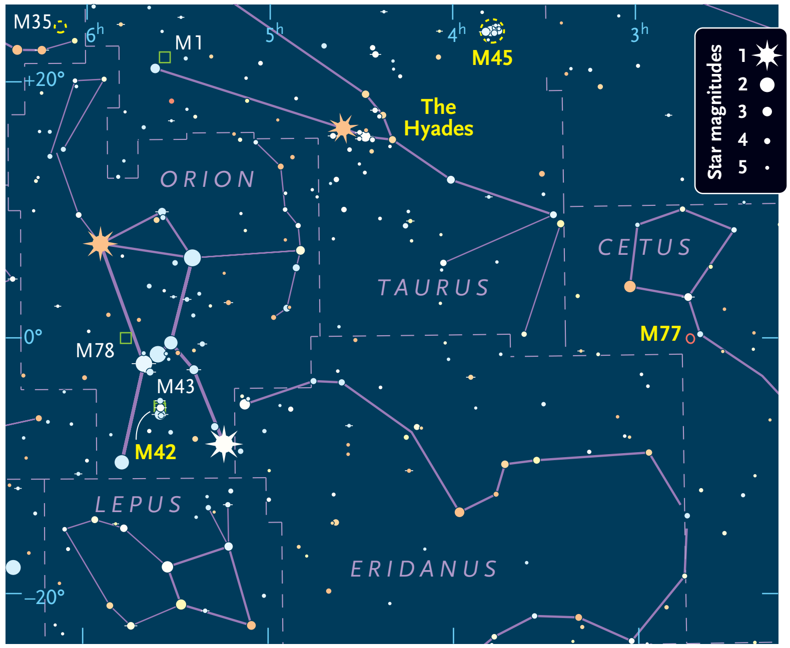
Our next step is the Helix Nebula, **NGC 7293** (Caldwell 63), 700 light-years away in Aquarius. The Helix is a planetary nebula, a shell of gas blown off by a dying star, and the closest planetary nebula to Earth. That proximity makes it a tough catch, as its light is spread over so much sky. You'll need a clear night and binoculars or a rich-field scope to see this faint ring of light.

We see light that left the Helix in the early 1300s, when science was in full flower in the Islamic world. The greatest astronomer of the age was Ulugh Beg, born in 1394, who built an immense observatory at Samarkand and charted nearly a thousand stars. He also determined the length of the sidereal year to within 25 seconds, and measured Earth's axial tilt more accurately than either Nicolaus Copernicus or Tycho Brahe.

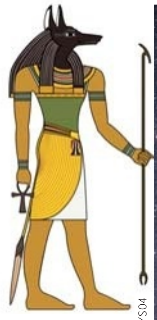
If the last nebula was elusive, the next one should not be: it's the famous Orion Nebula, **M42/M43**. The Orion Nebula is a "total object," meaning that it looks good at every aperture and magnification, from the naked eye to the Hubble Space Telescope. Recent measurements have refined the nebula's distance to 1,344 light-years. That takes us back to the mid-600s, when astronomy was largely dormant in the West. Classical manuscripts by Ptolemy and others awaited discovery by Islamic and later European scholars. But astronomy was thriving in Tang dynasty China. The Dunhuang Star Chart, which dates from around the year AD 700, includes 1,300 stars — more than the catalogs of either Ulugh Beg or Tycho Brahe (albeit not to the same positional precision). A more complete celestial atlas wouldn't exist until Johannes Hevelius published his catalog of 1,564 fixed stars in 1687.

Our next step gets us three for the price of one: open clusters **M36**, **M37**, and **M38** in Auriga. The members of this trio are all at similar distances, between 4,100 and 4,500 light-years. The light we see now left these clusters in the late third millennium BC. In Egypt's Middle Kingdom, coffin lids were inscribed with diagonal star tables. Across Europe, stone circles were in use at observatories of impressive sophistication, grave goods from China recorded dozens of constellations, and early Polynesian explorers were navigating by the Sun and stars. References to celestial objects were also common in the oral histories that would eventually be written down in *The Iliad*, *The Odyssey*, and the Hebrew Bible.

Another step of similar length carries us out to the Double Cluster in Perseus, composed of **NGC 869** and **NGC 884**. At a little more than 7,000 light-years away, the Double Cluster is significantly closer to the edge of the Milky Way Galaxy than we are; it resides in the Perseus Arm rather than our own Orion Spur. Now we're at 5000 BC, a time when early agricultural societies watched the night sky and charted the motions of the heavens. The oldest known observatory is at Warren Field in Scotland, where astronomers used 12 pits to track the phases of the Moon and subsequently, the



A TOTAL OBJECT This wide-field composite image, taken with the VISTA telescope at ESO's Paranal Observatory in Chile, shows an unusual view of a familiar object, the Orion Nebula. Astronomers used VISTA's infrared capabilities to peer through obscuring dust clouds to capture the 1,344-year-old light emanating from star-forming regions in the heart of the nebula.



Anubis

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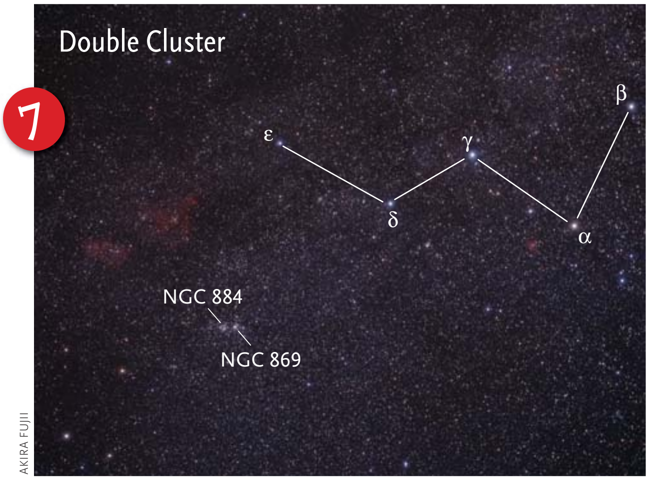
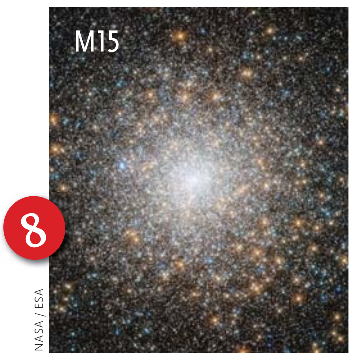
AKIRA FUJII

THREE FOR THE PRICE OF ONE. Open clusters M36, M37, and M38 in Auriga lie between 4,100 and 4,500 light-years from Earth. The light left this trio between 2000 and 2500 BC, the early years of the Middle Kingdom of Egypt.



AKIRA FUJII

DOUBLE CLUSTER The so-called Double Cluster, composed of NGC 869 and NGC 884, lies just over 7,000 light-years from Earth. Although located in Perseus, you might find it easier to starhop to the duo from Epsilon (ε) Cassiopeia.



NASA / ESA

MARTIN GERMANO

DISTANT DAZZLERS *Left:* Globular cluster M15 isn't particularly close, but its suns create a sparkle in even small scopes. *Right:* Looking at NGC 7006 means looking deep into human history: 137,000 years ago *Homo sapiens*, *Homo neanderthalensis*, *Homo floresiensis*, and *Homo erectus* shared our planet.

lunar month. Amazingly, the Warren Field calendar dates back to 8000 BC, so by 5000 BC similar observatories had already been in use for at least three millennia!

Until now we've been taking little steps in time and space. Now we'll start to run, and our first stride covers 33,000 light-years, to the globular cluster **M15** in Pegasus. Despite its distance, M15 is an easy catch in binoculars and a rewarding sight in telescopes of all sizes. That's because it's huge, a sphere of more than 100,000 stars spanning almost 90 light-years.

The Ice Age was in full swing 33,000 years ago, and fully modern humans lived alongside mammoths, saber-toothed cats, cave bears, and woolly rhinos. The lives of our ancestors were ruled by the hunt, and so were their myths. In 2013, French scientist Julien d'Huy (Université de Paris) found that cultures across the globe have myths that connect the Cosmic Hunt to the constellation Ursa Major, implying a shared mythological history that predates the settlement of the Americas. It seems that we've always told stories about the sky.

Jump! Now we're well outside the disk of the Milky Way, looking back from a distance of 137,000 light-years. Here floats another globular cluster, **NGC 7006**, in the constellation Delphinus. At 300,000 times the mass of the Sun, NGC 7006 is only about two-thirds the size of M15. And at four times the distance, it's a much less impressive sight than we saw at our previous stop. But observe it anyway, both to see how much detail you can tease out, and simply for the thrill of looking out past the edge of the galaxy.

Humans were much more diverse 137,000 years ago, and by diversity I don't mean races or cultures but species. The first anatomically modern *Homo sapiens* appeared in Africa almost 200,000 years ago. Europe and the Near East were home to Neanderthals, *Homo neanderthalensis*, with whom we would coexist and occasionally interbreed for the following 100,000 years. And Asia held surviving populations of *Homo erectus* and the diminutive *Homo floresiensis*. The thought of so many kinds of humans coexisting over so much time fills me with wonder.

Another, longer stride carries us to the closest large galaxy outside the Milky Way, **M31**, the Andromeda Galaxy. M31 is the easiest external galaxy to observe, and the view will only get better as Andromeda and the Milky Way move toward a collision and merger in about 4 billion years.

We see light that left Andromeda 2.5 million years ago. There were already multiple species of hominins around back then, but they didn't look much like us. The earliest members of our own genus, *Homo habilis*, were making simple stone tools in East Africa. They lived alongside robust australopithecines like *Paranthropus*, which would coexist with various species of *Homo* for the next million years.

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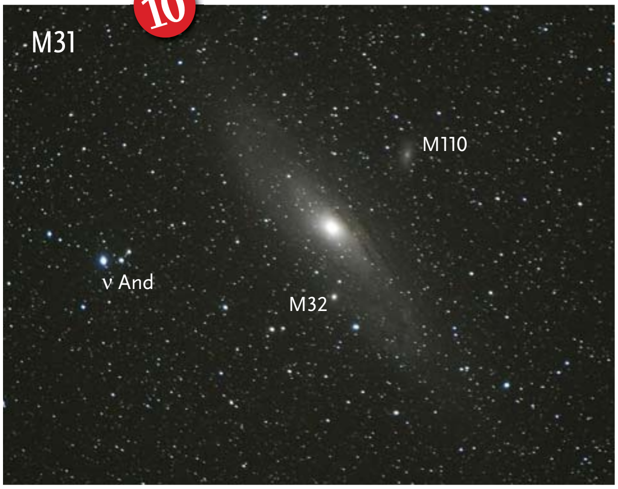

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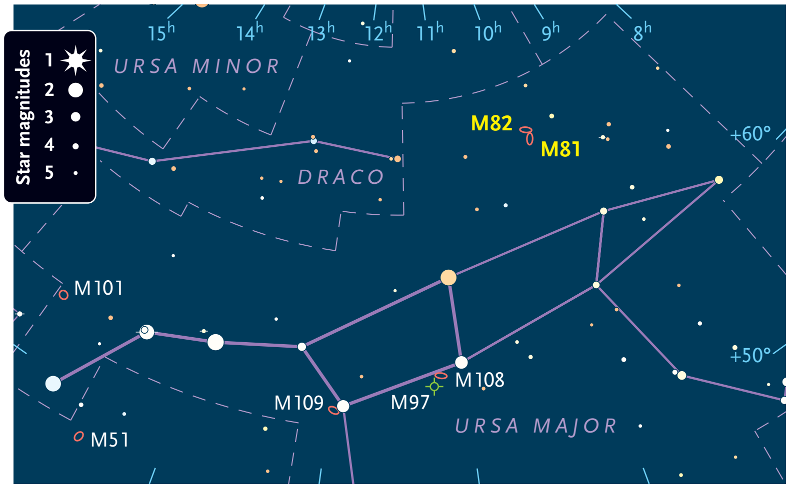
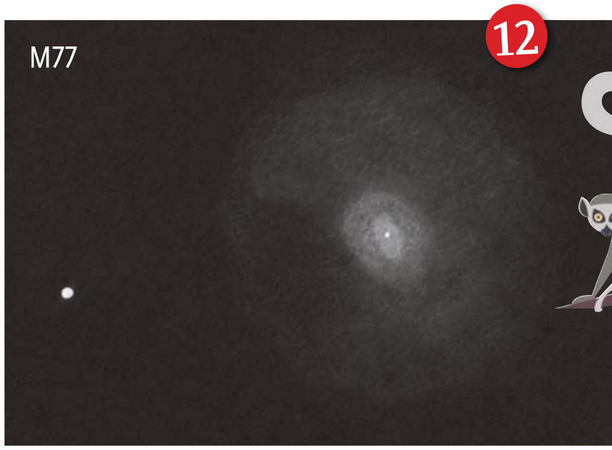


CLOSEST NEIGHBOR *Left:* At 2.5 million light-years distant, M31, the Andromeda Galaxy, is the closest large galaxy to Earth. When the light you see today left Andromeda, members of *Homo habilis* were making and using stone tools for chopping and scraping in East Africa.

11

FRED ESPENAK

12



MARTIN SCHOENBALL

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TRULY REMOTE *Left:* M81 and M82 lie about 12 million light-years from Earth. Visually, they are 31 arcminutes distant from each other; the actual distance between them is 150,000 light-years. *Right:* Spiral galaxy M77 in Cetus shows us its face from some 47 million light-years away. At 274× in a 10-inch f/5 scope, the elongated core, bright with star-forming activity, pops into view.

Now we leap to **M81** and **M82**, a pair of galaxies in Ursa Major that fit comfortably together into a single low-power eyepiece field. M81 and M82 are both about 12 million light-years away. We're getting truly remote now. Twelve million years ago the first kelp forests had just appeared in Earth's oceans. India was slowly colliding with Asia to start pushing up the Himalayas, now the planet's tallest mountain chain. And somewhere in southern Asia or northern Africa, two lineages of apes had just diverged. One would evolve into orangutans, and the other would later diversify into gorillas, chimps, and eventually, australopithecines, *Homo erectus,* Neanderthals, and us.

We have one last step to take, to the barred spiral galaxy **M77** in Cetus. Face-on spirals are sometimes tough targets, as their orientation spreads out their light. Not so with M77, which has an active galactic nucleus that makes it fairly easy to detect, even across the intervening 47 million light-years.

It's sunset in Wyoming, 47 million years ago. The sun glides down over the canopy of a tropical forest that extends all the way to northern Canada. Palm trees grow in Alaska, and Antarctica is lush and green. The nearly-global rainforest is home to an evolutionary explosion of mammals and birds. No longer suppressed by the giant dinosaurs, mammals have evolved into a bewildering array of forms, including the earliest hoofed herbivores, saber-toothed carnivores, four-finned whales, and bats. Among them are little lemur-like primates that scamper through the trees looking for insects, bird nests, and fruit. They have no way of knowing that someday their descendants will travel through space, walk on the Moon, and see back to the beginning of the universe.

But the little primates are energetic and curious, and sometimes, at night, they look up at the stars. ✦

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*As a professional paleontologist and amateur astronomer, **Matt Wedel** is obsessed with everything big and old.*

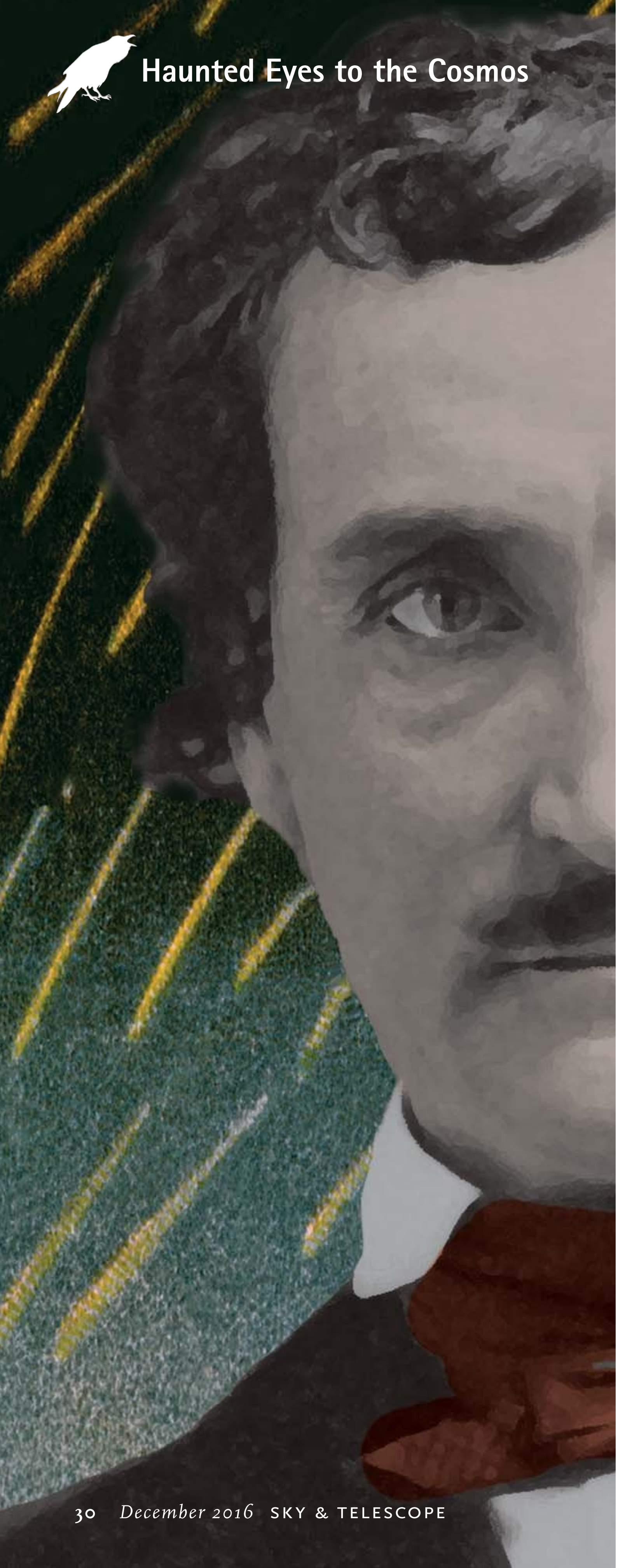


PHOTO ILLUSTRATION: *S&T* / PAT COPPOLA

The Comets of

Poe had some weird ideas for dead

Donald W. Olson
& Shaun B. Ford

Edgar Allan Poe (1809–49) is a legend in American literature for his poetry and tales of the macabre and grotesque. He invented the horror story and the detective story. Less well known are his fascination with astronomy and the astronomical references, occasionally even obsessions, that appear throughout his work.

For example, Tycho's supernova of 1572 inspired the poem "Al Aaraaf" (1829). "The Unparalleled Adventure of One Hans Pfaall" (1835) tells the story of a voyage to the Moon by balloon; along the way it discusses zodiacal light, the inclination of the Moon's orbital plane, and possible explanations for secular changes in the orbit of Encke's Comet. In a signature scene at the beginning of Poe's "Murders in the Rue Morgue" (1841), as the characters walk through Paris they cast their "eyes upward to the great nebula in Orion." Poe remarks on the immense distances to the stars and the light-travel times from Sirius and 61 Cygni in his footnotes to various editions of "The Thousand-and-Second Tale of Scheherazade" (1845 and 1850).

Poe's book-length *Eureka* (1848) is a passionate polemic on physical cosmology long before the field was invented. In flights of mystical imagination and philosophical mania, Poe declares that the universe is arranged as an enormous "cluster of clusters," the clusters being

> merely what we have been in practice of designating "nebulae" and, of these "nebulae", one is of paramount interest to mankind. I allude to the Galaxy, or Milky Way. [...] The Galaxy, let me repeat, is but one of the clusters which I have been describing — but one of the mis-called "nebulae" revealed to us — by the telescope alone, sometimes — as faint hazy spots in various quarters of the sky. We have no reason to suppose the Milky Way really more extensive than the least of these "nebulae".

Edgar Allan Poe

spirits to converse upon. Where did he get them?

Unlike any astronomers of his day, Poe further proclaims an evolving big-bang universe, with

> Matter's having been radiated, at its origin, atomically *[i.e., as a gas]*, into a limited sphere of Space, from one, individual, unconditional, irrelative, and absolute Particle Proper.

Poe uses an anthropic-principle argument to assert that the universe must be extremely old in order for us to be here observing it. Yet it cannot be so old that it would violate Olbers' paradox; Poe anticipates an essential part of the modern resolution of the paradox when he offers this explanation of why the night sky is dark:

> Were the succession of stars endless, then the background of the sky would present us an uniform luminosity, like that displayed by the Galaxy — since there could be absolutely no point, in all that background, at which would not exist a star. The only mode, therefore, in which, under such a state of affairs, we could comprehend the voids which our telescopes find in innumerable directions, would be by supposing the distance of the invisible background so immense that no ray from it has yet been able to reach us at all.

Although he subtitled *Eureka* a "prose-poem" rather than an essay on science, Poe was convinced that he had unmasked the plan of God: the universe expands from a point-like beginning in "one instantaneous flash," with stars then "condensing into visibility from invisible nebulosity." Gravity pulls stars and gas into galaxies, while the galaxies separate from each other. The universe evolves through our present state and a future in which stars will "grow grey in giving birth and death to unspeakably numerous and complex variations of vitalic development," eventually achieving an unknown Divine Will, before all finally recollapses into a singular point under Newton's law of gravity, "with a velocity accumulating in the inverse proportion of the squares of the distances at which lay the inevitable End."

Reviewers savaged the book, calling it unreadable lunacy or "a damnable heresy," but Poe considered it his greatest life work. He wrote to his aunt Maria Clemm, "I have no desire to live since I have done *Eureka*. I could accomplish nothing more." In fact he wrote little further, nearly died of an opiate overdose, then died the following year of causes unknown.

In more ancillary roles, Poe had repeatedly brought the Moon, constellations, and planets into his poems, such as "Evening Star" (1827) and "Ulalume" (1847) — both of which compare and contrast the Moon and Venus — and into many other writings. The cosmos entranced him and excited his deepest mysticism.

