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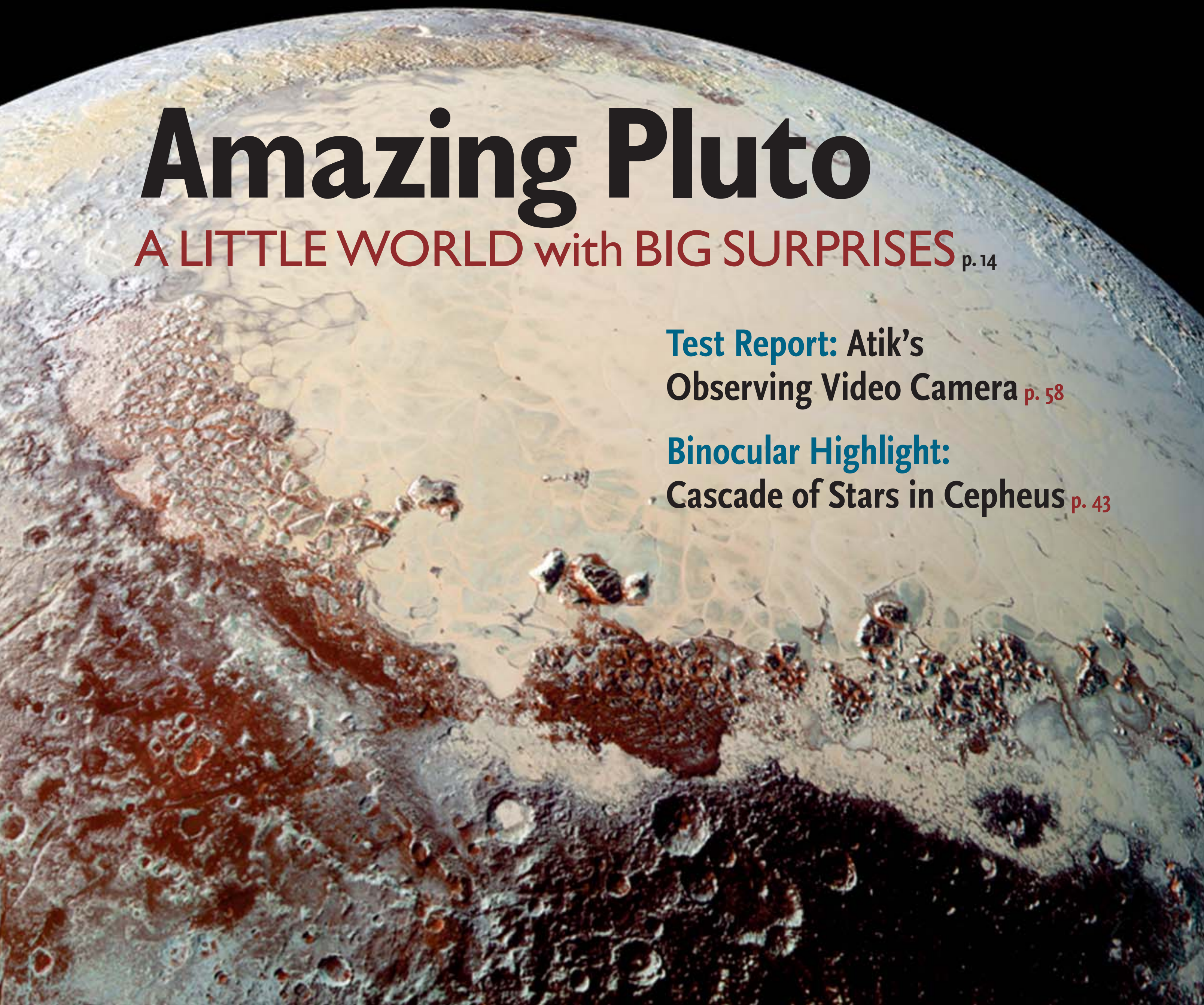
OCTOBER 2016



Amazing Pluto

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photo by Rob Dickinson

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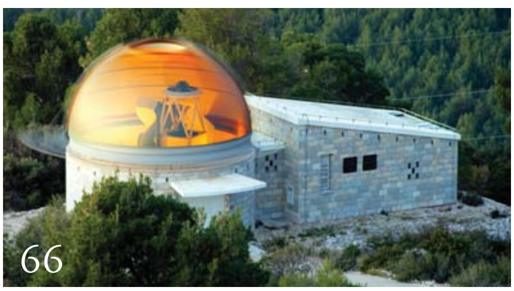
SKY & TELESCOPE

October 2016 VOL. 132, NO. 4

On the cover: The New Horizons spacecraft found a vast plain and Rockies-high mountains on Pluto. The world might still be active today.