SEAN SWEENEY; RAVEN GRAPHIC: BIGSTOCKPHOTOS.COM/FOSIN

STAR-WINDS **Edgar Allan Poe again walks the streets of Boston. This statue, created by artist Stefanie Rocknak and unveiled by the Edgar Allan Poe Foundation of Boston in 2014, stands on the edge of the Boston Common near the intersection of Boylston and Charles Streets. Every night Poe's fictional raven, emerging from the restless traveler's suitcase, casts his lamplit shadow on the floor.**

GIUSEPPE NACCARI, *ATLANTE ASTRONOMICO* (1904)

RAIN OF BIELIDS Biela's Comet never collided with the Earth — but fragments of it did! The comet was due back in 1872. Instead the world received a meteor storm, with several thousand visible per hour radiating from the predicted direction of the comet's approach.

Meteor Storms in 1872 and 1885

Although Biela's Comet itself never struck Earth, this comet had an unusually interesting history after Poe's story — and fragments of it did light up Earth's atmosphere.

Biela's Comet was not observed during its unfavorable predicted return near its perihelion passage in 1839. But during its apparition of 1845–46, Matthew Fontaine Maury was astonished to see that the comet had split into two components that moved together and developed parallel tails as they approached the Sun. There were reports of a bridge of material between them. Both main objects were recovered at their 1852 return, but after that year they were never seen again.

Then on November 27, 1872, the very date when Earth passed closest to the comet's orbit, astronomers were again astonished as fragments of the disintegrated Biela's Comet produced a spectacular meteor storm. A similar rain of meteors fell from the sky on November 27, 1885. The meteors are known as the Bielids or Andromedids, after the constellation containing the radiant. Occasionally the shower is still weakly active.

"The Conversation of Eiros and Charmion"

Poe had a thing for comets in particular. Our astronomical history group at Texas State University became especially intrigued by the extensive references to comets in "The Conversation of Eiros and Charmion," a short story first published in the December 1839 issue of *Burton's Gentleman's Magazine*. The tale takes the form of a dialogue between two spirits, male and female, adrift in a heavenly realm. An apocalyptic event has destroyed humanity and terrestrial life; the agent of destruction was a comet on a path that "would bring it into very close proximity with the earth." As the comet drew closer, scholars had reassured the world that comets were "vapory creations of inconceivable tenuity. . . altogether incapable of doing injury to our substantial globe, even in the event of contact." The end indeed came not by a collision, but by the comet's atmosphere mingling with Earth's, extracting all the nitrogen, and replacing it with pure oxygen. The result was a "final destruction of all things by fire. . . . A combustion irresistible, all-devouring, omni-prevalent, immediate. . . the whole incumbent mass of ether in which we existed burst at once into a species of intense flame. . . . Thus ended all."

This discourse in the afterlife includes some very specific scientific references to the composition of the atmosphere and to the orbits and physical properties of comets. We became curious about what motivated Poe to write this particular tale. Could we determine the books from which he derived his scientific statements? Could we identify the actual comets that inspired him?

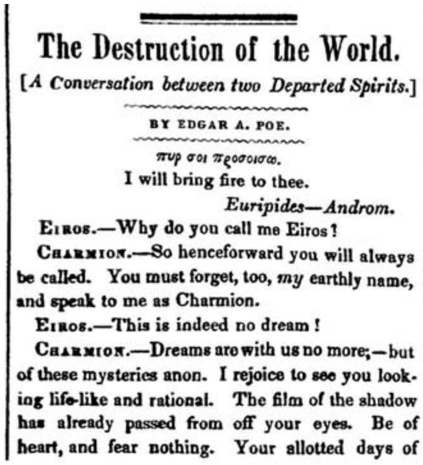
Earth's Atmosphere

We started our hunt with a pioneering study by Margaret Alterton, who pointed out that Poe's passages about Earth's atmosphere and combustion came from *The Christian Philosopher* by Thomas Dick (1774–1857):

> Of 100 measures of atmospheric air, 21 are oxygen, and 79 nitrogen. The one, namely, oxygen, is the principle of combustion, and the vehicle of heat, and is absolutely necessary for the support of animal life, and is the most powerful and energetic agent in nature. . . . If the nitrogen were extracted from the air, and the whole atmosphere contained nothing but oxygen. . . combustion would not proceed in that gradual manner which it now does, but with the most dreadful and irresistible rapidity. . . instantly a universal conflagration would commence. . . .

In "The Conversation of Eiros and Charmion," Eiros repeats this passage almost verbatim:

> . . .the air which encircled us was a compound of oxygen and nitrogen gases, in the proportion of twenty-one measures of oxygen and seventy-nine of nitrogen in every one hundred of the atmosphere. Oxygen, which was the principle of combustion, and the vehicle of heat, was absolutely necessary to the support of animal life, and was the most powerful and



The Destruction of the World.

[*A Conversation between two Departed Spirits.*]

BY EDGAR A. POE.

πυρ σοι προσοισω.

I will bring fire to thee.

Euripides—Androm.

EIROS.—Why do you call me Eiros?

CHARMION.—So henceforward you will always be called. You must forget, too, *my* earthly name, and speak to me as Charmion.

EIROS.—This is indeed no dream!

CHARMION.—Dreams are with us no more;—but of these mysteries anon. I rejoice to see you looking life-like and rational. The film of the shadow has already passed from off your eyes. Be of heart, and fear nothing. Your allotted days of

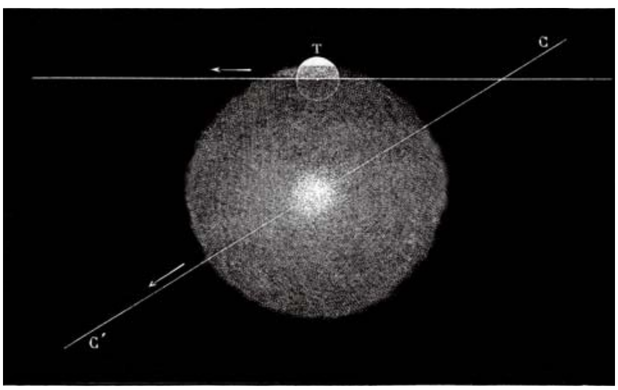
FEARFUL SPECTACLE ***Above:*** **After its perihelion passage in February, the Great Comet of 1843 developed a spectacularly long tail. This chromolith from Amédée Guillemin's *The World of Comets* (1877) shows the appearance of the comet under Orion and in front of Sirius on March 19, 1843. *Right:* Two weeks later Poe reprinted his cometary tale of Eiros and Charmion, now with the title "The Destruction of the World [A Conversation between two Departed Spirits]", on the front page of a newspaper called the *Philadelphia Saturday Museum* for April 1, 1843.**

> energetic agent in nature. . . . What would be the result of a total extraction of the nitrogen? A combustion irresistible, all-devouring, omni-prevalent, immediate. . . .

The Leonids of 1833?

What astronomical phenomenon might have inspired Poe to think about fire in the atmosphere? Biographer Arthur Quinn suggested "the rain of meteors visible in Baltimore in the early morning of November 13, 1833. . . . The dread on the part of some of the beholders that the end of the world was at hand. . . might easily have suggested to Poe the description by Eiros of the comet which brings destruction to the world."

The Leonid meteor storm of 1833 was indeed a spectacular event. However, Poe wrote about a comet, and astronomers did not make the connection between comets and meteor showers until 1866, when Giovanni Schiaparelli (1835–1910) showed that the Perseid meteors and Comet Swift-Tuttle share very similar orbits. Poe would not have been able to associate a meteor shower with the approach of a comet. And the Leonids do not fit the story.



AMÉDÉE GUILLEMIN. *THE WORLD OF COMETS* (1877)

BEING GASSED **The astronomer Heinrich Olbers remarked in 1828 that Biela's Comet "may pass at a very small distance from us, and even so near, that its atmosphere may be in contact with our globe." This diagram illustrates the possibility, with Biela's Comet making a hypothetical close passage (C to C′) that allows its atmosphere to mix with that of Earth (T = Terre = Earth).**

Halley's Comet? Encke's Comet?

Arthur Quinn offered as an alternate theory that Poe "probably saw Halley's Comet in 1835." Several more recent commentators also endorse the idea of Halley's Comet as inspiration for the story. In his notes to the tale, Poe scholar Thomas Mabbott also argued that Poe might have been interested in Encke's Comet, because "its periodicity had been calculated," it had returned in 1838, and it "was expected again in 1842."

Poe's astronomical references in other works demonstrate that he was aware of both Halley's and Encke's comets. But neither of those posed a threat to collide with Earth.

We wondered: Did any other comet, known in the 1830s, have an orbit that intersected or nearly intersected Earth's orbit?

Eventually we realized that only one comet matched this requirement of Poe's story.

Biela's Comet

Biela's Comet was first observed in 1772 by Jacques Leibax Montaigne. It received its name in 1826 when Wilhelm von Biela and Jean-Félix Adolphe Gambart identified it as periodic. The comet was observed in 1832 and its next return was predicted for 1839, the year Poe's tale appeared.

An essential point of the Eiros and Charmion story is that Poe's fictional comet passes so close that its atmosphere mingles with ours. Exactly such a possibility was discussed in the scientific literature of the 1820s and 1830s for Biela's Comet.

COURTESY POE HOUSE BALTIMORE, INC. (2)

LOOKING DEEP This small refractor, reputed to be the instrument Poe used to study the heavens as a teen, is displayed at the Poe House museum in Baltimore. The telescope and its pillar-and-claw stand were made by the London firm of Thomas Blunt and brought back from England by Poe's foster father, John Allan.

Heinrich Olbers, the astronomer most associated today with "Olbers' paradox," remarked about Biela's Comet in *The American Journal of Science:* "at some time the comet may pass at a very small distance from us, and even so near, that its atmosphere may be in contact with our globe. " Joseph Johann von Littrow, writing in the same journal during 1833, pointed out: "Of all the comets which are known to astronomers, that of Biela is the only one whose orbit is such as to admit of its ever coming in contact with the Earth. This is a circumstance which renders that body an object of deep and peculiar interest to the inhabitants of our globe."

Poe could conceivably have seen these notes in a scientific journal. But to find more likely candidates for Poe's reading, we surveyed popular astronomy books from the 1830s. Probably the most famous were the multiple editions of Elijah Hinsdale Burritt's *The Geography of the Heavens,* issued in large printings in 1833, 1836, 1838, and later years. (Peggy Aldrich Kidwell surveyed the Burritt volumes and their enthusiastic public reception in *Sky & Telescope* for January 1985.)

The 1838 edition of Burritt's book includes language identifying Biela's Comet as a perfect candidate for Poe's fictional destroyer:

> . . . the path of Biela's comet passes very near to that of the Earth. . . the matter of the comet extends beyond that path . . . Thus, if the Earth were at that point of its orbit which is nearest to the path of the comet, at the same moment that the comet should be at that point of its orbit which is nearest to the path of the Earth, the Earth would be enveloped in the nebulous atmosphere of the comet. . . . This is the comet which was to come into collision with the Earth, and to blot it out from the Solar System.

British astronomer John Herschel in 1833 published a popular book titled *A Treatise on Astronomy*. In 1834 an American edition appeared with a passage related to a recent "comet panic" caused by Biela's Comet:

> The other comet of short period which has lately been discovered is that of Biela . . . Its orbit, by a remarkable coincidence, very nearly intersects that of the earth; and had the latter, at the time of its passage in 1832, been a month in advance of its actual place, it would have passed through the comet — a singular rencontre, perhaps not unattended with danger.

Poe himself said that he had read John Herschel's book; one of Poe's later essays describes events in the summer of 1835: "Harpers had issued an American edition of Sir John Herschel's 'Treatise on Astronomy,' and I had been much interested in what is there said respecting the possibility of future lunar investigations. . . . I longed to write a story embodying these dreams." Thus resulted his 1835 story about Hans Pfaall's balloon voyage to the Moon.

Poe's inspiration for using a comet as a world-ending agent almost certainly came from his reading about Biela's Comet, possibly in *The American Journal of Science* but more likely in the books by Elijah Burritt and John Herschel.

Lexell's Comet

However, another intriguing passage in "The Conversation of Eiros and Charmion" doesn't fit at all with the behavior of Biela's Comet. As Poe's fictional comet approaches Earth, scientists offer reassurances that nothing need be feared. Says Eiros,

> The very moderate density of these bodies had been well established. They had been observed to pass among the satellites of Jupiter without bringing about any sensible alteration either in the masses or in the orbits of these secondary planets. We had long regarded the wanderers as vapory creations of inconceivable tenuity, and as altogether incapable of doing injury to our substantial globe, even in the event of contact.

As the comet draws even closer to Earth, reassurances are repeated:

> . . . the harmless passage of a similar visitor among the satellites of Jupiter was a point strongly insisted upon, and which served greatly to allay terror.

Lexell's Comet & Earth

Poe's story alludes to the remarkable 1779 passage of Lexell's Comet through Jupiter's satellite system. Nine years earlier, this same comet also had an exceptional encounter with Earth. On July 1, 1770, Lexell's Comet passed Earth at a distance of only 0.0151 a.u., about 6 times the distance of the Moon. This ranks as the closest approach of a comet to our planet in recorded history. But its subsequent very close encounter with Jupiter — quite a coincidence! — tugged it into an orbit that will keep it from coming close to us again.

Poe almost certainly derived these passages from the 1834 Philadelphia edition of John Herschel's popular book. Herschel describes an encounter between Lexell's Comet and Jupiter thusly:

> In the case of the remarkable comet of 1770, which was found by Lexell to revolve in a moderate ellipse in the period of about 5 years, and whose return was predicted by him accordingly, the prediction was disappointed by the comet actually getting entangled among the satellites of Jupiter, and being completely thrown out of its orbit by the attraction of that planet, and forced into a much larger ellipse. By this extraordinary rencontre, the motions of the satellites suffered not the least perceptible derangement — a sufficient proof of the smallness of the comet's mass.

Elijah Burritt's 1838 edition cites Herschel's words and summarizes this passage as "sufficient proof of the aeriform nature of the comet's mass." So Poe's mention of a comet "observed to pass among the satellites of Jupiter" was definitely inspired by Lexell's Comet.

Stars Visible Through Comets

Another passage from Poe's dialogue of the dead offers reassurance about the low density of comets in a different way altogether:

> The exceeding tenuity of the object of our dread was apparent; for all heavenly objects were plainly visible through it.

Once again Poe was apparently influenced by Herschel:

> Stars of the smallest magnitude remain distinctly visible, though covered by what appears to be the densest portion of their substance; although the same stars would be completely obliterated by a moderate fog, extending only a few yards from the surface of the earth. . . . It will then be evident that the most unsubstantial clouds which float in the highest regions of our atmosphere . . . must be looked upon as dense and massive bodies compared with the filmy and all but spiritual texture of a comet.

Herschel described his own observations of Biela's Comet on September 23, 1832:

> . . . it passed directly over a small cluster or knot of minute stars of the 16th or 17th magnitude *[sic]* . . . the stars of the cluster being visible through the comet.
>
> A more striking proof could not have been offered of the extreme translucency of the matter of which this comet consists. The most trifling fog would have entirely effaced this group of stars; yet they continued visible. . . .

Conclusions

So we are confident that the mystery is settled. The scientific passages in Poe's 1839 story were derived from Thomas Dick's *The Christian Philosopher,* Elijah Burritt's *The Geography of the Heavens,* and John Herschel's *A Treatise on Astronomy,* all available to him in the 1830s. The details about comets are based on the characteristics of Biela's and Lexell's comets.

Then after we completed this work, we discovered that we were not the first! In 1963, Elva Baer Kremenliev at UCLA submitted a Ph.D. thesis, "The Literary Uses of Astronomy in the Writings of Edgar Allan Poe." She used John Herschel's 1834 American edition as a source and connected "The Conversation of Eiros and Charmion" to both Biela's Comet and Lexell's Comet. ✦

***Don Olson** is author of* Celestial Sleuth, *which includes many of his* Sky & Telescope *articles (Springer, 2014) and the forthcoming* Celestial Sleuth: Further Adventures *(Springer, 2017). He teaches physics and astronomy at Texas State University, where **Shaun Ford** is a graduate student in English and Philosophy.* *The authors are grateful for research assistance from Margaret Vaverek at Texas State University's Alkek Library.*

Eudosia & Neander

Our search of popular astronomy books available to Poe turned up one more worth mentioning: James Ferguson's *An Easy Introduction to Astronomy for Young Gentlemen and Ladies,* published in Philadelphia in 1819. It takes the form of a dialogue between a brother and sister named Neander and Eudosia, and their thoughtful conversation includes the following reassurance about the danger of comets:

> *Eudosia:* But, as we were talking about the comets, pray, are they not dangerous? We are always frightened when we hear of their appearing, lest their fiery trains should burn the world.
>
> *Neander:* That is owing to People's not knowing better. . . . And, as to those appearances, which are called the tails of the comets, they are only thin vapours, which arise from the comets, and which could not hurt any planet, if it should happen to go through that vapour when the comet is crossing the plane in which the planet's orbit lies. . . .
>
> *Eudosia:* This is comfortable doctrine, indeed.

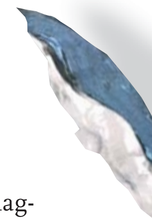
Poe's format for the dialogue of Eiros and Charmion, and its remarks on academics who claimed that comets are too tenuous to be harmful, may have been in part inspired by Ferguson's book for young readers.

It appeared when Poe was ten. During the next few years, while being educated under his stepfather John Allan, Poe studied the heavens with a telescope (likely the one pictured on the facing page). Did he possess this book to go with it?

Charon & Company

Pluto's five moons proved to be more complicated than the New Horizons team ever imagined.

J. KELLY BEATTY



THIRD IN A SERIES

Sky & Telescope's October issue (p. 14) details New Horizons' results about Pluto's surface, and November's issue (p. 18) explores Pluto's atmosphere and its solar-wind interactions. This final article examines Charon and its four smaller siblings.

As NASA's New Horizons spacecraft closed in on its prime objective early last year, mission scientists were *expecting* to be surprised by Pluto. Still, no one was prepared for the sculpted-ice wonderland and off-the-charts geologic complexity revealed by New Horizons during its historic flyby on July 14, 2015 (*S&T*: Nov. 2015, p. 18).

But Pluto's moons were a different story. Telescopic study had shown that Charon, by far the largest, is dark-hued and spectroscopically bland (topped with water and ammonia ices only). It seemed likely to prove little different than dozens of other bleak, cratered, outer-planet moons seen at close range over the past few decades. Nonetheless, the New Horizons team planned a full range of observations — even timing the craft's arrival so it could duck briefly into Charon's shadow for a pair of occultations to detect any hint of atmosphere.

This moon's four small siblings, all found with the Hubble Space Telescope, were unresolved blips before the encounter. The two larger of these, Nix and Hydra, had been discovered in mid-2005 by a "Pluto Companion Search Team" led by Harold Weaver (Johns Hopkins Applied Physics Laboratory) and Alan Stern (Southwest Research Institute, or SWRI). The timing of those finds, about a half year before New Horizons left Earth, gave the mission team a chance to tweak the encounter plan and work in some detailed observations of them.

However, the discoveries of tiny Kerberos and Styx came in 2011 and 2012, respectively. With the spacecraft already more than halfway to Pluto, all the team could do was dedicate a small reserve of "Unknown TBD" imaging slots to the two latecomers — not optimal, but it was at least something.

What the mission's scientists hoped to find, if nothing else, were clues as to why all the orbits and spin axes of everything in the Pluto system are swung way over to one side — much like the situation with Uranus and its family of moons. And how did Pluto end up with Charon, a moon big and massive enough to skew the system's center of gravity into the empty space between them?

A Manufactured Family

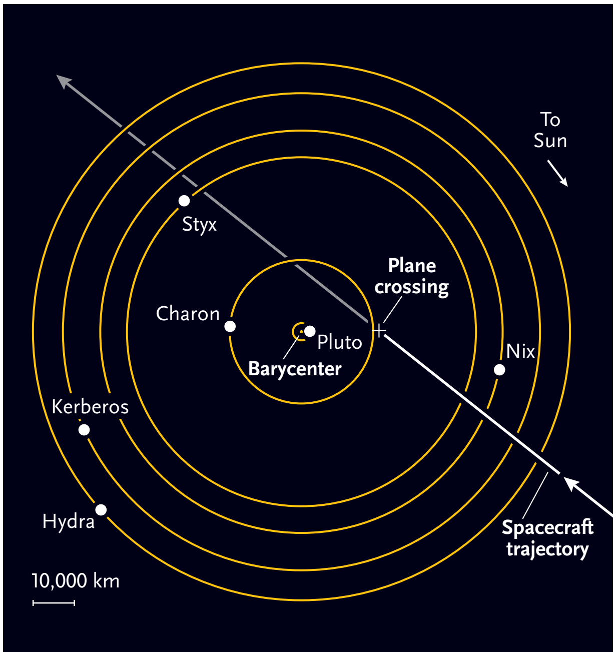
Almost as soon as U.S. Naval Observatory astronomer James Christy discovered Charon in 1978 (delightfully recounted by Govert Schilling in the June 2008 issue), theorists hypothesized that something big had slammed into Pluto eons ago, spurting out enough debris to form Charon and dramatically altering the system's angular momentum and overall geometry.

In 2005, Robin Canup (SWRI) used the computer-simulation techniques she'd developed to explore a giant-impact origin for the Moon to model a similarly cataclysmic Charon-forming impact. The details were different, involving smaller, ice-rich Kuiper Belt bodies that collided at only about 1 km per second (2,000 mph) and generated hardly any melting. But the model's outcome satisfyingly left Pluto with one relatively big, close-in moon in a dramatically reoriented equatorial plane.

Six years later, after the discovery of Nix and Hydra, Canup went back to the digital drawing board and reworked the collision's specs. The key tweak was requiring both Pluto and the impactor to be compositionally layered (*differentiated*), with rocky centers and icy exteriors. This time the computer simulations spit out Pluto and Charon, as before, and enough icy debris to yield a handful of smaller satellites as well.