PHOTO: NASA / JHUAPL / SWRI



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October 2016 Digital Extra

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- **Eta Carinae**
  Watch the newest ideas about this explosive star unfold in 3D.
- **LISA Pathfinder Surpasses Expectations**
  Successful first results pave the way for a future space-based gravitational wave detector.
- **Light Pollution Report**
  Read the latest on the status of light pollution across the globe.

Photo Gallery

Image by Bill Mark

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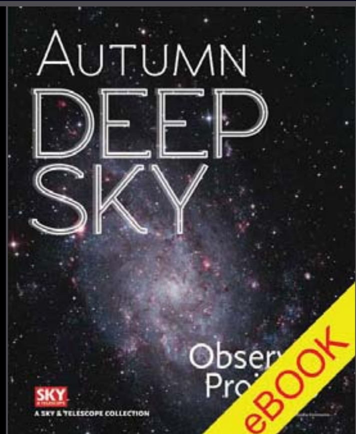

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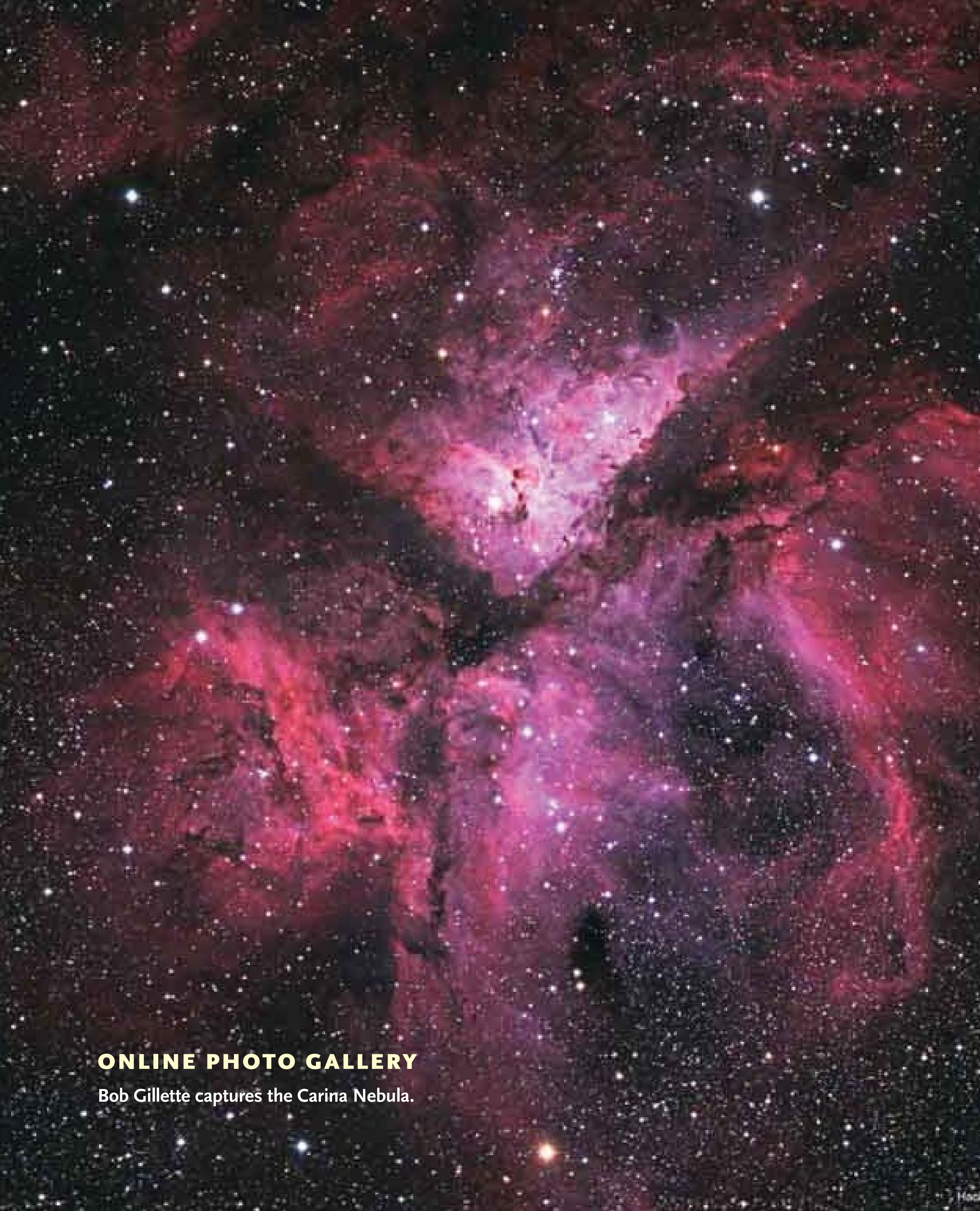