COLD CLASH Thanks to results from New Horizons, planetary scientists are more convinced than ever that Pluto's precursor collided with a somewhat smaller object early in solar system history. This mashup of ice-encrusted worlds left Pluto spinning on its side and five moons — sizable Charon and four small siblings — orbiting nearby.

ILLUSTRATION BY CASEY REED



TIGHT FIT Pluto's compact system of moons actually orbits the *barycenter* (center of gravity) of the Pluto-Charon pairing. Dynamicists are exploring whether any of the small moons are locked in spin or orbital resonances with each other or with Charon.

S&T: LEAH TISCIONE; SOURCE: SIMON PORTER ET AL.

CLOSE-KNIT FAMILY ***Below:*** **Pluto's four outer moons (especially Styx and Kerberos) have strongly elongated shapes that suggest they assembled from smaller fragments. New Horizons observed only Nix and Hydra well during its July 2015 flyby. The limb of much larger Charon provides a sense of scale.**

New Horizons' hi-and-bye flyby didn't provide lots of opportunities to view Pluto's four small moons closely, but images taken at long range provided enough coverage to establish their sizes, refine their orbits, and clock their rotation rates.

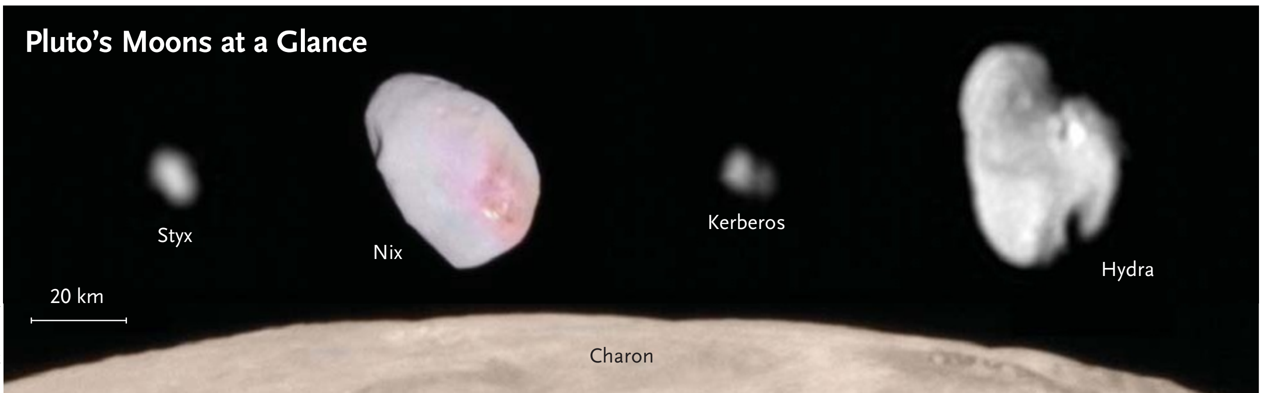
Mark Showalter (SETI Institute), who led the team that discovered Styx and Kerberos, thinks the moons' elongated shapes (see the table below) imply that they're clumps of smaller objects that merged at low speeds. In fact, he imagines that Pluto once had hundreds of small moons that eventually got swept up into Charon and its four smaller siblings.

Thanks to strong tidal interactions with their parent planet, small, close-in moons typically end up forced to orbit with only one face pointing at the planet. That's the norm everywhere else in the solar system. But not so with Pluto's small moons. "Tidal locking isn't what's going on — we knew that," Showalter explains. "But we didn't anticipate what *is* going on."

All four appear to be spinning chaotically, at rates much faster than their orbital periods — in fact, Hydra spins around 89 times during each 38-day-long orbit. Moreover, an analysis led by Simon Porter (SWRI) shows that all four are rolling on their sides, with rotation axes nearly in their orbital planes — though the pole directions have been especially difficult to pin down. Nix has a spin axis that appears to be *precessing* (wobbling) randomly, and the pole for Kerberos might actually point in the direction opposite that of the present estimate. "It's not just chaos but pandemonium," Showalter admits. "We've not seen anything like this before."

Compositionally, the evidence for a big-splat origin

Pluto's Moons at a Glance



NASA / JHU-APL / SWRI

Moon	Year of discovery	Semimajor axis (km)	Orbital period (days)	Rotation period (days)	Rotations per orbit	Diameter (km)	Obliquity (axial tilt)
Charon	1978	19,596	6.387	6.387	1.0	1,212 ± 2	0°
Styx	2012	42,413	20.162	3.24	6.2	14 × 10 × 8	121° ± 30°
Nix	2005	48,690	24.855	1.829	13.6	50 × 31 × 26	108° ± 20°
Kerberos	2011	57,750	32.168	5.31	6.0	18 × 11 × 9	95° ± 10°
Hydra	2005	64,721	38.202	0.430	88.9	56 × 41 × 37	94° ± 30°

seems clear. "All four moons — especially Hydra — have albedos that are very, very high, between 60% to 80%, near that of pure water ice," explains Hal Weaver (Johns Hopkins University Applied Physics Laboratory), who headed the Hubble effort that found Nix and Hydra. That's a nice fit to Canup's giant-impact model, in which the small moons assembled from clumps of icy mantle that rocketed away from the impact zone.

One puzzle, Weaver notes, is how these little moons have managed to stay uncontaminated by the darkening effects of "space weathering" and infalling carbon-rich dust over billions of years. One plausible idea is they exert so little gravitational force that small-scale impacts simply chip away the topmost layers over time, exposing the pristine ice that lies underneath.

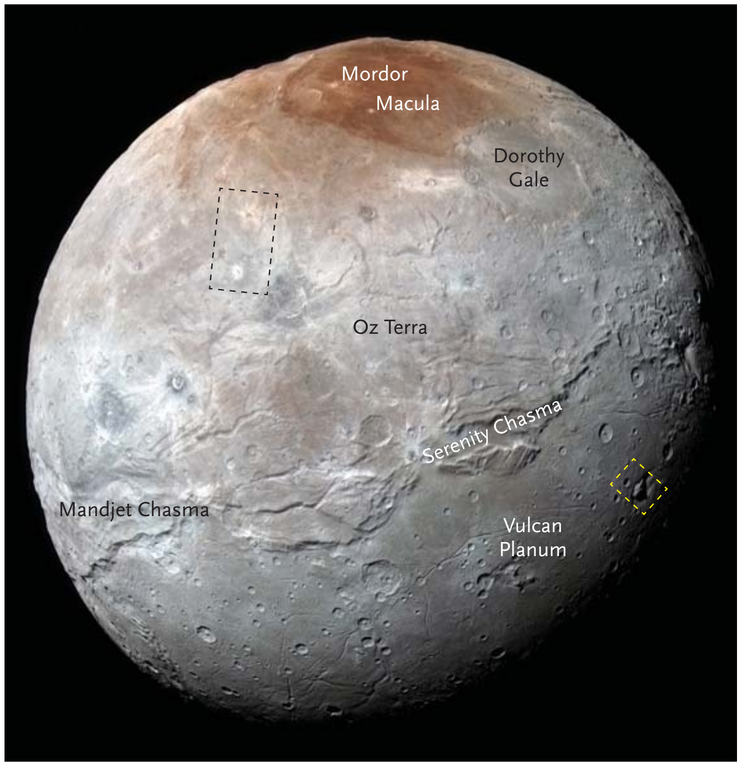
It's worth noting that, in 2012, a trio of dynamicists led by Andrew Youdin (Harvard-Smithsonian Center for Astrophysics) predicted, on purely dynamical grounds, that these four moons would be small and icy rather than big and dark. Their orbits are spaced so closely, the team reasoned, that if they were large, massive bodies, then they would perturb one another's orbital motion noticeably — an effect that isn't happening.

Of the four moonlets, New Horizons only recorded Nix particularly well. It's pocked by more than a dozen impact craters — enough of them, SWRI investigator Kelsi Singer concludes, to imply that its surface is roughly 4 billion years old. This, together with the moons' other shared properties (such as circular orbits in the same plane and similarly bright surfaces), makes a strong case that not only did a giant, system-forming impact create the whole family but also that this cataclysmic event occurred very early in solar-system history.

Charon: Witness to History

Having assumed all along that Pluto's big splat was an ancient event, planetary geologists expected that the icy (but rock-hard) surface of Charon would preserve eons of cratering history — and it does. As was the case with Pluto, the spacecraft saw only one hemisphere of Charon well during its brief visit, and that half displays two broad areas with lots of impact scars. The southern one, informally named Vulcan Planum by the team, appears smoother than the northern one, dubbed Oz Terra. But based on the abundant craters they bear, both appear to be at least 4 billion years old.

Vulcan Planum is relatively smooth with distinct sets of parallel furrows and, here and there, relatively few craters. New Horizons geologists suspect that parts of Charon were "refreshed" soon after its formation. Perhaps the surface was pushed and pulled around by tectonic forces, or maybe torrents of sluggish, nearly frozen brine erupted from its interior in several episodes of *cryovolcanism*. Especially curious are a few isolated, high-standing mountains 3 or 4 km high that are surrounded by depressed "moats" up to 2 km deep.

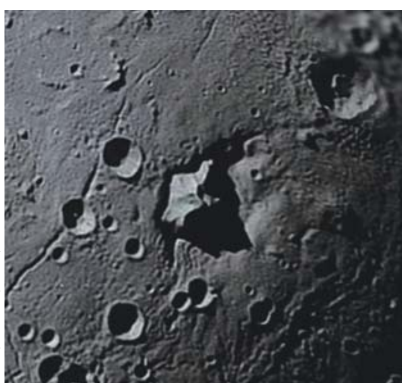


NASA / JHU-APL / SWRI

CHARON'S COMPLEXITY Far from the bland, cratered ice world that many expected, Charon boasts an array of geologic features. Most distinctive are ruddy-hued Mordor Macula at the north pole and, near the equator, rift canyons (*chasma*) created when the water-ice crust of Charon expanded as it froze. Dashed boxes mark locations of close-up images below and on page 40.

What *really* got the team's immediate attention, however, are huge gashes that separate the northern and southern plains. This enormous fracture system girds the moon's midsection for at least 1,600 km (1,000 mi) — four times the Grand Canyon's length and twice as deep in spots — and likely continues onto the "farside" of Charon not seen well during the flyby. The part nicknamed Serenity Chasma can be more than 50 km wide and 5 km deep; Mandjet Chasma, to its west, reaches depths of 7 km.

"It looks like the entire crust of Charon has been split open," observes John Spencer (SWRI) — the kind of



NASA / JHU-APL / SWRI / ROMAN TKACHENKO

MOATED MOUNTAIN Mission scientists don't yet know why some isolated mountains on Charon are surrounded by depressed "moats." This mount, dubbed Kubrick Mons, is about 4 km high.

crustal rending seen on Earth (the East African Rift, for example) and Mars (Valles Marineris). "Every tectonic feature that we see is being opened up and pulled apart," adds Ross Beyer (SETI Institute and NASA Ames).

The most logical explanation is that Charon once had an interior ocean of water that expanded as it slowly froze. The overlying crust would have cracked wide open to accommodate the increased volume. Beyer explains: "If you blow up a balloon, then cover it with papier-mâché, and then pump it up some more, it'll crack."

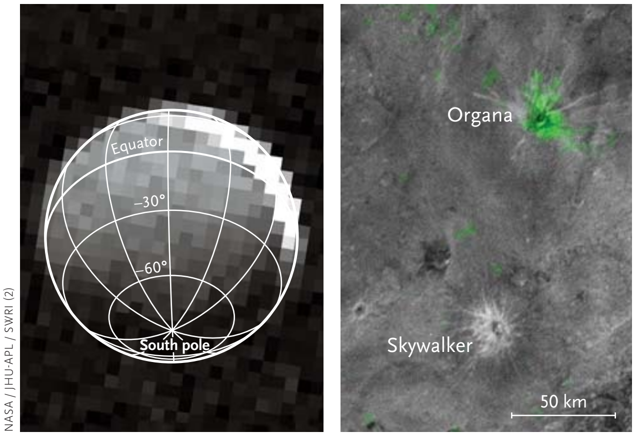
Charon's added girth amounts to a 1% enlargement in surface area (roughly the size of Newfoundland), corresponding to an increase in radius of 3 km. Achieving that, Beyer says, would have required an outer shell of water about 35 km thick to freeze from the top down.

Other mission scientists, meanwhile, have fixated on an enigmatic, red-stained depression at Charon's north pole. Mordor Macula, as it's informally named, has a dark inner zone about 275 km across and a less-dark outer zone, 450 km across, that gradually fades at its margin. Although there are hints of ridges or faults along the outer margin, the reddish coating seems too thin and spread out to have come from inside Charon.

Instead, the team's leading explanation implicates Pluto as the cause. The idea, says Will Grundy (Lowell Observatory), is that some of the methane gas (CH_4) escaping to space from Pluto's upper atmosphere ends up as a thin deposit of frost at Charon's colder-than-cold poles. Over time, ultraviolet sunlight and cosmic radiation convert these simple molecules into much more complicated long-chain hydrocarbons, called *tholins,* that have a characteristically red color.

But that's just at the poles. Overall Charon has the water-ice-dominated composition that researchers expected. There aren't any deposits of nitrogen, methane, or carbon monoxide (like those on Pluto). Charon is too warm on average — a balmy 44 Kelvin (–380°F) — to keep these volatile compounds from sublimating into gas, and its gravity too weak to hang onto them once airborne. In fact, Charon appears to have no atmosphere at all: the upper limit as measured by the spacecraft is no greater than a few picobars of surface pressure (a few trillionths of what we enjoy here on Earth).

In contrast, ammonia (NH_3) is quite stably solid at Charon's temperature and isn't going anywhere, and ground-based observations first spotted ammonia on the moon's surface in 2007. The spacecraft's LEISA spectrometer detected widespread hints of ammonium hydrate ($NH_3 \cdot H_2O$) and a particularly strong concentration of ammonia near a particularly fresh-looking crater nicknamed Organa. It's not clear yet whether a reservoir of ammonia-rich material lies hidden just below Charon's surface, is gurgling up from great depth, or has been arriving from afar aboard impacting bodies.



NASA / JHU-APL / SWRI (2)

MYSTERIOUS CHEMISTRY ***Left:*** **Here's the night side of Charon, weakly bathed in light from Pluto (the sunlit crescent is at upper right). An analysis led by Will Grundy (Lowell Observatory) shows that Charon's south pole also has some kind of darkening — perhaps a reddish coating like that at the north pole.** ***Right:*** **The green area shows an exposure of ammonia ice, as detected by the LEISA spectrometer at 2.2 microns, around a fresh-looking crater informally named Organa. Nearby is a similar crater, dubbed Skywalker, that has bright rays but lacks an ammonia deposit.**

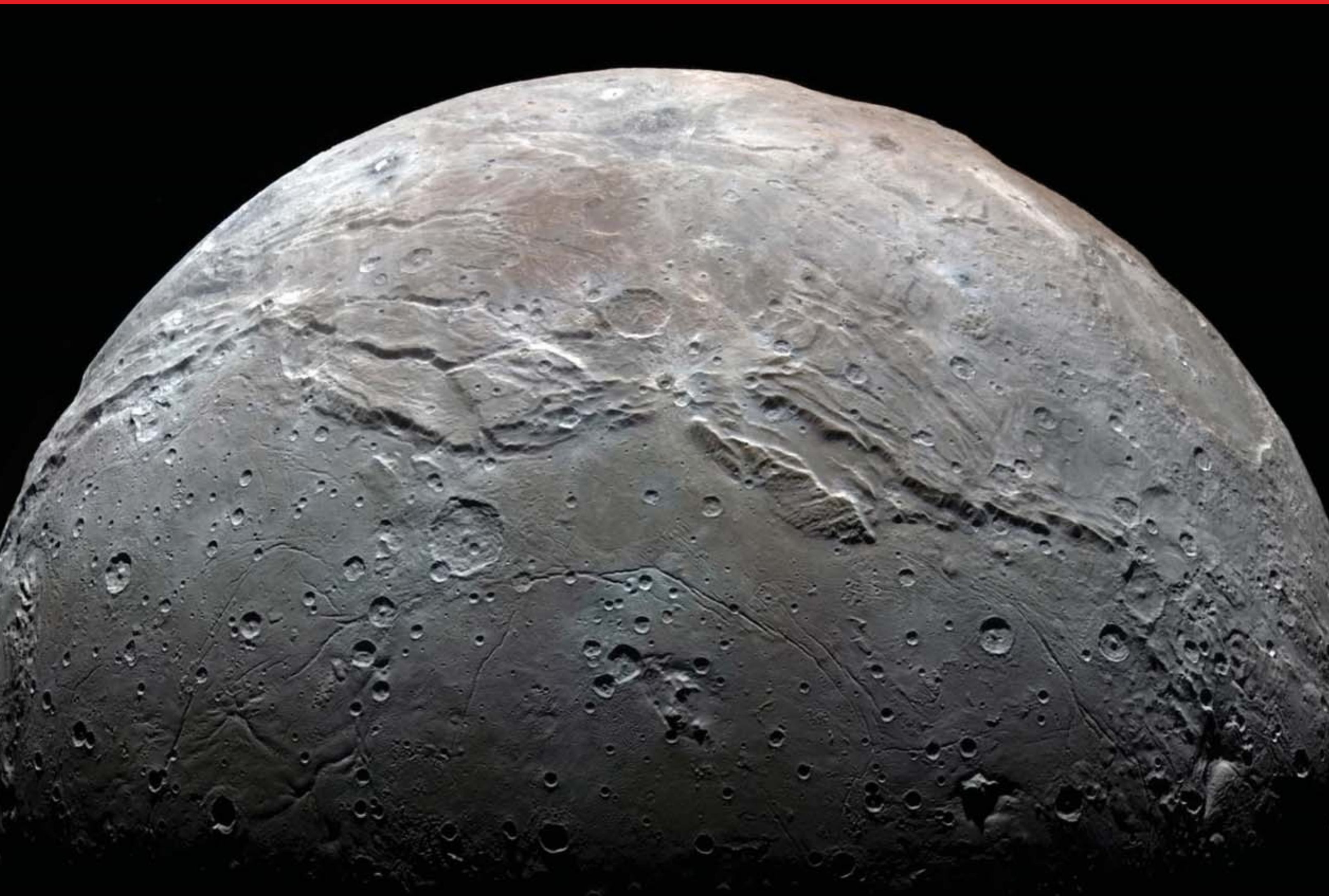
Clues to the Kuiper Belt

Although New Horizons has long since left Pluto's vicinity, the rich scientific results from Charon and its small siblings will pay bonus dividends in future studies of the Kuiper Belt. In particular, the distribution of crater sizes found on Vulcan Planum hints that the billions of bodies floating out there are bigger than thought. Scientists had suspected the Kuiper Belt's basic building blocks were predominantly only about 1 km across, but based on Charon's craters the norm should instead be tens of kilometers in size — more akin to what's found in the asteroid belt. That's also the likely diameter of New Horizons' next target, 2014 MU_{69}, which it'll fly past at close range on January 1, 2019. ✦

Senior Editor ***Kelly Beatty*** *wasn't around when Clyde Tombaugh spotted Pluto in 1930, but he was all over the discoveries of Charon, Nix, Hydra, Kerberos, and Styx.*

Official Feature Names? Not Yet

The feature names used in this article resulted from suggestions and votes made by the public via **ourpluto.org**. Those for Charon, for example, commemorate fictional explorers, their vessels, and their destinations, as well as the authors and artists who envisioned those journeys. But none of them has been approved yet by the International Astronomical Union's Working Group for Planetary System Nomenclature. On August 9th members of the WGPSN finally sat down with key New Horizons scientists — the first in what promises to be an extended series of meetings to hammer out what we'll ultimately call the peaks, valleys, and uniquely quirky features in the Pluto system.



This simulated view of a half-phase of Pluto's moon Charon was generated from images captured by New Horizons' Multispectral Visible Imaging Camera (MVIC).

In This Section

PHOTOGRAPH: NASA / JHU-APL / SWRI / ROMAN TKACHENKO

OBSERVING
Sky at a Glance

DECEMBER 2016

3 **DUSK:** Look for the waxing crescent Moon 7° above or upper left of Venus, the bright "Evening Star" in the southwest.

4 **DUSK:** The Moon shines 5–6° right of the little yellow-orange light of Mars.

12–13 **NIGHT:** The dark limb of the waxing gibbous Moon occults Aldebaran for most of the United States and Canada, as well as westernmost Europe; see page 50.

13–14 **NIGHT:** The strong and reliable Geminid meteor shower peaks on the evening of December 13th in the Americas, and it should be fairly active on the nights before and after, too. However, the full Moon will hide all but the brightest meteors.

18 **MORNING:** Regulus, the brightest star in Leo, sparkles 5–6° lower left of the waning gibbous Moon after midnight December 17–18.

NIGHT: Algol shines at minimum brightness for roughly two hours centered at 10:46 p.m. EST (7:46 p.m. PST); see page 51.

21 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 7:35 p.m. EST.

LONGEST NIGHT OF THE YEAR in the Northern Hemisphere. Winter solstice occurs at 5:44 a.m. EST (2:44 a.m. PST; 10:44 UT).

22 **MORNING:** Rising in the east by about 3 a.m. standard time, the waning crescent Moon, bright Jupiter, and white Spica form a line about 9° long.

Planet Visibility
SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

◀ SUNSET — MIDNIGHT — SUNRISE ▶

Mercury	SW — Visible through December 19
Venus	SW
Mars	S — W
Jupiter	E — S
Saturn	Visible beginning December 27 — SE

Moon Phases

First Qtr December 7 4:03 a.m. EST	Full December 13 7:05 p.m. EST
Last Qtr December 20 8:56 p.m. EST	New December 29 1:53 a.m. EST

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

Using the 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. Above it are the constellations in front of you. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing.

EXACT FOR LATITUDE 40° NORTH.

Galaxy
Double star
Variable star
Open cluster
Diffuse nebula
Globular cluster
Planetary nebula

When

Late October	Midnight*
Early November	10 p.m.
Late November	9 p.m.
Early December	8 p.m.
Late December	7 p.m.

*Daylight-saving time

A Galaxy in the Giraffe

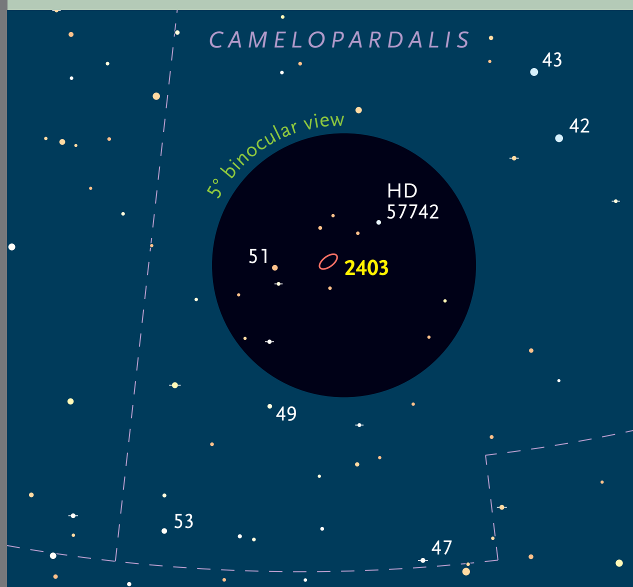
Confession time: I have not paid nearly as much attention to NGC 2403 as I should have. I like binocular observing, and I like galaxies, and I especially like galaxies that are easy to see in binoculars. But I've visited **NGC 2403** (Caldwell 7), a spiral galaxy in Camelopardalis, the Giraffe, only two or three times in my life.

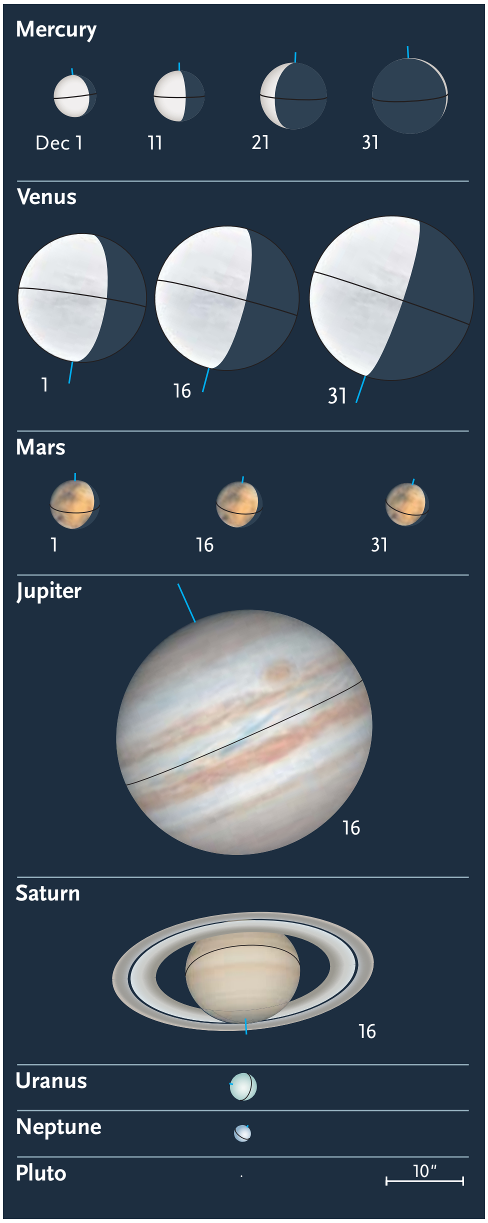
That's just plain crazy. First off, NGC 2403 is bright. Most sources estimate its brightness between magnitude 8.1 and 8.4 — as bright or brighter than any of the Virgo Messier galaxies! And in *Deep-Sky Companions: The Caldwell Objects*, Stephen J. O'Meara records an independent visual estimate of magnitude 7.3, which is getting out of "bright" and into "how are you overlooking this thing?!" territory.

Second, the galaxy is easy to find, just over 7° northwest of Omicron (ο) Ursae Majoris, the bright star that marks the "nose" of the Great Bear. NGC 2403 sits just south of the imaginary line that connects a pair of 6th-magnitude stars, 51 Camelopardalis and HD 57742. The galaxy's brightness may be boosted slightly by a pair of 11th-magnitude foreground stars that sit about 2′ on either side of its core, but you'll need to revisit it with a telescope to tease them out.

So if NGC 2403 is so great, why haven't I spent more time looking at it? Partly it's the galaxy's location in the dim and mostly unremarkable constellation Camelopardalis. Sandwiched between the bright lights of Ursa Major and Perseus, the celestial Giraffe doesn't exactly draw the eye. But mostly it's just bad timing. When NGC 2403 is culminating, so is the winter Milky Way, and I tend to get distracted by the heavenly buffet that runs from Cepheus to Canis Major.

But no more. I'm going to spend more time looking at NGC 2403. You should, too. It's the holiday season — go get yourself a galaxy. ✦





Sun and Planets, December 2016

	December	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$16^h\ 29.2^m$	–21° 48′	—	–26.8	32′ 26″	—	0.986
	31	$18^h\ 41.4^m$	–23° 06′	—	–26.8	32′ 32″	—	0.983
Mercury	1	$17^h\ 47.3^m$	–25° 48′	18° Ev	–0.5	5.5″	83%	1.215
	11	$18^h\ 43.4^m$	–25° 04′	21° Ev	–0.5	6.6″	63%	1.013
	21	$19^h\ 03.7^m$	–22° 37′	15° Ev	+0.8	8.7″	22%	0.773
	31	$18^h\ 18.2^m$	–20° 28′	6° Mo	+4.0	9.9″	3%	0.679
Venus	1	$19^h\ 37.0^m$	–24° 01′	43° Ev	–4.2	16.8″	69%	0.991
	11	$20^h\ 26.3^m$	–21° 35′	45° Ev	–4.3	18.1″	65%	0.921
	21	$21^h\ 12.7^m$	–18° 15′	46° Ev	–4.3	19.6″	61%	0.850
	31	$21^h\ 55.8^m$	–14° 13′	47° Ev	–4.4	21.5″	57%	0.777
Mars	1	$21^h\ 15.3^m$	–17° 25′	67° Ev	+0.6	6.5″	88%	1.438
	16	$21^h\ 59.3^m$	–13° 32′	63° Ev	+0.8	6.1″	89%	1.535
	31	$22^h\ 42.0^m$	–9° 12′	59° Ev	+0.9	5.7″	90%	1.634
Jupiter	1	$13^h\ 03.0^m$	–5° 26′	52° Mo	–1.8	32.9″	99%	6.000
	31	$13^h\ 18.8^m$	–6° 56′	79° Mo	–1.9	35.4″	99%	5.563
Saturn	1	$17^h\ 06.2^m$	–21° 33′	9° Ev	+0.5	15.1″	100%	11.020
	31	$17^h\ 21.3^m$	–21°51′	19° Mo	+0.5	15.1″	100%	10.976
Uranus	16	$1^h\ 16.3^m$	+7° 24′	116° Ev	+5.8	3.6″	100%	19.488
Neptune	16	$22^h\ 44.4^m$	–8° 55′	75° Ev	+7.9	2.3″	100%	30.192
Pluto	16	$19^h\ 09.6^m$	–21° 25′	22° Ev	+14.3	0.1″	100%	34.143

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

Planet disks at left have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

The Sun and planets are positioned for mid-December; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side). "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st, and an hour earlier at month's end.

***Fred Schaaf** welcomes your comments at fschaaf@aol.com.*

Fred Schaaf

Through a High Window

Peer into the awesome majesty of the starry skies.

"The others cast themselves down upon the fragrant grass, but Frodo stood awhile lost in wonder. It seemed to him that he had stepped through a high window that looked on a vanished world. A light was upon it for which his language had no name. All that he saw was shapely, but the shapes seemed at once clear cut, as if they had been first conceived and drawn at the uncovering of his eyes, and ancient as if they had endured for ever. He saw no colour but those he knew, gold and white and blue and green, but they were fresh and poignant, as if he had at that moment first perceived them and made for them names new and wonderful."

— J. R. R. Tolkien, *Fellowship of the Ring*

FAREWELL TO LORIEN BY TED NASMITH

The passage above describes Frodo's experience of first having his eyes uncovered in the enchanted land of Lórien. Frodo stands, lost in wonderment, on a bright, sunny day, and yet this passage reminds me of the enchanted — but real-life — experience of astronomical observing on a starry night.

Stars twinkle to produce a new sight every instant, yet they are "ancient as if they had endured for ever." We don't see new colors in heavenly objects, but they certainly seem fresh-found, glowing in purity in the dark. The innumerable stars, star patterns, and especially features on other planets provide us with the opportunity to create for them "names new and wonderful."

But the most important similarities between Frodo's experience and an astronomer's observations on a dark December night are those of the "high window" on "a vanished world."

A high window on utterly original sights. What is a telescope essentially but a "high window" that opens upon something truly awesome: sights absolutely unavailable on our planet or in any non-astronomical component of our lives? No natural sight on Earth comes close to simulating the view of a crowd of up to hundreds of sparkling lights witnessed in a telescopic observation of open cluster M37 (in Auriga just outside the constellation's pentagon) or M35 (in the northwestern feet of Gemini) or M41 (in Canis Major about 4° south of Sirius). No riverine landscape or desert plateau mimicks the brilliant view of the two perfect, intense, and almost-touching sparks of a double star like Castor or Rigel or — the most challenging — Sirius in a telescope. Nothing we see around us comes close to reproducing the dramatic view of the luminous and colored, multi-star-centered and star-sprinkled fan of M42, the Great Orion Nebula.

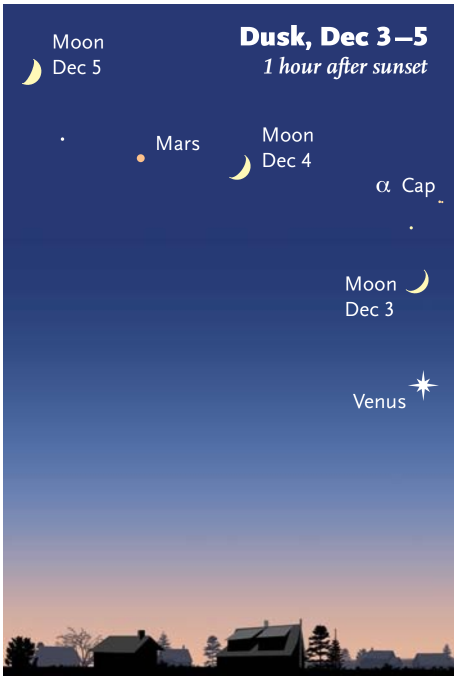
Frodo feels that he's "stepped through" the high window. But isn't that the impression we astronomers often have, especially with the wide, flat fields offered by the modern generation of eyepieces, pioneered by Al Nagler?

A high window on a vanished world. But what about Frodo's idea of a "vanished world" on the other side of the window? In astronomy there are countless worlds vanished in a special but quite literal sense: vanished because what we're seeing is what the stars or galaxies looked like years or even billions of years ago, not what they look like now. Even light, the fastest thing in the universe, takes long periods of time to cross those immense distances.

There's an even more amazing kind of vanishing in astronomical observing. We're the ones so short-lived that we're vanishing. A human lifespan is no longer than one swift glance in comparison to Carl Sagan's "cosmic calendar," the life of the universe compressed into a single calendar year. But when you think of how much joy and wonder that all of us astronomical Frodos can take in during just a quick look through the telescope or at the sky, a glance doesn't seem like a small thing. ✦

Year-End Extravaganza

The final month of 2016 offers views of all five bright planets.



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 December the brightening beacon of Venus really soars, appearing noticeably higher in the southwestern dusk with each passing week. To Venus's lower right, Mercury puts in its own evening appearance for the first three weeks of December, and Mars remains in view well up in the south-southwest at dusk. The separation between Venus and Mars decreases dramatically over the course of the month. Jupiter continues to climb at dawn, reaching its highest in the south before sunrise at year's end. And late in the month, Saturn returns to the dawn view very low in the southeast.

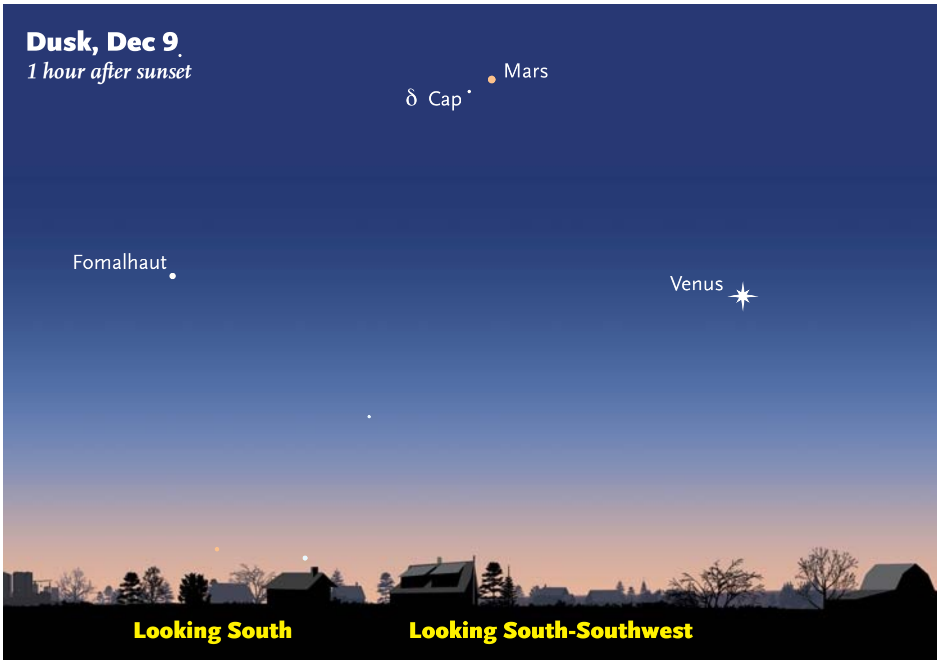
DUSK

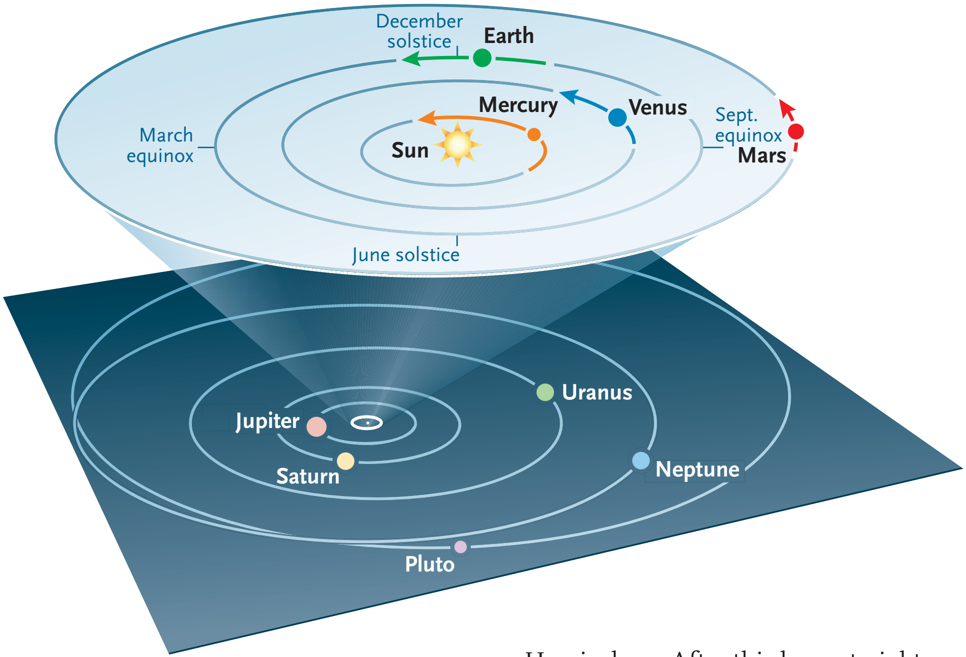
Venus has shone too near the Sun or the horizon for good visibility nearly all year —but that's been changing. The interval between sunset and Venus-set increases from 3 hours to about 3¾ hours in December for viewers around latitude 40° north. Perhaps more notably, the sunset altitude of Venus increases from about 24° to 34°. Look for the "Evening Star" shining bright and obvious in the southwest as December twilight fades.

The blaze of Venus swells from magnitude –4.2 to –4.4 during December, as the planet races from eastern Sagittarius all the way through dim Capricornus. In a telescope, Venus's diameter enlarges from 17″ to 22″ while its gibbous phase thins from about 68% to 56% lit.

Mercury popped into the fading dusk in late November, low in the southwest. It remains there through the first two weeks of December at nearly the same height and brightness (magnitude –0.5). Mercury reaches greatest elongation, 21° east of the Sun, on December 10th.

In the telescope, Mercury's gibbous disk thins to 60% lit by December 14th, when it's 7″ wide. Mercury appears noticeably lower and noticeably fainter





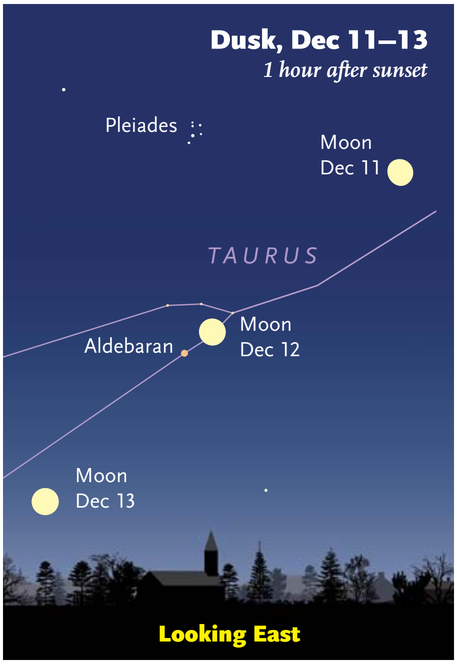
ORBITS OF THE PLANETS
The curved arrows show each planet's movement during December. The outer planets don't change position enough in a month to notice at this scale.

each day (reaching magnitude 0.0 on the 17th) and is lost from view around the 19th. It passes through inferior conjunction with the Sun on December 28th.

Mars dims from magnitude +0.6 to +0.9 in December but still vastly outshines any of the faint stars it passes in eastern Capricornus and southwestern Aquarius. However, fast and fading Mars is being chased by even faster and brightening Venus, which is about 100 times brighter than Mars this month. The two planets shine on either end of the crumpled triangle of Capricornus from December 9–11, with Mars 1½° from 3rd-magnitude Delta (δ) Capricorni at the eastern end of the Sea-Goat.

Mars comes into view not far past the meridian at each nightfall this month, but you'll have trouble making out any detail on it in the telescope now that its disk has shrunk to 6″ wide.

Neptune stands fairly high in Aquarius at nightfall all month. The tiny-looking 8th-magnitude planet is occulted by the dark side of the first-quarter Moon after dark in the northeast United States on December 6th. **Uranus** in Pisces climbs highest late in the evening. See the October issue, page 50, for finder charts for both Neptune and Uranus. **Pluto** is lost in the solar glare in December.



PRE-DAWN AND DAWN

Jupiter, in Virgo, rises around 2:30 a.m. as December begins, 1 a.m. as it ends. Its magnitude improves from –1.8 to –1.9, and its width in the telescope from 31″ to 35″. The Planet King reaches the meridian during dawn by the final days of the month, glowing fairly high in the south as it edges closer and closer to Spica.

Saturn passes through conjunction with the Sun on December 10th, so it's not visible for most of the month. By Christmas morning, however, Saturn rises an hour before the Sun, glowing faintly through the brightening dawn at magnitude +0.5. Look for it lower left of the magnitude +1.0 twinkling of Antares.

SUN AND MOON

The **Sun** reaches the December solstice at 5:44 a.m. EST on the 21st, marking the beginning of winter in the Northern Hemisphere and summer in the Southern Hemisphere. After this longest night of the year, the Sun begins its six-month return northward.

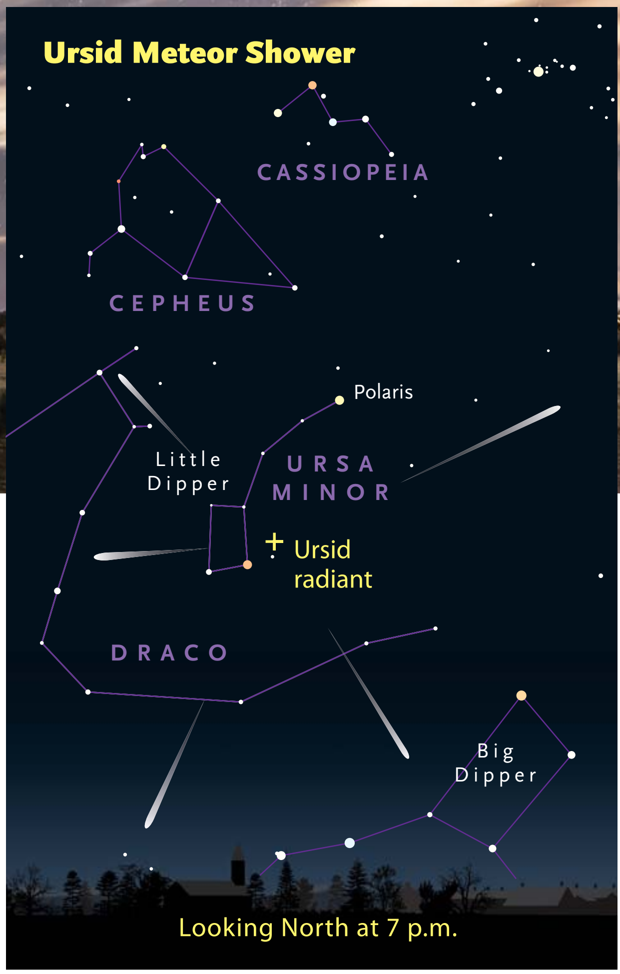
The **Moon** is a slender crescent some 10° above very low Mercury in bright twilight on December 1st. The waxing lunar crescent cuts about 8° to the right of Venus on December 2nd and 7° above Venus on the 3rd. The next day, the thickening crescent hangs about 6° right or lower right of Mars. On the 5th it's 7° to Mars's upper left.