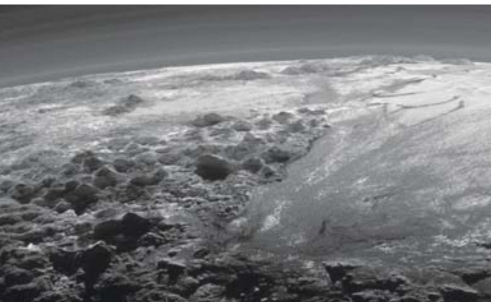
ONLINE PHOTO GALLERY

Bob Gillette captures the Carina Nebula.

A World Away

EACH OF US BOWLED OVER by images sent home by the New Horizons spacecraft after its July 2015 flyby of Pluto — and who wasn't? — likely harbors a particular favorite. Maybe it was that first close-up, true-color photo of Pluto with its distinctive heart-shaped region. Or the eclipse-like vignette that highlights this bantam world's tenuous atmosphere. Or maybe the edge-on shot of Charon's limb revealing that moon's Grand Canyon.

For me it's the image below. I still shake my head in wonder at it, in part because this perspective (taken from 11,000 miles away) provides a strangely familiar way "in" to this mysterious planetary body. For so much of what we see in this 230-mile-wide view resembles what we might see on Earth.



NASA / JHU-APL / SWRI

We notice a curved horizon, haze layers, and long, inky shadows denoting a setting Sun. We behold mountains and plains, with recognizable elements such as pyramidal summits and flat expanses abutting ranges, as the Great Plains do the Rockies. We've seen aerial prospects vaguely similar to this from airplane windows. Could we perhaps be looking north up the Antarctic Peninsula, with the South Shetlands beyond?

We can imagine hiking into the hidden valleys sandwiched between the 11,000-foot peaks seen here. The ranges even have informal names that we can relate to: Norgay Montes (middle left) and Hillary Montes (on the skyline), honoring the first two climbers to reach the top of Mt. Everest. For me, this photograph instantly evokes that deep human urge to explore. I just want to get down there and start investigating *on foot*.

But wait. It's all an illusion. This place is *nothing* like our home planet. Those mountains are not made of rock but of rock-solid water ice. The plains consist of frozen nitrogen, methane, and carbon monoxide. Pluto lies on average about 3 billion miles away from the Sun. The temperature on that plain? About 37 kelvin (–393°F), and that's without wind chill. Simply putting your foot down on the "ground" would be challenging in a place with 1/15 Earth's gravity. And breathing without aid? Forget it. Pluto's vanishingly thin atmosphere is mostly nitrogen, with whiffs of methane.

This distant, frigid, supremely otherworldly orb and its largest satellite are so fascinating that we're devoting three feature articles to reviewing all we've learned about them since our robotic emissary whipped past 15 months ago. The first story, on page 14, delves into Pluto's surface and interior. Those in coming issues will focus on its atmosphere and on Charon and its small siblings, respectively. The author of all three is Senior Editor Kelly Beatty, who was at mission control during the flyby. Enjoy — from the comfort of our solar system's habitable zone. ✦

Peter

Editor in Chief

SKY & TELESCOPE

Founded in 1941 by Charles A. Federer, Jr. and Helen Spence Federer

The Essential Guide to Astronomy

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UNIVERSITY OF CAMBRIDGE

On the night of June 14, 1887, Isaac Roberts used his 20-inch reflector to take a 60-minute-long exposure that captured the short trail of asteroid 80 Sappho (circled). He first imaged it in 1886.