On the night of December 12–13, the night before it's full, the Moon occults Aldebaran for westernmost Europe and all the United States except Alaska (see page 50).

The waning gibbous Moon is 4° lower right of Regulus at dawn on December 18th. The waning lunar crescent stands just a few degrees to the upper right of Jupiter on December 22nd, with 4th-magnitude Theta (θ) Virginis peeking between the two (for viewers in North America). The next morning the Moon forms a fairly compact triangle with Jupiter and Spica. On the morning of December 27th the Moon hangs 4° or 5° above Saturn, low in the southeast, as dawn brightens. On the 28th, the razor-sharp waning crescent will be almost indiscernible in an even brighter sky, well to Saturn's lower left. ✦

The Geminids & the Ursids

The Moon messes with one shower, but another comes a week later.



This year Earth passes through the old reliable Geminid meteor stream right at full Moon; the shower is due to peak on the night of December 13–14. The Geminids are abundant enough that you're likely to see a few of the brightest ones through the moonlit sky, but you'll have to be patient. And the sky will be just too poor for a meaningful meteor count. We often

Above: **Although bright moonlight will wash the sky for the Geminid meteors this year, a few of the brightest always show through — such as this one Alan Dyer caught over New Mexico on December 12, 2014.** ***Right:*** **The Ursids fly in directions away from a spot near the bowl of the Little Dipper. The shower's radiant swings below Polaris from nightfall all through the evening.**

urge readers to do meteor counts for several nights before and after a shower's peak, to obtain a longer record of what the shower is up to — especially because fewer people observe away from the peak. But this year, the last time you'll get even one moonless dark-sky hour is before dawn on December 11th. Then you're mooned out until after nightfall on the 16th (for mid-northern latitudes).

So let's turn some needed attention to December's other significant meteor shower: the Ursa Minorids, which are briefly active three days before Christmas. The Ursids' nominal peak lasts just 12 hours, supposedly how long the shower remains above half maximum strength. This year the peak should come around 9^h UT December 22nd, good timing for North America, especially the West: 4 a.m. EST, 1 a.m. PST.

The shower's radiant is near Kochab at the bowl of the Little Dipper. This spot is circumpolar, just 14° from the north celestial pole, so the Ursids are active all night (and all day too). But the radiant stands highest just before dawn, and this year the waning Moon, one day past third quarter, rises around 1 a.m. local time on the morning of December 22nd. Earlier, you're about equally well off all the way from nightfall on the 21st until moonrise; the radiant changes altitude little during this time. The higher a shower's radiant, the more meteors appear all over the sky.

Don't expect much. The Ursids are typically reported to produce 5 to 15 meteors visible per hour under a very dark sky. The International Meteor Organization (IMO) lists its peak zenithal hourly rate as just 10. And that's under theoretical ideal conditions, which includes the radiant being overhead — and for this shower, that doesn't happen outside the Arctic! For meteor watchers around latitude 40° north, the Ursid radiant remains about 30° high from dusk until 1 a.m., so the rate you see even under very dark-sky conditions will be about half the zenithal hourly rate that's actually occurring.

But surprises happen. Outbursts with ZHRs of up to 50 or 100 or more were observed in 1945, 1986, and 1993. Long-time meteor observer Robert Lundford witnessed the 1993 outburst. "It caught me totally off guard," he wrote. "My data sheet filled with over 100 entries, and I had to scribble some 50 more on the blank side of the sheet." Several lesser enhancements have also been reported over the years, and, says the IMO, "Other events could have been missed easily."

That's because the Ursids are very poorly observed. Maybe it's the cold, maybe it's the Geminids stealing the glory, maybe it's their sparseness, or people being busy just before Christmas. So if you'd like to collect some data that meteor scientists really want — and if an hour lying back in a lawn chair and gazing into the stars appeals you to even if the action is likely to be quiet — go to **www.imo.net/visual** to learn the standardized methods for carrying out a scientific meteor count and reporting it in.

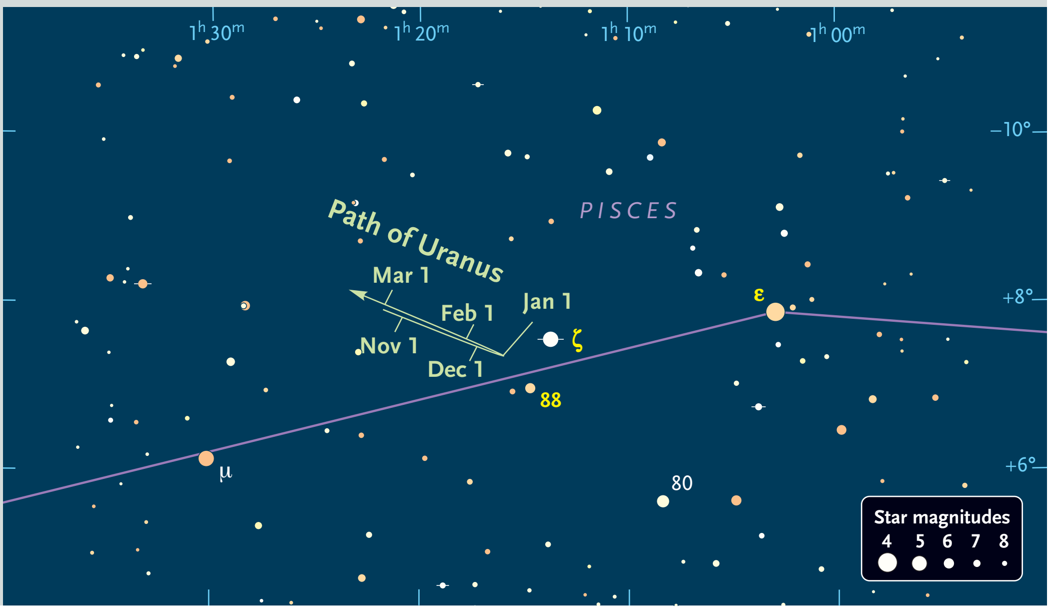
If you're more ambitious you can also record the meteors' magnitudes, or plot their paths on a special star map in case some even lesser shower with a different radiant proves to be active too.

The Ursids originate from Comet 8P/Tuttle, which has an orbital period of 13.6 years. The shower was apparently discovered more than a century ago by the great meteor observer William F. Denning, but coordinated studies of it didn't begin until after the outburst of 1945.

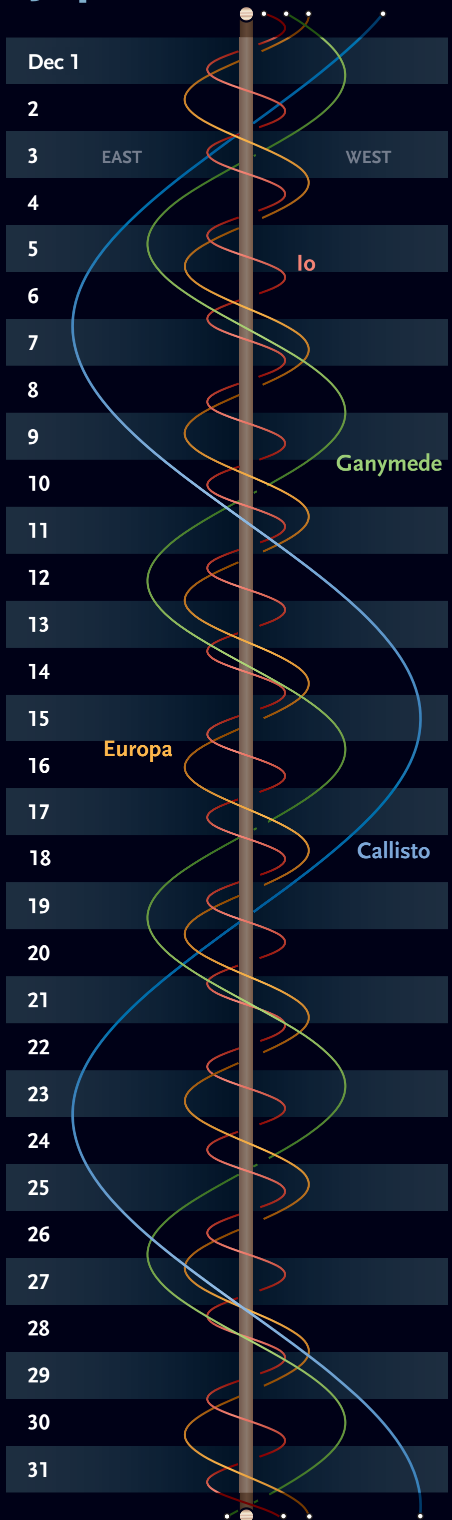
Quick Uranus Spotter: Can You Detect the "Secret Naked-Eye Planet"?

From November through January, Uranus forms a triangle less than 2° long with Zeta (ζ) and 88 Piscium. Uranus is magnitude 5.7 or 5.8, Zeta is 5.2, and 88 is 6.0. Binoculars show the pattern easily — and here's a nice chance to try for Uranus with your unaided eye from a dark site.

This field is in the southern cord of the two Pisces fishes. The brightest two stars of Aries point 18° down to 4.2-magnitude Epsilon (ε) Piscium, crossing Eta along the way.



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.

Jupiter at Dawn

November and December find Jupiter rising in the early-morning hours; it offers the highest and best telescopic viewing as dawn begins to brighten. By mid-November Jupiter is about 20° up in the southeast around that time (for observers at mid-northern latitudes). Then in December it will climb from 30° to 40° high for early observers giving it their scrutiny as the stars begin to fade at the start of the day.

You'll find Jupiter still relatively small. In December it enlarges from 33 to 36 arcseconds wide across its equator.

Any telescope shows Jupiter's four big Galilean moons. Binoculars usually show at least two or three. Identify them at any date and time using the diagram at left (in which north is up, east is left).

All the interactions in December between Jupiter and its satellites or their shadows are tabulated on the facing page. All of them are visible in amateur telescopes. The table is complete worldwide; look for events at times when Jupiter will be well up in a dark sky for your location. Eastern Standard Time is UT minus 5 hours, CST is UT – 6, MST is UT – 7, and PST is UT – 8.

Here are the times, in Universal Time, when Jupiter's Great Red Spot should cross the central meridian: the line down the center of the planet's apparent disk from pole to pole. The dates, also in UT, are in bold.

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

December 1, 7:01, 16:57; **2,** 2:52, 12:48, 22:44; **3,** 8:40, 18:35; **4,** 4:31, 14:27; **5,** 0:23, 10:18, 20:14; **6,** 6:10, 16:06; **7,** 2:01, 11:57, 21:53; **8,** 7:49, 17:44; **9,** 3:40, 13:36, 23:32; **10,** 9:27, 19:23; **11,** 5:19, 15:14; **12,** 1:10, 11:06, 21:02; **13,** 6:57, 16:53; **14,** 2:49, 12:45, 22:40; **15,** 8:36, 18:32; **16,** 4:27, 14:23; **17,** 0:19, 10:15, 20:10; **18,** 6:06, 16:02; **19,** 1:58, 11:53, 21:49; **20,** 7:45, 17:40; **21,** 3:36, 13:32, 23:28; **22,** 9:23, 19:19; **23,** 5:15, 15:10; **24,** 1:06, 11:02, 20:57; **25,** 6:53, 16:49; **26,** 2:45, 12:40, 22:36; **27,** 8:32, 18:27; **28,** 4:23, 14:19; **29,** 0:15, 10:10, 20:06; **30,** 6:02, 15:57; **31,** 1:53, 11:49, 21:44.

These times assume that the spot is centered at System II longitude 253°. It will transit 1⅔ minutes earlier for each degree less than 253°, and 1⅔ minutes later for each degree greater than 253°.

Moon Again Occults Aldebaran

When the Moon crosses Aldebaran during this month's trip around the zodiac, it will be one day short of full — and shining high over North America in the middle of the night of December 12–13. Mark your calendar.

Aldebaran will vanish on the Moon's invisible dark limb just a little beyond the Moon's sunlit celestial-eastern side, the side where the hills and crater walls cast thin shadows. As you stare at the orange firespark in the telescope, don't blink or you may miss its disappearance. Aldebaran will reappear from behind the Moon's bright limb up to an hour or more later. This event will be less easy to observe smack on the Moon's fully sunlit edge.

Some times: at **Halifax,** *disappearance* 12:30 a.m., *reappearance* 1:43 a.m. AST; **New York,** *d.* 11:13 p.m., *r.* 12:27 a.m. EST; **Washington, DC,** *d.* 11:07 p.m., *r.* 12:21 a.m. EST; **Atlanta,** *d.* 10:53 p.m., *r.* 12:00 midnight EST; **Toronto,** *d.* 11:03 p.m., *r.* 12:19 a.m. EST; **Chicago,** *d:* 9:48, *r.* 11:04 p.m. CST; **Kansas City,** *d:* 9:34, *r.* 10:49 p.m. CST; **Austin,** *d:* 9:24, *r.* 10:29 p.m. CST; **Denver,** *d:* 8:22, *r.* 9:33 p.m. MST; **Phoenix,** *d:* 8:05, *r.* 9:14 p.m. MST; **Los Angeles,** *d:* 7:01, *r.* 8:06 p.m. PST;

San Francisco, *d:* 7:06, *r.* 8:05 p.m. PST; **Seattle**, *d:* 7:29, *r.* 8:10 p.m. PST.

The occultation can also be seen from parts of Western Europe before dawn on the 13th. For a map and detailed predictions for more than 1,100 locations, see **https://is.gd/occndec2016**. The page consists of three long tables: for the disappearance, the reappearance, and the locations of the cities. The first two letters designate the country.

Telescope users in south Florida will see a near miss, with Aldebaran skimming just beyond the Moon's south polar regions. The southern limit of the occultation — the graze line — crosses Florida from roughly Port St. Lucie to Port Charlotte. The northern graze line crosses remote parts of Canada.

Asteroid Occultation

Late Monday night December 12–13, telescope users from the Texas Gulf Coast north to Winnipeg can watch for an 8.8-magnitude star in central Cetus to vanish for up to 9 seconds, occulted by the 14th-magnitude asteroid 772 Tanete. The occultation will take place around 1:30 a.m. CST in Texas and 1:32 a.m. CST in Winnipeg. The star will be fairly low in the southwest.

This event is of special interest. Observations of another occultation by Tanete, on April 18, 2004, suggest that it has a small satellite a few hundred miles from the main object. The upcoming event could settle it.

Get details, a map of the predicted path, and finder charts at **https://is.gd/occlt**. Read how to record and time asteroid occultations by video (it's easier than you think) in the September issue, page 48. ✦

Minima of Algol

Nov.	UT	Dec.	UT
3	6:42	1	22:51
6	3:31	4	19:40
9	0:19	7	16:29
11	21:08	10	13:18
14	17:57	13	10:08
17	14:46	16	6:57
20	11:35	19	3:46
23	8:24	22	0:35
26	5:13	24	21:24
29	2:02	27	18:13
		30	15:02

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

Phenomena of Jupiter's Moons, December 2016

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

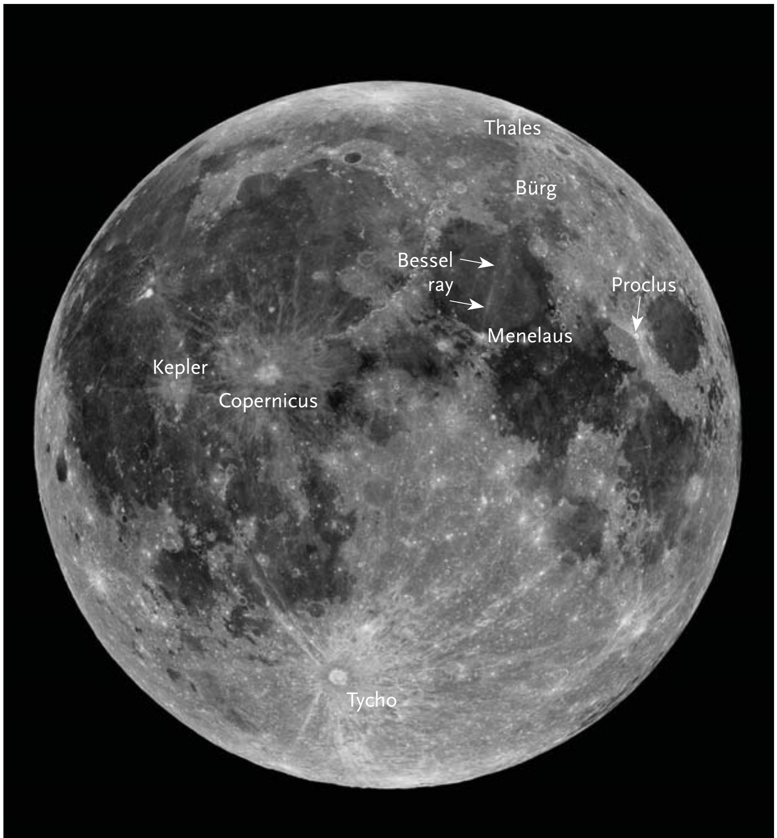
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, 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.

Mystery Ray in Serenitatis

Lunar geologists still can't identify the Bessel ray's source crater.

Splashes of bright rays are among the most conspicuous lunar features. When the Moon is nearly full, the vast ray system from **Tycho** seems to girdle the nearside like the segment boundaries of a peeled orange. **Copernicus** likewise exhibits an extensive ray family, with streamers stretching halfway across Mare Imbrium. A similar but smaller system radiates from **Kepler**.

A characteristic of all these familiar families is that we can readily identify their source craters. But many shorter and fainter rays have ambiguous parentage. Most famous and controversial is the so-called **Bessel ray**, a straight, bright streak in the southern half of Mare Serenitatis that lies tangent to the 16-km-wide crater **Bessel**. The brightest segment of the ray is 150 km long, though less certain extensions likely double this length.



Several craters display impressive sets of ejected rays when the Moon is near full. But the so-called Bessel ray, splashed across Mare Serenitatis, might be from one of several craters, including Thales, Bürg, or Menelaus.

NASA / LUNAR RECONNAISSANCE ORBITER

A little background is in order here. Rays are long trails of debris that get ejected radially during the formation of impact craters. Their brightness can arise from either or both of two mechanisms. First, fragmentation of any lunar rock creates highly reflective rubble that over time will become "space weathered" by radiation to darker tones after about a billion years of exposure to space. (Even craters that formed in dark mare lavas, such as Messier, have bright rays.) The second way is to slam into light-toned highland rocks, which then spray out intrinsically bright ejecta. Some of this includes coherent chunks large enough to create secondary craters.

No matter the cause, you can identify the source crater for a given splash of rays by looking to find a relatively fresh, large crater from which these streaks fan out radially. (Also, spectral studies can determine if the rays contain highland or mare material, which also aids in identifying their source.) The Bessel ray is widely assumed to come from Tycho, about 2,000 km distant, both because the ray points toward Tycho and because it contains highland rock fragments. Situated deep in the lunar highlands, Tycho's impact surely excavated an abundance of bright material.

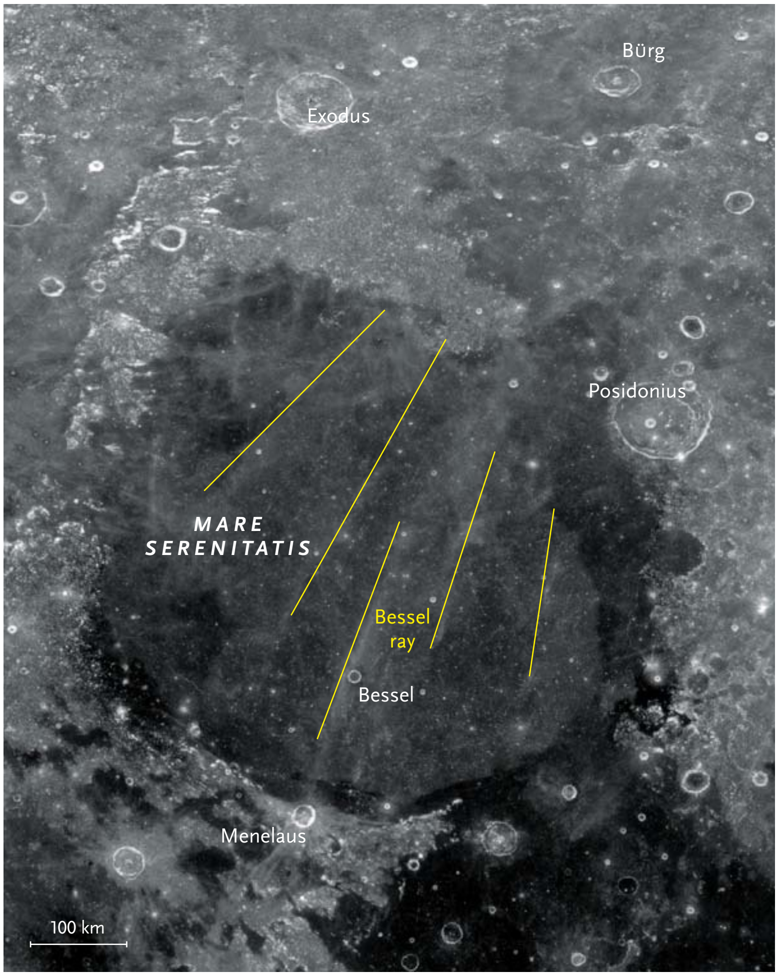
Yet I offer two cautions against concluding that the Tycho origin is definite. Observe during full Moon, and you'll see that most of the continuous Tycho rays, such as the one that reaches Mare Nectaris to its northwest, extend only 1,000 to 1,500 km — well short of Bessel's distance. Additionally, there are other ray craters besides Tycho that formed in the highlands and ejected fragments of bright-toned rocks.

So what other craters could be the source of the Bessel ray? Your first thought might be to pick Bessel itself. But rays typically extend in multiple *radial* directions from their source, not in a straight line alongside it. And Bessel formed in deep Serenitatis lavas, not in highland material. So scratch that idea.

The next nearest possible source crater is **Menelaus**, a young, 27-km-wide crater just 75 km from the middle of the Bessel ray. The projectile that formed Menelaus slammed half into the highland material of the rugged Montes Haemus and half into the adjacent mare.

Menelaus *does* have a strange ray system that fans out about 100 km to the southwest, about the same distance

Lunar researchers have identified a set of five light-hued streaks on Mare Serenitatis, including the Bessel ray, that might have been ejected from Bürg crater to their northeast.



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to the east, and possibly also to the west. A single, faint possible ray segment runs northward, exactly in line with the Bessel ray. But if the entire Bessel ray came from Menelaus, then it would extend about 285 km — much longer than other parts of Menelaus' weak ray system. This seems unlikely.

In 2010, lunar scientists Gwen Bart and Jay Melosh, then at the University of Arizona, proposed that the Bessel ray and four other short ray streaks on Mare Serenitatis all diverge from the crater **Bürg**, about 750 km away in Lacus Mortis. This is a surprising hypothesis, because it's not obvious that Bürg even *has* a ray system. But this 41-km-wide crater sits amid a halo of spectrally immature soils, ones that have not yet been space-weathered sufficiently to darken. No rays can be traced in any direction other than the putative distant ones in Serenitatis. Additionally, the Bürg impactor slammed into the mare lavas of Lacus Mortis, and I don't know if it dug deeply enough to excavate highland materials.

A final possible source for the Bessel ray is **Thales**. With a diameter of 31 km, this young, rarely noticed ray crater sits amid bright, jumbled highlands and basin ejecta at 50° north, near Humboldtianum basin. Thales formed from a strongly oblique impact that left a broad "zone of avoidance" (lacking rays) to the north, with bright rays streaming out in other directions; in this sense it's a larger version of **Proclus**. One of Thales' bright rays extends 750 km, passing east and south of Bürg. Perhaps you can convince yourself that it aligns with the Bessel ray.

If you're keeping score, I've listed five possible source craters for the Bessel ray. Bessel itself is least likely, and I'd also rank Menelaus as low probability. If the five short bright lines in Serenitatis are indeed all rays, their convergence on Bürg is hard to refute. But Bürg has no other conspicuous rays. Both Tycho and Thales do have major ray systems, and both were blasted into bright-toned highland rocks. But the Bessel ray is a geometric long shot for both of them.

The early 20th-century German selenographer Philipp Fauth wrote, "The crowns of rays spread out over the face of the full moon, and seem to mock at all explanation." Despite more than 100 years of astronomical progress since Fauth made this observation, we still have an incomplete understanding of rays. Perhaps the recent series of advanced lunar orbiters has collected data that can resolve the Bessel ray mystery. I, for one, am tired of not knowing the answer. ✦

The Moon • December 2016

Phases

FIRST QUARTER
December 7, 9:03 UT

FULL MOON
December 14, 0:05 UT

LAST QUARTER
December 21, 1:56 UT

NEW MOON
December 29, 6:53 UT

NASA / LRO

For key dates, yellow dots indicate which part of the Moon's limb is tipped the most toward Earth by libration under favorable illumination.

Distances

Perigee 358,461 km	**December 12, 23h UT** diameter: 33′ 20″
Apogee 405,870 km	**December 25, 6h UT** diameter: 29′ 26″

Favorable Librations

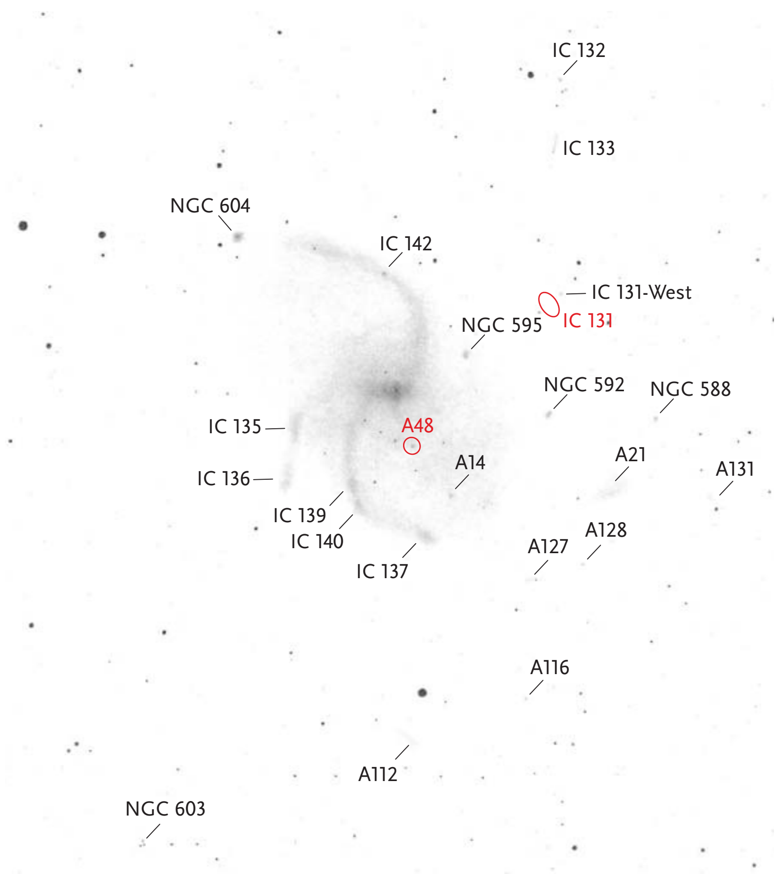
Mouchez (crater)	**December 11**
Byrd (crater)	**December 15**
Bailly (crater)	**December 24**

M33 in a 10-inch Scope

Take an extended look at one of our close galactic neighbors.

In a constellation full of galaxies, Messier 33 is called the Triangulum Galaxy, as though it were the only one there. **M33** was certainly the first galaxy discovered in Triangulum, and in many ways it's the most impressive.

One of the things that makes M33 appear so dim also helps make it exceptionally fascinating — we see it nearly face-on. If we look at spiral galaxies that are similar to each other and the same distance away from us, those we see face-on have their light spread over a larger area of the sky than those we see edge-on, thus they appear more ghostly. On the other hand, face-on galaxies offer us an unfettered view of their internal structure. The viewing angle, combined with M33's neighborly distance of only 2.9 million light-years, offers us a remarkable opportunity to pick out numerous features inside the galaxy with a modest backyard telescope.



The author's sketch above shows the objects — star clouds, H II regions, and nebulae — she observed with her 10-inch reflector over the course of several nights. Red labels mark the features she was unable to distinguish in the eyepiece.

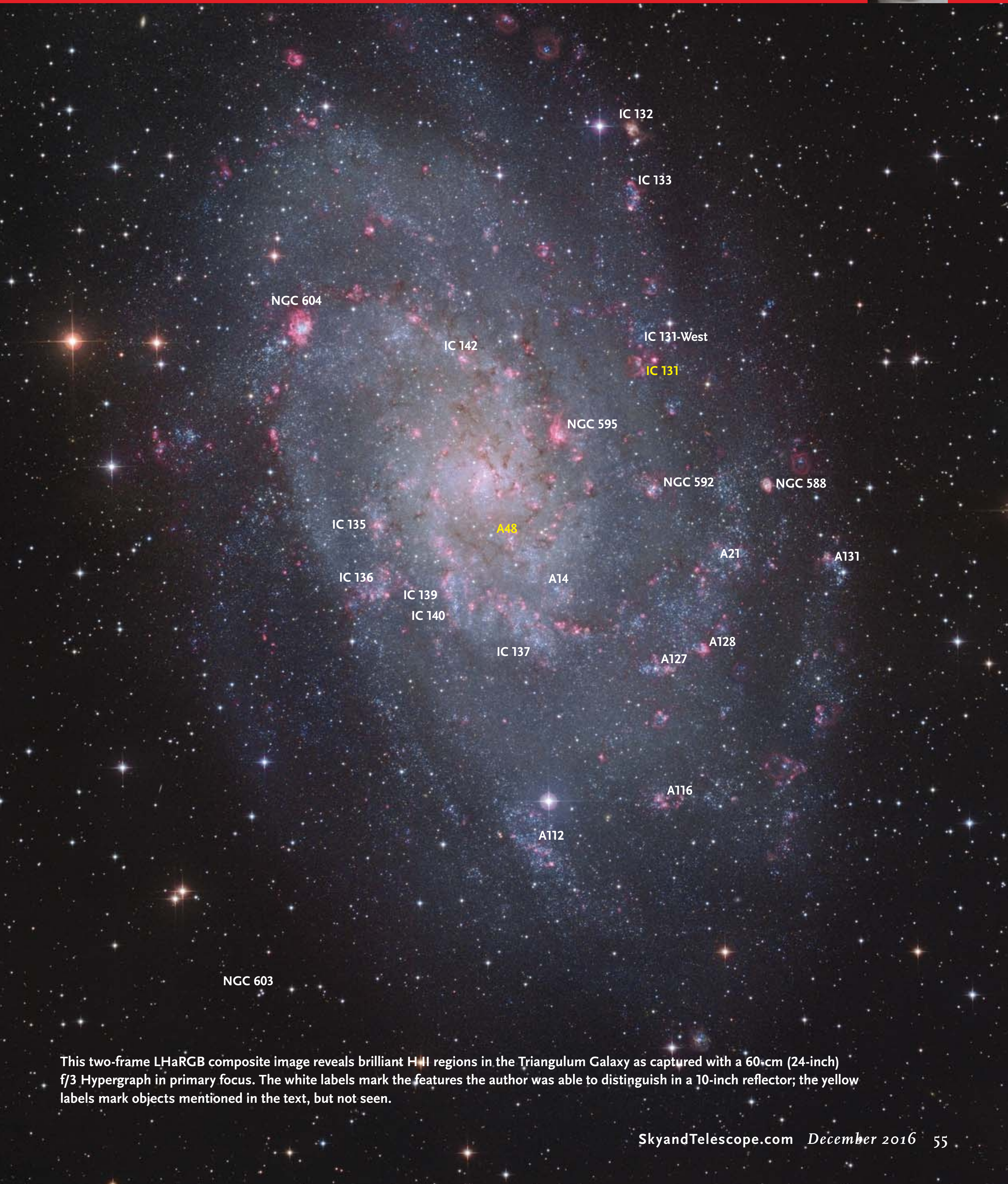
My first foray among the star clouds and nebulae of M33 was made 13 years ago with my 14.5-inch scope, but I was curious about how many of these extragalactic wonders might reveal themselves to my 10-inch reflector. With that in mind, I decided to undertake a sketching project that ended up covering the moonless hours of several clear nights. I was amazed at the results.

No one ever accused me of being an artist, but I was pleased when the sketch was done. However, the sketch was far too subtle to show up on the printed page, so I had to darken it and increase the contrast to create a serviceable guide for locating and recognizing the objects within. I used a magnification of 88× to draw the most obvious parts of the galaxy's face and the brightest stars, while details were later teased out at powers of 187×, 213×, and 299×. On a night of exceptional transparency, an astonishing number of stars were visible on and around the galaxy. It would have taken a large chunk of valuable observing time to place them all, so I settled for adding those that could help pinpoint the objects.

The first thing you should try for is **NGC 604**, a region of ongoing star formation whose brightest suns energize a giant cloud of glowing hydrogen, known as an H II region. NGC 604 ranks among the largest and most massive H II/star-forming regions (H II/SFRs) known and is roughly 60 times the diameter of the Orion Nebula. NGC 604 looks lumpy through the 10-inch scope and displays two axes, one running southeast-northwest and a shorter one jutting out from it to the east-northeast. The galaxy's northern spiral arm winds out toward NGC 604, becoming quite tenuous before meeting it.

IC 142 is a smaller knot visible farther inward along that same spiral arm. The shortest side of the skinny triangle of stars just north of the spiral arm points more or less toward IC 142 and serves as a handy guide. This is another H II/SFR, as are the rest of the objects we'll encounter unless otherwise noted. While some observers find that applying a narrowband nebula filter helps NGC 604 show a bit better, a filter is unlikely to significantly benefit the view through a 10-inch scope when it comes to IC 142 and M33's other H II/SFRs. Here we see mostly their stellar populations.

JOSEF PÖPSEL / STEFAN HEUTZ / STEFAN BINNEWIES

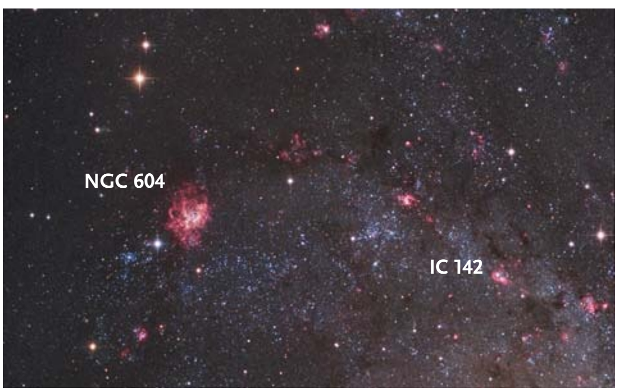


This two-frame LHaRGB composite image reveals brilliant H II regions in the Triangulum Galaxy as captured with a 60-cm (24-inch) f/3 Hypergraph in primary focus. The white labels mark the features the author was able to distinguish in a 10-inch reflector; the yellow labels mark objects mentioned in the text, but not seen.

Although you'll find brighter targets ahead, let's first call on a few of the dim ones that are conveniently located near distinctive stars. Beyond the visible body of the galaxy, a 9th-magnitude star hovers 18′ north-northwest of M33's center. It's the brightest star in the area. On my sketch you'll notice a tight pair of 13th-magnitude stars to its west-southwest. **IC 132** is a very faint spot perched north of the pair. When I looked at the double star, inadvertently invoking averted vision, I saw **IC 133** to the south as a long, very faint strand of haze. I drew what I took for an extremely faint foreground star at its southern tip, but deep-sky images reveal two tiny blobs here. Studies indicate that they're associated with M33. One may be a compact star cluster, and the other an emission nebula.

About 6′ south-southwest of IC 133 we come to an 11th-magnitude star, the brightest in the area. **IC 131** rests 2.7′ southeast, but I couldn't see it. With averted vision, however, a tiny spot appeared west-northwest of its position. This spot is a compact H II region often equated with IC 131. According to NGC/IC researcher Harold Corwin, this can't be the object Guillaume Bigourdan discovered: "Bigourdan's measurements clearly point at IC 131's star clouds, his description fits them, and he specifically mentions the compact H II region calling it a 13.5 magnitude star." Indeed there's an amazing tangle of nomenclature surrounding this tiny smudge. One designation that assuredly belongs to it is **IC 131-West**, even though the name springs from the murky waters of historical misunderstanding.

Now we come to three of M33's brightest H II/SFRs, **NGC 595**, **NGC 592**, and **NGC 588**. Once located, each can be seen with direct vision on a nice night, but I find NGC 595 a little more difficult to spot against the galaxy's glow. To help pinpoint NGC 595's position, try visualizing the long, isosceles triangle it makes with the two relatively bright, sketched stars to its west-northwest.



JOSEF PÖPSEL / STEFAN HEUTZ / STEFAN BINNEWIES

The glowing knots of NGC 604 and IC 142 in M33's northern arm signal the presence of hydrogen ionized by star formation.

West-southwest of NGC 588 you'll find a distinctive pentagon of stars. On the best of my nights with M33, **A131** was visible with averted vision as a smudge reaching northeast from the pentagon's brightest star. The "A" in the designation indicates that a stellar association lives here, but such star clouds generally include H II regions as well. To A131's east, **A21** is faintly visible, looking like an extension of M33's dominant southern arm and punctuated by a fairly dim star off its east-southeastern end.

Farther south, **A128** emerges with averted vision as a small, very elusive spot of haze. Gently tapping the scope helps. An easily visible star marks the position of **A127**. The glow east of this star requires averted vision, but can be reliably seen after first locating it, and there may be a touch of haze west of the star. The right triangle of stars west-southwest of A128 and A127 helps sort out their positions, and keeping the bright star south of the galaxy out of the field makes them easier to spot. Closer to the star, **A116** is tiny and very tough to see, while **A112** is an extended band of mist with very low surface brightness.

Easier to detect are the large star clouds that embellish the southern spiral arms. The dominant arm contains **IC 137**, which appears sizeable and patchy, with low surface brightness. Farther inward along the arm, **IC 140** and **IC 139** form its brightest stretch. East of the dominant arm, a more subdued one is softly enhanced by **IC 136** and **IC 135**.

On my first night I sketched an arc of stars south of M33's core. Since the fourth one to the right corresponds to the position of **A48**, I assumed that was it. But you know what they say about assumptions. A little research indicates that there's a star superimposed on A48 (Pul-3 120174 with a blue magnitude of 13.3), so that must be what I observed. **A14** sits only 3.4′ southwest of this star, but I didn't pursue it until two observing nights later. This small star cloud harbors almost no nebulosity, and it's not difficult to see with averted vision.

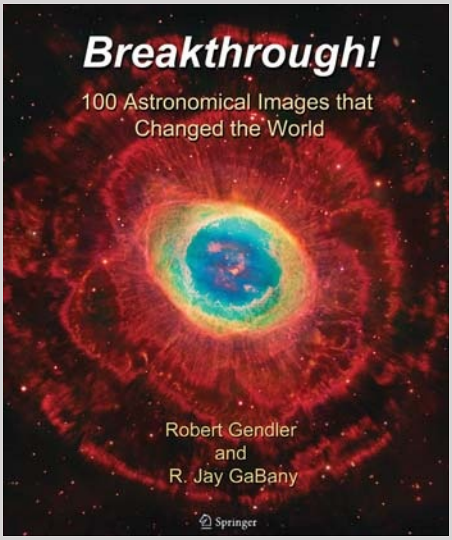
This leaves us with one final target, well divorced from the visible galaxy. Bindon Stoney, working under Lord Rosse, discovered **NGC 603** in 1850. He described it as a "small nebula or cluster with three stars in it." In reality, there are three stars here, but no nebula or cluster. Use the meandering starfall east of M33 to lead you to NGC 603. At 187× it looks small and fuzzy with possible star spots, while at 299× it precipitates into a tiny right triangle of extremely faint stars. It's easy to imagine that unfavorable conditions might conspire to make such a tight little grouping of stars appear nebulous.

It was a lot of fun tracking down the denizens of M33, and I aspire to collect a few more this observing season. I very much hope you'll enjoy the hunt, too. ✦

Book Review
Mario Motta

Evolution of Astroimaging

Breakthrough! 100 Astronomical Images That Changed the World



Robert Gendler and R. Jay GaBany
Springer, 2015
171 pages, ISBN 978-3-319-20973-9,
$34.99, hardcover; $24.99 eBook.

As an astrophotographer who grew up in the days of hypered Kodak 2415 technical pan film and hand guiding, lived through the development of charged-couple devices, and revels in today's fantastic images from advanced astrophotographers and satellites, I thoroughly enjoyed *Breakthrough! 100 Astronomical Images That Changed the World*. Like Galileo's first revolutionary description of the view through a telescope, the coupling of a camera to a telescope led to a dramatic revolution of understanding. The common theme in both events is that each has changed our perception of the universe in some way.

Breakthrough! is a marvelous history of imaging. Gendler and GaBany, who are well-known advanced astroimagers, start with the earliest forays into daguerreotypes and then detail the development of astrophotography over the past 175 years, all the way up to today's advanced imaging and processing. The authors accomplish this through a series of 100 carefully selected images, starting with the first daguerreotype of the Moon taken in 1840 and ending with today's deepest images of the universe taken by the Hubble Space Telescope. The images are accompanied by well-written descriptions highlighting the importance and significance of each photograph. Along the way, the history of imaging naturally unfolds, as does an evolving interpretation of the universe made possible with each new image.

The authors describe the images not only in terms of the evocative beauty presented, but also to explain either a new, deeper insight into science revealed by the image or an advance in the techniques of imaging and processing. I especially enjoyed the presentation of photographs from the 19th and early 20th century: how they were obtained and how they changed humanity's perception of its place in the universe. Each image has changed our conception of the universe in some way over the last 175 years. Readers will recognize many of the newer images that were unveiled with some fanfare during the last 30 years as newsworthy items that changed our appreciation of the universe. It's wonderful to have these spectacular images collected in one volume.

In keeping with the old adage that one picture is worth a thousand words, this marvelous collection of images, supported with excellent descriptions, offers a concise history of the art and science of astronomy, recording the greatest milestones in the history of modern astronomy. I thoroughly recommend this book, particularly as it was written by a pair of very accomplished astroimagers, both of whom have advanced the field not only with their own photography, but with innovative processing techniques that have enhanced even images from the Hubble Space Telescope and other professional observatories. This is a volume worth keeping as a reference source for many years to come. ✦

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*Amateur astronomer and cardiologist **Mario Motta** observes with his 32-inch f/6 relay telescope from Gloucester, MA. He is a board member of the International Dark-Sky Association (IDA) and has been active in light pollution control issues since 1990 when he co-founded the New England Light Pollution Advisory Group (NELPAG).*

 Tony Flanders

Meade's LightBridge Mini Series


ALL PHOTOS BY S&T: SEAN WALKER

The author finds Papa Scope very comfortable to use when it's placed on a chair. Solid chairs are much easier to find than sturdy, portable tables.

Meade LightBridge Mini Specifications

	Mini 82	Mini 114	Mini 130
Aperture	82 mm	114 mm	130 mm
Focal length	300 mm	450 mm	650 mm
Focal ratio	f/3.7	f/4.0	f/5.0
Weight	3.8 lb (1.7 kg)	10.8 lb (4.9 kg)	13.6 lb (6.2 kg)
Low mag.	12×	17×	25×
Medium mag.	33×	50×	72×
High mag.	67×	—	—

Small, light, and easy to use, these scopes provide great value for their very low cost.