In Praise of Isaac Roberts

I really enjoyed Alan Hirshfeld's "The Nebula War" (*S&T:* June 2016, p. 36) and the involvement of 19th-century amateur astronomer Isaac Roberts. Although Roberts concentrated on astrophotography of deep-sky objects, he is also known for his photos of Neptune and for the first-ever photograph of an asteroid, 80 Sappho, in December 1886.

Roberts mounted his photographic plates at prime focus of his 20-inch reflector, to avoid the loss of light that would occur from using a secondary mirror. Moreover, his best deep-sky images were taken from 1890 onward, after he moved from Maghull, north of Liverpool, to his Starfield observatory on Crowborough Hill near the southern coast of England. His reflector ended up in London's Science Museum.

Philip Corneille
De Haan aan zee, Belgium

Debating Red vs. Amber Light

My congratulations to Robert Dick for his very excellent article on night vision (*S&T:* June 2016, p. 22). His explanations are extremely clear and understandable. My experience with color vision and measurements comes from working for RCA on the development of color picture tubes. This article has filled in some gaps in my understanding.

George Gadbois
Lancaster, Pennsylvania

TOM SALES

Mating a pill vial with a small flashlight can yield amber-colored illumination for use while observing.

Write to Letters to the Editor, Sky & Telescope, 90 Sherman St., Cambridge, MA 02140-3264, or send e-mail to letters@SkyandTelescope.com. Please limit your comments to 250 words. Published letters may be edited for clarity and brevity. Due to the volume of mail, not all letters can receive personal responses.

I agree that the main problem with using red light is that you can't see anything with it! If it's true that an amber light of just 1 or 2 lux will suffice for a night-vision-friendly flashlight, then this represents a huge breakthrough for astronomers, especially amateurs.

I wanted to fashion an amber flashlight for myself, so I tried to locate a 590-nm LED. But I managed to jury-rig an amber light by pairing a Garrity single-LED flashlight with an old amber-colored pill vial. (I knew they had to be good for *something*!) I've tried it, and it works! It's possibly a tad too bright, but if I don't stare directly at the LED, it seems to leave my night vision intact.

The best part is that it gives out a gentle glow when placed face down, making it into a miniature amber lantern. I accomplished that by lining the inside with several layers of parchment paper to diffuse the light sideways. The light is a pretty color, reminiscent of candlelight, and is easy to read charts by, even in "lantern" mode. Yet, when used as a flashlight, the beam passes nicely through the bottom of the vial, which then simply acts as an amber filter.

Tom Sales
Somerset, New Jersey

Robert Dick responds: *Thank you for taking the time to explore this topic. One key aspect of any luminaire is to eliminate glare. Glare from a red LED will compromise your night vision too. So the optics and shielding are almost as important as the spectrum of the light. Most flashlights can't be dimmed very well, and as you pointed out this is necessary. The peak in the spectrum is not too critical, so what you are using is fine. Minimizing (avoiding) blue is critical, however.*

Upon reading "Is Red Light Really Best?" in the June issue, I arrived at a conclusion opposite to the author's — using the same data. He makes it clear that studying a star chart in faint light requires the high resolution that only cone cells provide.


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Given this truth, his first graph (p. 23) contains all the information a stargazer needs to decide what color light to use. It shows that, with yellow or blue rays, the rod cells are activated by much fainter light than the cone cells are. So the rods become washed out — and sensitive night vision is lost — if one uses a light bright enough to activate the cones.

However, with red rays, the rods and cones are activated about equally, so the rods are not washed out much by light that activates the cones. This is why observers should use dim red lights.

I can say that my experience is not like Dick's, for I suffer essentially no loss of night vision after reading a star chart by dim red light. I hope that the amber lights that he recommends do not become acceptable at the star parties I attend.