TABLETOP TELESCOPES have become very popular in recent years, and it's easy to see why. Lightweight, compact, inexpensive, and easy to use — what's not to like? The most recent entry in this field is the LightBridge Mini series, a family of three Newtonian reflectors from Meade Instruments with apertures of 82, 114, and 130 mm.

The word "family" is particularly appropriate in this case, because when you see all three lined up on a table, it's hard not to think of them as Papa Scope, Mama Scope, and Baby Scope. I will refer to them by those names, which seem more distinctive than Mini 130, Mini 114, and Mini 82.

At first glance, they seem identical except for size, but differences emerge on closer inspection. Papa and Mama have identical mounts, which attach to the optical tubes using dovetail joints. That allows you to rebalance the scopes if you use heavy eyepieces. Baby's mount is much smaller, more lightly built, and attaches to the tube directly. That also is appropriate. Baby's moment arm is so short that even a heavy eyepiece exerts little torque, and few people will want to use heavy, costly eyepieces with a $59 telescope.

All the scopes use identical red-dot finders, and they all have very similar rack-and-pinion focusers. The finders and focusers are simple and effective, though far from the highest quality available.

The telescopes arrive fully assembled in their boxes, except that the red-dot finders need to be attached. This is a very welcome feature to beginners, who can use the scopes within minutes after unpacking them. The only potential stumbling block is the need to align the finders with the main optics.

Mama Scope arrived in perfect collimation, but Papa's collimation needed to be corrected before it could deliver good high-power images. Both Mama and Papa have

When seen side by side, the LightBridge Mini 82, 114, and 130 look like Baby Scope, Mama Scope, and Papa Scope, respectively.

LightBridge Mini 82

U.S. price: $59

WHAT WE LIKE:

Extremely small and light

Very easy to use

WHAT WE DON'T LIKE:

Low-quality eyepieces and Barlow

Poor high-power performance

LightBridge Mini 114

U.S. price: $149

WHAT WE LIKE:

Very light for aperture

Very good at low and medium powers

WHAT WE DON'T LIKE:

Mount slightly stiff

Hard to focus at high power

LightBridge Mini 130

U.S. price: $199

WHAT WE LIKE:

Very light for aperture

Good views at low and high power

WHAT WE DON'T LIKE:

Mount slightly stiff

Mount slightly shaky at high power

conventional mirror cells with three large knurled collimation knobs and three narrower but longer locking knobs. Both have center-spotted mirrors, making them very easy to collimate if you purchase or build an appropriate collimation device. (See **skyandtelescope.com/astronomy-resources/collimation-tools/**.) But the instructions in the manual for collimating a telescope without such a device are confusing at best.

Baby's primary mirror is glued directly to the back of the tube, with no provision for collimation. The scope could in theory be collimated by tilting the secondary mirror, but this would be difficult because the primary mirror has no center spot.

Baby Scope

The LightBridge Mini 82 has an 82-mm primary mirror, as its name implies. The mirror is extremely fast (f/3.7) and has a spherical rather than paraboloid surface, which guarantees that it cannot deliver sharp images at high magnifications.

Despite its spherical mirror, Baby provides pretty good low- and medium-power views when used with the MA (modified achromat) eyepieces supplied with Mama and Papa. Unfortunately, although Baby's eyepieces have the same focal lengths as Mama's and Papa's, they are Huygenians, an inexpensive design that works particularly poorly in scopes with short focal ratios. The Huygenians have apparent fields of view of just 30°, compared with 50° for the MAs, and they're only reasonably sharp in the central 10°. Even so, Baby provides acceptable views of large star clusters such as the Pleiades and Beehive, and like any half-decent telescope, it shows a wealth of detail on the Moon.

Although the 26-mm Huygenian has a narrow apparent field of view, its 11.5× magnification is so low that it provides a big 2.6° true field of view. That makes it very easy to locate your target with the red-dot finder. And once located, targets are very easy to track; the simple tabletop mount is amply smooth and sturdy for such a tiny optical tube.

The scope's biggest liability is that it's very hard to coax decent planetary views out of it. The 9-mm Huygenian provides 33×, enough to show that the planets are extended disks rather than simple points of light and to show four moons of Jupiter and one moon of Saturn. But 33× doesn't quite show Jupiter's two main belts or separate Saturn's rings cleanly from the disk. For that you need to use the supplied Barlow lens, which shows extreme false color everywhere except in the center of the field of view. The net effect is that you can indeed see Jupiter's main belts and Saturn's rings, but only if you use the 9-mm eyepiece together with the Barlow and make sure to keep the planet in the very center of the field of view.

Mama Scope and Papa Scope have three large collimation screws and three locking screws.

Baby Scope attaches directly to the mount at left, but Papa and Mama have dovetail bars that make it easy to detach and/or balance the tubes.

All three scopes include three collimation screws to adjust the secondary mirror position.

Mama Scope

I've spent innumerable happy hours observing the night sky with my Orion 4.5-inch StarBlast, so I was pleased to see that the optical tube of the LightBridge Mini 114 appears to be precisely identical, except for the paint job.

Indeed, Mama has exactly the same strengths and weaknesses as the StarBlast. It's outstanding at low power; the stock 26-mm MA eyepiece gives a vast 3° true field of view at 17×, enough to encompass the entire Veil Nebula or the Andromeda Galaxy with its two main companions. The view is also impeccable with the 9-mm MA at 50×, an excellent magnification for deep-sky observing with this aperture, and ample to show pretty views of Jupiter's main bands and Saturn's rings.

Things get more problematic when you attempt serious planetary observing by adding a 2× Barlow lens or using an eyepiece with very short focal length. The focuser is fine for a 9-mm eyepiece, but it's hard to make the tiny adjustments needed to achieve good focus at 100× or higher. I also had some problems with the mount, which I'll describe later.

Papa Scope

As much as I love Mama's 114-mm f/4.0 optics due to my long experience with the StarBlast, I have to admit that the 130-mm f/5.0 mirror of the LightBridge Mini 130 is clearly superior. You give up a little at the low-power end, achieving "only" a 2° field of view using the 26-mm MA eyepiece for 25×. On the other hand, the low-power view is much sharper near the edge than Mama's because inexpensive eyepieces work far better at f/5 than at f/4. A 24-mm eyepiece with a 68° apparent field of view increases Papa's true field of view to its theoretical maximum of 2.5° — a worthy investment even though it's likely to cost almost as much as the telescope itself.

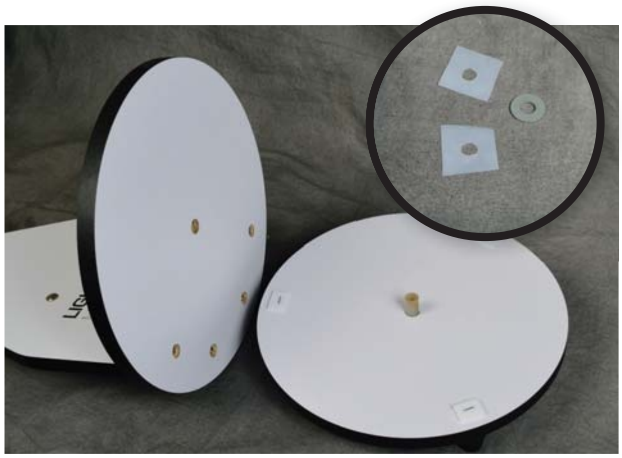
Whatever Papa loses at the low-power end, it more than makes up for at high power. The combination of extra aperture and magnification means that Papa resolves globular star clusters far better using its 9-mm eyepiece at 72× than Mama does at 50×. And when you add a 2× Barlow to achieve 144×, you're in the planetary major leagues. This is enough to show the Cassini Division in Saturn's rings easily when the atmosphere allows, and to show considerable detail on Jupiter and on Mars near opposition. Focusing is a little hard at 144×, but no more so than at 100× using Mama — and the gorgeous views are worth a little hassle.

Mount Issues

The LightBridge Mini series is striking for its unusually small and lightweight mount. For instance, Mama weighs three pounds less than the StarBlast, which is very noticeable when you're carrying the scope in one hand. Unfortunately, the mount is a little underbuilt; it takes about one second for vibrations to damp out when

Baby's Huygenian eyepieces at left look very much like Mama's and Papa's modified achromats, but the modified achromats have much better optical quality.

To improve the azimuth motion, remove the lock washer that holds the turntable to the base.



***Above*: Inspect the Teflon pads on the base. Smooth off any rough spots and countersink any staple that protrudes above the pad. *Inset*: Cut the two "washers" shown here from the sides of a plastic milk jug, sandwich a USS ½-inch washer between them, and stack them on the spindle. (The steel washer has a 9/16-inch inner diameter and 1⅜-inch outer diameter.) When re-assembling the mount, tighten the lock washer and then back it off about ¼ turn to make sure that the turntable rotates smoothly.**

A milk-jug washer next to the altitude locking knob reduces but does not eliminate the knob's tendency to bind. A better fix is to order an inexpensive three-piece thrust ball bearing from McMaster Carr (mcmaster.com).

focusing Papa at high power. That's not a major obstacle, but it's long enough to be mildly annoying.

Although Mama's and Papa's mounts are nominally identical, the ones that I received behave rather differently, due to some subtle variations in construction quality. Papa's azimuth motion was a little jerky until I improved it with a steel washer and two "washers" cut from milk jugs, as described on the previous page.

The altitude motion of the mount supplied with Mama has a more serious defect: the locking knob rotates with the tube when you push the scope upward but tends to stick when you push the scope downward, causing it to loosen over time. I traced the aberrant behavior to the fact that the shaft is slightly loose in its socket. That allows the shaft to tilt due to the telescope's weight and causes the locking knob to bind. This must be a problem endemic to one-arm mounts, because many other tabletop scopes have a ball-bearing race next to the locking knob to ensure that all the friction is on the telescope side and none on the knob side.

If you encounter this problem, you could send the defective mount back to Meade and hope that the replacement mount works better. Alternatively, a three-piece thrust ball bearing for a 7⁄16-inch shaft (part 6655K36 from **mcmaster.com**) eliminates the problem entirely, at a cost of about $10 including shipping. Or you can just live with it. Gentle pressure with your right hand is sufficient to keep the locking knob snug, and it's easy to retighten the knob when needed.

Conclusions

All three of these telescopes provide good value for their extraordinarily low prices, but Baby Scope, the LightBridge Mini 82, has the narrowest niche. Its ease of use, tiny size, and outstanding cuteness make it a fine gift for a novice, especially a child. But anybody who gets hooked on astronomy will soon want a better telescope. Baby's superfast spherical mirror means that it's not really worth upgrading with better eyepieces.

Mama is a wonderful deep-sky scope — simple, lightweight, and highly capable. Even on the planets, its weakest suit, it would be hard to find another scope in its price class that can match its performance.

But if you can afford an extra $50, Papa is better still. It's at least equal to Mama for deep-sky observing and far superior on the planets. It has the same tiny footprint, stands just 2½ feet tall in storage position, and remains as easy to use and almost as light as Mama. Just add a collimation tool, and how can you go wrong? ✦

S&T Contributing Editor ***Tony Flanders*** *is a long-time fan of simple, inexpensive telescopes.*

The Other 130-mm Tabletops

The Meade LightBridge Mini has identical optical specifications to the Astronomers Without Borders OneSky, which we reviewed in the February 2014 and December 2015 issues. It's also very similar to the Zhumell Z130 (available from **telescopes.com**), and all three telescopes sell for very nearly the same price. We hope to compare them in detail in a future issue, but here are the most important points.

The LightBridge Mini 130 is the lightest of the bunch, and has the smallest footprint. Its mount vibrates more than the others, but it's still well within acceptable limits for most people.

The OneSky is almost as light as the Mini 130, and it's extremely compact when the tube is collapsed. It's hampered by its nonstandard helical focuser, and the open tube requires a shroud when used near bright lights. On the plus side, the collapsible tube provides unlimited in-focus for use with cameras and binoviewers.

The Zhumell Z130 is the sturdiest of the three scopes, but it achieves that by being surprisingly heavy and bulky. It's also impossible to collimate without tools.

THE GREAT AMERICAN ECLIPSE

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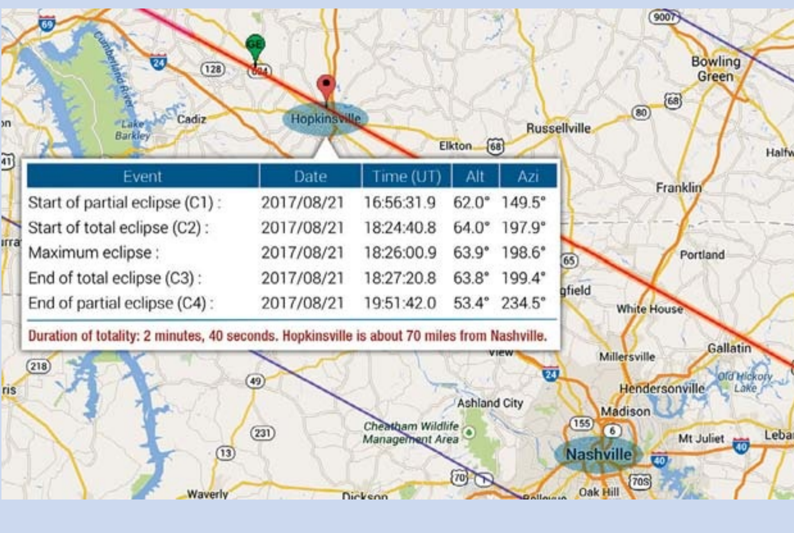
Get more mileage out of your eclipse experience when you combine it with a classic summer vacation. Join *Sky & Telescope* for The Great American Eclipse of August 17–21, 2017. Based amidst the many attractions of Nashville, Tennessee, we plan to view the eclipse near the point of greatest eclipse (see also the green "GE" drop pin below) near Hopkinsville, Kentucky. From the Oregon desert to the Carolina coast, we've scrutinized the data and factors for viewing sites. Clear skies, duration, maneuverability, remoteness, and potential activities are all part of the equation, and Hopkinsville is a terrific all-around location.

Official kickoff is August 17, 2017, in Nashville, Tennessee. In vacation mode, get to know the region's rolling hills and dense woods in an encounter with Stones River National Battlefield, then a relaxing sojourn in Lynchburg including a Jack Daniel's Distillery sampling tour. Absorb the latest in contemporary astronomy in sessions with Drs. Stassun and Weintraub from Vanderbilt University. We'll also spend the morning at Vanderbilt University's Dyer Observatory in science conversation, solar observation, and enjoyment of nature. Check out Nashville's unparallelled music scene. Hopkinsville welcomes you eclipse day, August 21, with good viewing prospects in a site with all the features you need on a hot summer day. Join *Sky & Telescope* for a relaxing and memorable eclipse experience in the Nashville region. Reserve now as this eclipse experience is certain to sell out.



Event	Date	Time (UT)	Alt	Azi
Start of partial eclipse (C1) :	2017/08/21	16:56:31.9	62.0°	149.5°
Start of total eclipse (C2) :	2017/08/21	18:24:40.8	64.0°	197.9°
Maximum eclipse :	2017/08/21	18:26:00.9	63.9°	198.6°
End of total eclipse (C3) :	2017/08/21	18:27:20.8	63.8°	199.4°
End of partial eclipse (C4) :	2017/08/21	19:51:42.0	53.4°	234.5°

Duration of totality: 2 minutes, 40 seconds. Hopkinsville is about 70 miles from Nashville.

SPEAKERS

Dr. Keivan G. Stassun is Professor of Physics and Astronomy at Vanderbilt University. He earned his Ph.D. in Astronomy as a National Science Foundation Graduate Research Fellow at the University of Wisconsin, Madison. He was a postdoctoral research fellow with the NASA Hubble Space Telescope Program before joining the faculty at Vanderbilt. Professor Stassun's research on the birth of stars, eclipsing binary stars, exoplanetary systems, and the Sun has appeared in the prestigious research journal *Nature,* has been featured on NPR's *Earth & Sky,* and has been published in more than 100 peer-reviewed journal articles.

Dr. David Weintraub is a Professor of Astronomy at Vanderbilt University, where he also directs programs in the Communication of Science and Technology and in Scientific Computing. He earned his bachelor's degree in Physics and Astronomy at Yale in 1980 and his Ph.D. in Geophysics & Space Physics at UCLA in 1989 before he was appointed to the Vanderbilt Astronomy faculty in 1991. In 2011–2012, he served as Chair of the University Faculty Senate and served previously as Chair of the College of Arts & Science Faculty Council. He is an expert in the study of star and planet formation and is the author of three books for popular audiences, including *Religions and Extraterrestrial Life: How Will We Deal With It?*

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New Product Showcase

◀ **SENSITIVE CMOS** QHYCCD announces the first in its line of back illuminated CMOS cameras, the QHY183C ($949). This compact camera is designed around a 20-megapixel Sony IMX183 color CMOS sensor with 2.4-micron-square pixels in a 5,544 × 3,694 array. The unit features 2-stage thermoelectric cooling producing regulated temperatures down to 40° below ambient. Its USB 3.0 interface downloads up to 15 frames per second at full resolution, and even more when using a smaller region of interest. The camera also features 128 megabytes of built-in DDR memory to buffer image data and avoid dropping frames with slower computers. See the maufacturer's website for additional details.

QHYCCD
qhyccd.com

SMARTPHONE ADAPTER Tele Vue Optics now offers the FoneMate ($95). This universal smartphone adapter permits users to firmly attach and position any smartphone camera to their telescope's eyepiece. Its innovative adjustable clamps allow you to put your phone's camera perfectly centered and as close to the eye lens as possible, reducing vignetting in your photos. The clamps lock in place with a single knurled screw, and the unit works with any Dioptrix-compatible Tele Vue eyepiece.

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TARGETING THE "Tutulemma"

Tutulemma: Blend of Turkish word tutulma (meaning eclipse) and the English word analemma.

ALL PHOTOS PROVIDED BY THE AUTHOR

Tunç Tezel

Here's a unique way to capture the total solar eclipse in 2017.

The total solar eclipse of August 21, 2017, is right around the bend. And while many photographers will target this rare meeting of the Sun and Moon using telescopes and telephoto lenses, I'm planning on shooting a very different kind of composite image of the event — a year-long analemma, with the eclipse adding that special shot to make the final result unique and interesting. Here's how I did it for the first time, back in 2006, and with a little planning, you can do it too.

Genesis of a Tutulemma

The motion of celestial objects has always fascinated me. In the early 1990s I began shooting composite photos of the retrograde motions of the bright planets, mostly Mars and occasionally Jupiter, Saturn, and Venus. These took several weeks to plan and then photograph, but it was well worth the effort. To this day, few other imagers have captured these unique photos that are often only presented as a squiggly line on a map.

This led me to set my sights on the ultimate long-term skyscape photograph: recording the analemma. This is a figure-8 pattern that depicts the Sun's mean motion in the sky, which changes due to Earth's axial tilt and orbital eccentricity, throughout an entire year. Careful calculation is required to successfully capture the analemma; the long duration of the event, combined with some rigid requirements on camera position, exposure times, and the narrow windows when each exposure can be captured, make it a very difficult project (*S&T:* Mar. 2000, p. 135).

In early 2005, I began planning my analemma photograph. To add to the excitement of the project, I planned to include an image of the totally eclipsed Sun, an event which was due to occur in my country on March 29, 2006. Unfortunately, my location in Bursa, Turkey, lay 400 km outside of the path of totality, so I had to come up with a plan to capture the event in my photograph.

A traditional analemma image captures all the images of the Sun on a single piece of film. But to do that, I'd have to set up the camera within the path of totality and fire the shutter every week or so for an entire year. This simply wasn't practical.

ANALEMMA ECLIPSE Eclipse photography is always challenging, but the results are well worth the effort. Author Tunç Tezel describes how he took the first-ever "tutulemma" composite, which includes the total solar eclipse of March 29, 2006.

A total solar eclipse is an uncommon and spectacular event, not something to be missed if possible. I'm not the most patient person, and I didn't want to risk ruining the project halfway through it during the big event. So I decided to build my analemma from a series of photos and assemble a composite of the result. This compromise afforded me the opportunity to use a digital SLR, rather than a film camera. I chose a Canon EOS 300D, which has an APS-C format CMOS detector, producing a significantly smaller field than a full-frame 35-mm camera.

With this smaller field-of-view in mind, I had to purchase a wide-angle lens as well; I settled on a Canon 10-to-22-mm super-wide zoom, which I would use at 10 mm. The lens arrived in early June 2005, and I started testing it (and marking the focus point) by shooting the motion of Venus in the evening sky.

Elevation and Angle

Next came some calculations and construction. The eclipse would not be total from home, but it would be 400 km to the south, around Antalya, Turkey. So first I had to calculate the position of an analemma containing the total eclipsed Sun visible from Antalya, where mid-totality would be at 1:56 p.m. local time (10:56 Universal Time). Then I had to find the time of day when an analemma in Bursa would be positioned at the same angle in the sky as the one in Antalya, and that turned out to be 30 minutes later, at 2:26 p.m. (11:26 UT). This can be done by calculating the hour angle of the Sun at the time of the eclipse, then determining when the Sun has the same hour angle from the location that I planned to shoot my analemma.

With this exact time in mind, I constructed a Styrofoam "nest," attached to a chimney on the rooftop of our apartment block, to seat the camera aimed at the intended part of the sky. When constructing yours, it's a good idea to have access to the camera's viewfinder or LCD screen. I also placed a strip of solar-filter mate-

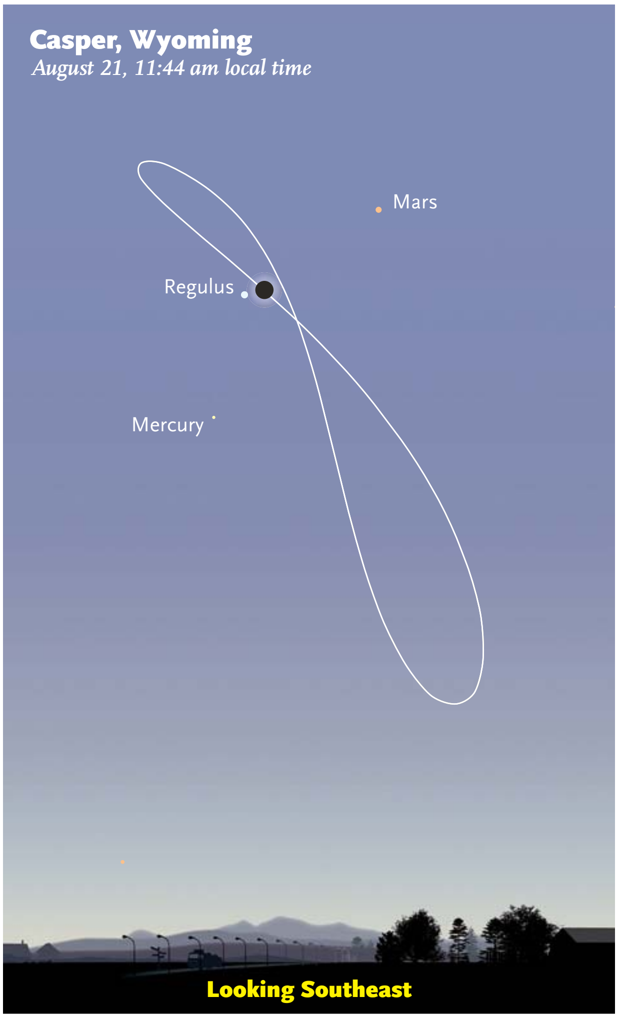
CAMERA STAGING The author fashioned a platform out of insulation foam that allowed him to remove the camera between exposures.

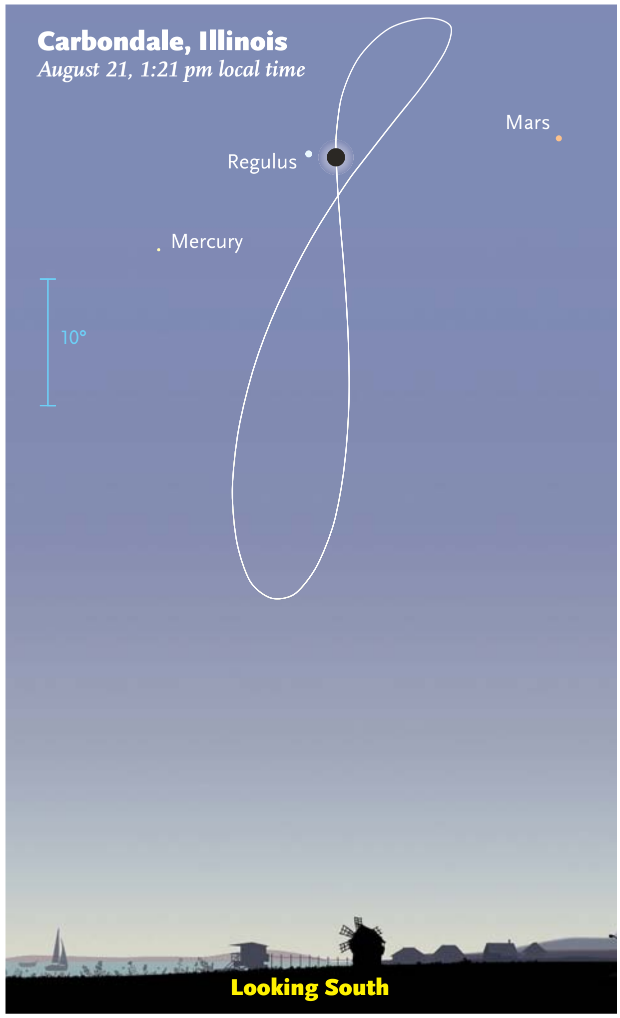
rial over the top 2/3 of the lens, in order to avoid overexposing the solar disk in each image while still having the foreground visible in each frame. This makes it a simple matter to align the individual frames. Using the zoom lens set to 10 mm and f/8, I settled on exposures between 1/60 and 1/100 of a second at ISO 200, though occasionally I needed longer ones if thin clouds were present.

I then began photographing the Sun on July 17, 2005. My routine on each designated day of a solar image was to set the camera to the correct exposure, ISO speed, and f/ratio, and then place the camera in its nest with the solar filter partially covering the lens. I then focused the lens to its predetermined point and shot three bracketed exposures using a shutter cable in manual mode. Using this technique I imaged the Sun from the rooftop on 26 separate dates between July 2005 and March 2006 — about every 9 or 10 days as the weather permitted.

Finally, the day of the eclipse came. We got to see it in beautiful conditions along with thousands of other visitors from Turkey and abroad. And my exposures came off without a hitch! I shot totality using a Zenit 12XP film camera and a 17-mm f/2.8 fisheye lens for 3 seconds on Fuji Reala 100 film, while I used the DSLR for close-up shots through a telescope.

After the eclipse, my career as a civil engineer forced me to modify my plans a bit. I had to move to a job site in Bolu, Turkey, about 250 km away; this meant I would not be able to continue shooting the pictures. What would happen to the project? Fortunately, my brother, Cenk, agreed to take over the job of shooting the remaining pictures from the same spot. I had to take the DSLR with me, but I left the Zenit and fisheye lens. This would pose some more technical problems during processing but was certainly better than having an incomplete result! He rushed to the rooftop from his office at mid-afternoon to set up the camera whenever skies permitted. In the end, he was able to record five additional frames from April to July, completing the project.





S&T: LEAH TISCIONE (2)

FIELD GROUNDWORK Planning the composition of your tutulemma requires knowing both where the Sun will be at the time of the eclipse as well as its daily shift for the entire year so that none of the analemma is blocked by obstructions. The above chart at left was plotted for Casper, Wyoming, while the chart at right depicts the view from Carbondale, Illinois.

PARTIAL FILTERING When shooting the analemma portion of the project, cover the top ⅔ of your camera lens with a strip of solar filter material or dark glass. This allows you to properly expose the Sun, while still including foreground objects that you'll need when aligning each frame. Otherwise, you'll overexpose the Sun while still not revealing many foreground objects, as in the frame at right.

Putting it All Together

Now that I had all the images, it was time to assemble the parts. I performed the bulk of the work in *Adobe Photoshop 7*. For the images acquired with the zoom lens, I corrected for barrel distortion using a third-party plug-in. The frames shot with the 17-mm fisheye had pincushion distortion, which I also tackled using the plug-in.

After the processing, the corrected images aligned perfectly, thanks to the visible strip of foreground in each image. I pasted each new layer over the previous one and then used the Layer option changed to "Lighten" to allow the Sun to appear in the darker sky. The result then displayed a complete analemma in a dark sky. I then flattened the layers into a single image while the foreground over my apartment was no longer necessary and thus discarded.

Once my analemma over Bursa was ready, it was time to add the eclipse image from Antalya. I pasted the Bursa analemma over the eclipse frame and carefully registered it into the proper position. Finally there it was: the first-ever "tutulemma," as I started calling it, with the total solar eclipse as the crowning achievement.

Considerations for 2017

While my composite isn't quite the same as shooting every frame on a single piece of film, it presented some challenges that can be useful to others interested in shooting their own.

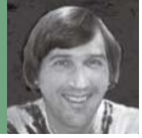
The upcoming eclipse of August 21, 2017, will present a better opportunity to capture a tutulemma of your own. The path of totality passes over many towns and cities in the United States, and if you're located at or near this path, you'll have an easier time creating the final image. Key to success is finding a suitable location without obstructions getting in the way of the Sun at the correct time of day throughout the entire year, but based on the time of day the eclipse will occur.

You'll also need a fixed setup strong enough to be left undisturbed for the duration of the project. Choose a design to either position the camera permanently, or one that allows you to remove and replace the camera accurately. It's a good idea to scout out possible framing compositions before constructing your setup. The analemma spans a large swath of the sky (47°) and requires a wide-angle lens to fit comfortably in your frame with an interesting foreground. This is especially important for observers in the eastern half of the U.S., where the eclipse occurs high in the sky and a super-wide-angle or even fisheye lens may be required.

If you'll be traveling to the eclipse path, the position of eclipsed Sun and the whole analemma will be angled slightly differently with respect to the horizon than it is in your sky at home. You'll need to calculate the offset for your location outside the path. As long as you account for these differences in your composition while pointing your camera, it's relatively easy to composite the individual images together in *Photoshop*.

So if you're up for the challenge of shooting a tutulemma, it's best to start planning and shooting as soon as possible — the earlier you start, the sooner you'll complete the analemma part of the project. Good luck! ✦

***Tunç Tezel** photographs nightscapes from some of the most picturesque locations on Earth.*



~~Take~~ Make a Seat

A happy butt adds an inch of aperture to your scope.

LOOK AROUND at any star party and you'll notice an interesting demographic: nearly all the old-timers are sitting down while they observe. One could assume that's because they're feeble and decrepit, but one would be wrong. They're sitting down because they can see more that way.

You should sit down, too. When you sit, your upper body is steady. You don't wobble around, and your eye stays put in the sweet spot of your eyepiece. You aren't wasting precious energy just keeping your balance; you can focus your attention on the view instead.

Problem is, a good observing chair costs about two hundred bucks. That's eyepiece money! So build one, already. The chair featured here, based on a design I copied from Oregon ATMer Frank Szczepanski, costs all of about twenty bucks in material and a day of your time. And in some ways, it's better than anything you can buy.

An observing chair with slats . . .

ALL PHOTOS BY THE AUTHOR

A good observing chair should be adjustable for height. The easiest way to do that is to make the seat slide up and down a rail, moving easily when there's no weight on it but locking tight when you sit on it. There are two basic ways to do that.

The first way is to provide horizontal slats or notches on the rail for the chair's crossbar to rest against. These provide a positive lock and help keep the seat level even if you lean from side to side. The downside of this design is that you have to stand up off the seat in order to adjust it to the next higher or lower slat.

If you use a flat rail and rely on the pinching action of the seat's crossbars to hold it in place, you can adjust the seat height by just lifting your weight off of it and raising or lowering the seat. Also, it's infinitely adjustable. You're not constrained by the slat separation distance; you can tweak it upward or downward half an inch at a time if you want. This would seem to be the ideal solution, but there's a downside. Have you ever seen one of those toys where a little monkey or a woodpecker on a spring rattles its way down a vertical pole? Your chair seat will do that whenever you bump it. It can also slip downward when you're sitting on it, dumping you unceremoniously on the ground. You need to make the rail grippy (think sandpaper, rubber shelf liner, or a thick coat of varnish), and you need to restrict the seat's ability to bounce. That's easily accomplished with felt pads on the sides of the seat supports, but if the felt is too tight, that limits your ability to raise the seat while just lifting your weight off it. The whole chair will lift up rather than letting only the seat slide upward.

I've tried it both ways and prefer the slats. You might like the flat face better. A slab of door skin plywood is cheap enough to experiment with; give it a shot and see which you prefer.

The photos tell you pretty much everything you need to know, but I'll mention a few design elements to prevent you from having to re-invent them:

Use big, beefy crossbars on the seat. They have to support more than just your weight. They support your weight times the lever arm of the seat, complicated by the angle they make with the rail. You can use a bolt and know that it won't shear off, but the bolt will dig into the

. . . or with a flat rail

The seat is a padded board on strong horizontal supports. Use big dowels rather than a small-diameter bolt to prevent denting the wooden uprights.

wooden rails. A one-inch dowel won't dig in so much.

Put a wide crossbar on the bottom of the rear upright. Don't put it on the front, because you often have to tuck the front of the chair up close to the scope's base. Put some feet on the ends of the crossbar so it doesn't touch the ground anywhere except at the ends. (It's more stable that way.)

Make sure you've got a positive locking bar holding the front and back uprights a set distance apart. You'll be tempted to use a rope — right up until the time you lean forward, the back rail scoots forward, too, then you lean back and fall over.

Other than that, it's pretty self-explanatory. Go for it. And enjoy that extra inch of aperture. ✦

Jerry Oltion is so comfy in his observing chair, he sometimes falls asleep at the eyepiece.

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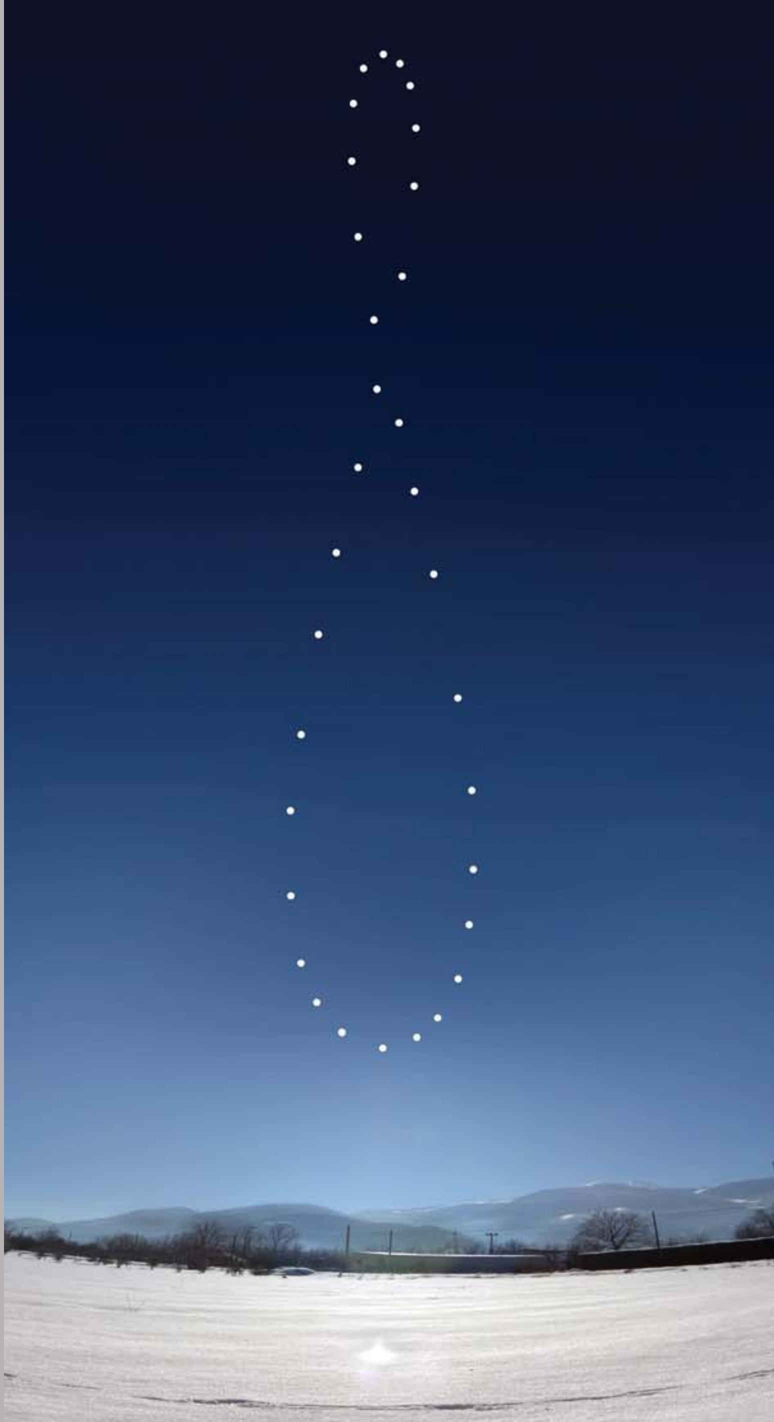
SHIMMER IN CYGNUS

Mike Keith

Sharpless 2-119 spans about 2° and surrounds 5th-magnitude 68 Cygni (at center), a bit east of the North America Nebula. At right (toward south) is a smattering of dark Bok globules.

Details: *Borg 60ED astrograph and Atik 460ex CCD camera with Hα, S II, and O III filters. Total exposure: 14 hours.*

SOLAR CYCLE
Giuseppe Petricca
Fresh snowfall in Sulmona, Italy, frames a 32-image *analemma,* a chronicle of the Sun's sky position shot at the same time of day throughout 2015. See page 66 for an analemma effort involving a total solar eclipse.
Details: *Nikon Coolpix P90 digital camera and solar filter used at f/8 and ISO 100. Sun exposures: 1⁄1,000 second.*



▲ **MARS AT ITS BEST**
Anthony Wesley
The dark plain of Syrtis Major and white clouds over Hellas basin dominate the view at top, captured April 29th at 17:58 Universal Time. In the lower image, taken May 14th (16:41 UT), a bright ring marks the towering, Arizona-size volcano Olympus Mons. North is up.
Details: *16-inch Newtonian reflector with Point Grey GS3-U3-32S4M video camera and Astrodon I-series RGB filters. Exposure: 1⁄30-second video frames, 90 seconds per filter.*

◂ **STARRY SNOWBALL**

Dan Crowson

One of the largest, brightest globular clusters, Messier 3 lies 34,000 light-years away. Its roughly 500,000 stars create a 6th-magnitude glow in Canes Venatici.

Details: *Astro-Tech AT12RCT Ritchey-Chrétien astrograph with SBIG STF-8300M CCD camera and LRGB filters. Total exposure: 6 hours.*

▾ **JELLYFISH NEBULA**

Barry Schellenberg

Also known as IC 443, this glowing bubble near Eta Geminorum is the remnant of a supernova that exploded roughly 5,000 light-years away.

Details: *Borg 101ED astrograph with QSI 683WS-8 CCD camera and Astrodon Hα, S II, and O III filters. Total exposure: 40.7 hours.*

▸ ALDEBARAN COVER-UP

Tunç Tezel

The Moon has been occulting the star Aldebaran regularly, and the event on July 2nd occurred with a waning crescent in twilight 2 days before new. This sequence, shot every 2 to 3 minutes, shows the star (at far left) disappearing behind the Moon's bright limb. **Details:** *Meade LX10 8-inch Schmidt-Cassegrain telescope and Canon EOS 6D DSLR camera at ISO 400. Exposures: 1⁄320 second.*

▾ UNEXPECTED AURORA

Steve Irvine

Although solar storms hadn't been widely predicted, a fine display appeared early on May 8th over Georgian Bay in southern Ontario. **Details:** *Canon EOS 6D DSLR camera and 17-to-40-mm zoom lens used at 17 mm and ISO 3200. Exposure: 20 seconds.* ✦

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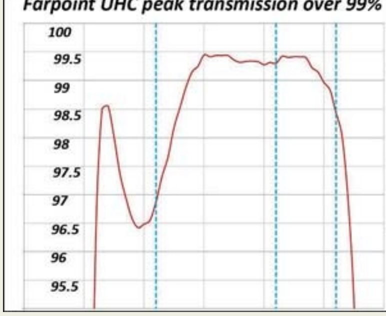

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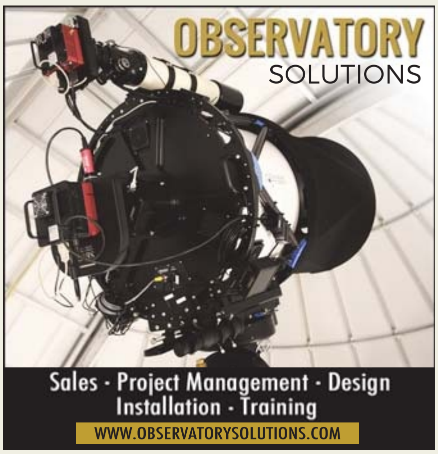

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John Church & William Murray

Three Centuries, One Scope

A single refractor witnesses the 1881, 1973, and 2016 transits of Mercury.

May 9th dawned clear in central New Jersey. The venerable 6¼-inch Hastings-Byrne refractor of the Amateur Astronomers Association of Princeton stood ready for its third transit of Mercury.

At age 137, the original objective, cell, and tube (*S&T:* Mar. 1979, p. 294) were in good condition. The nearly 8-foot-long, f/14.6 scope, transferred to a fully computerized Paramount ME mount in 2015, now offered its eye end at a more convenient height. And recently we'd added a full-aperture solar filter to the telescope.

REX PARKER

The Princeton group, with Church at eyepiece and Murray in striped shirt below the historic scope.

The refractor witnessed its first Mercury transit from Honolulu on November 7, 1881, when it was about two years old. Amateur astronomer Charles Rockwell, its original owner, had brought it there from his observatory in Tarrytown, New York, knowing that the Hawai'ian Islands were the northernmost land from which the complete transit would be observable. Rockwell timed all four contacts and reported them in *The Sidereal Messenger* (the *S&T* of its day) for April/May 1882. A year later he took the scope to remote Caroline Island in the mid-Pacific for the May 1883 total solar eclipse expedition (*S&T:* Mar. 1978, p. 211).

On November 10, 1973, several of our club members used the telescope, now in New Jersey, to observe the third and fourth contacts of that year's Mercury transit. Despite poor seeing, with the Sun only about 15° above the horizon, our timings were closer to the location-corrected predicted times than the averages of the total reported observations for those two contacts (*S&T:* Jan. 1974, p. 4).

Thus we had high hopes for the 2016 transit of our solar system's smallest classical planet. A group of us observed second contact and watched tiny Mercury march slowly across the Sun's face until early afternoon. But then clouds, those implacable foes of astronomers, drifted in from the west, and we were foiled in our attempts to see third and fourth contacts.

We still counted the day a major success. Many club members came out, several using their own equipment, and we had about 25 visitors as well.

The Hastings-Byrne refractor has also observed two consecutive transits of Venus, separated by 122 years. In 1882, Rockwell timed the first on December 6th from his Tarrytown observatory, as he related in *The Sidereal Messenger* for January 1883. For the transit of June 8, 2004, six of us observed and timed the third and fourth contacts using eyepiece projection onto a screen.

We hope to extend our noble telescope's string of Mercury-transit observations on November 11, 2019. But it won't be until December 8, 2125, that another transit of Venus will be visible locally. Hopefully the refractor will make it through another 109 years for future amateur astronomers to enjoy this spectacular sight. ✦

__John Church__, a retired research scientist, has been a member of the Amateur Astronomers Association of Princeton since 1971. __Bill Murray__ works at the New Jersey State Planetarium in Trenton and has been an amateur astronomer for more than 40 years. The authors would like to dedicate this article to observatory co-chair Gene Ramsey (in white shirt at right in photo above), who passed away on September 9th.

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