Roger Venable
Chester, Georgia

Thank you for this very interesting article. Perhaps red light became conventional wisdom purely by adoption long ago from photographic darkroom practice, in which dim red was used because black-and-white emulsions were not sensitive to it, rather than its suitability for low-light human vision.

Ken Wood
Newport, Wales

My variable-intensity red light is always used at the brightest setting because, at age 77, my old eyes need maximum brightness to really see anything. At star parties I always use a red light because that's the norm, but I'd read that green light works well at low levels. So on my own I gave green light a try and found that my night vision didn't suffer. I just use it at a lower intensity.

The jury might still be out, but I think most observers will find any color *other* than red to be intrusive in a group setting. However, when observing by ourselves, it might be worth experimenting with other colors. Eyes differ from person to person, and you might just find — as I did — that red isn't your "sweet spot."

Jack Kramer
Lily Lake, Illinois

For the Record

✵ *In Richard Wilds's article on dark nebulae (*S&T*: July 2016, p. 30), Altair's brightness is 1st (not 2nd) magnitude. Also, the star labeled 12 Scuti in the finder chart is actually Eta (η) Scuti; the 4th-magnitude star to its immediate east (left) is 12 Aquilae. Also, the second and third sentences of the second paragraph on p. 33 should read: "Using 27 Aql as your starting point, slide 34′ to the southwest, in search of B139. A small planetary nebula, NGC 6778, shines 5′ below this southeast-northwest dark smudge."*

✵ *The 99%-reflective mirror coatings mentioned in our Test Report of the Astro-Tech 14-inch Ritchey-Chrétien telescope (*S&T*: July 2016, p. 62) are a manufacturer's specification, not a value measured by* Sky & Telescope.

75, 50 & 25 Years Ago

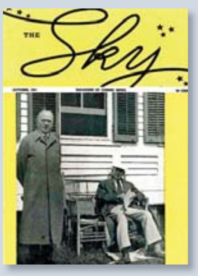
Roger W. Sinnott

October 1941

A Magazine Is Born "The editors note and announce the closing with this issue of another period for *The Sky*, and its combination with another journal of fine standing — *The Telescope*, at present published bi-monthly by the Bond Astronomical Club, Harvard Observatory, Cambridge, Mass.

"*Sky and Telescope* will be the name of these combined publications, beginning with the issue of November, 1941. The present *Sky* editors will continue in the same capacity with the new magazine, but Sky Publishing Corporation will be located at Harvard Observatory.

"Of the same size and format as *The Sky*, the new magazine will have four additional pages each month [beyond the present 24], thereby making it possible to retain all the best features of both original periodicals . . ."

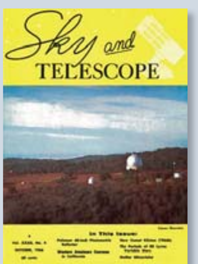


Thus editors Charles and Helen Federer marked their move from New York City's Hayden Planetarium to a broader publishing arena. They would also drop The Sky*'s quaint but lovable subtitle, "Magazine of Cosmic News."*

October 1966

Polarized Variables "Not a few readers of this magazine have spent long hours at the telescope following the brightness changes of the Mira-type or long-period variable stars. Now K. Serkowski . . . reports the unexpected discovery that the light of many long-period variables is partially polarized. Moreover, this polarization is intrinsic — arising in the stars themselves rather than the interstellar medium — and its amount can vary considerably.

"Dr. Serkowski's observations were made at Lowell Observatory in Arizona, with two single-channel polarimeters attached to the 21-inch reflector. . . . Previously, the highest known polarization for any star in high galactic latitudes was 0.6 percent. [But] the light of V Canum Venaticorum has a polarization of six percent."



Polish astronomer Krzysztof M. Serkowski (1930–81) is also remembered for the Serkowski law, an empirical formula for the wavelength dependence of interstellar polarization.

October 1991

Stellar Flare-up "In this year of major flares on the Sun, we can rest assured that our star is very well behaved compared to some others. A flare that released 100 million times more energy than typical white-light solar events has been recorded on the 6th-magnitude star V711 Tauri, report Gregory W. Henry (Tennessee State University) and Douglas S. Hall (Vanderbilt University). It may have been the most intense stellar flare ever observed.

"V711 Tauri is an RS Canum Venaticorum star, a pair of closely orbiting yellow subgiants (types *G*5 and *K*1). . . . The big flare lasted 6 to 7 hours. Covering about 8 percent of the *K* star's visible disk, it blazed with 10 times the *total* light of the Sun and brightened the entire system by 0.7 magnitude in blue light. . . ."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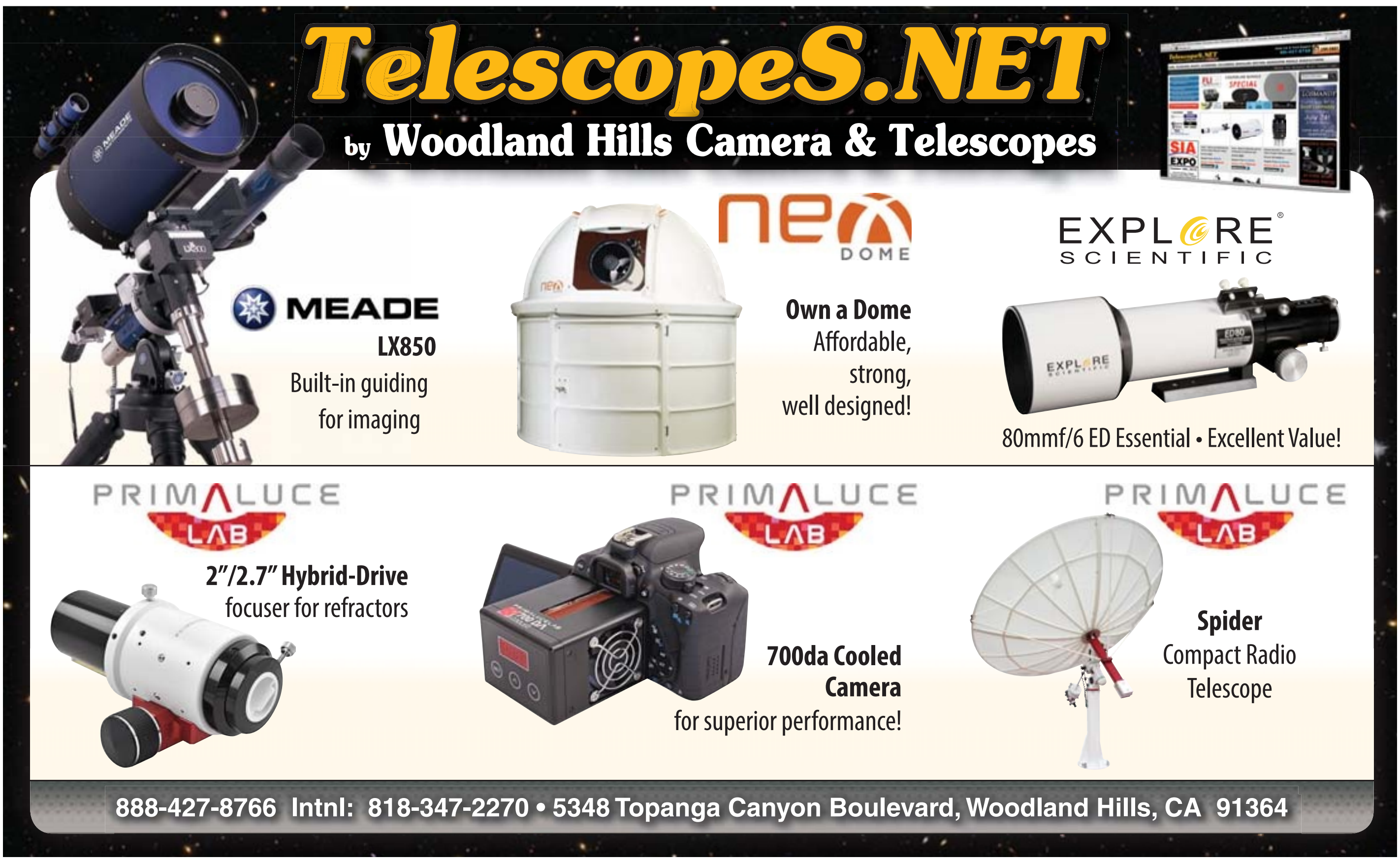
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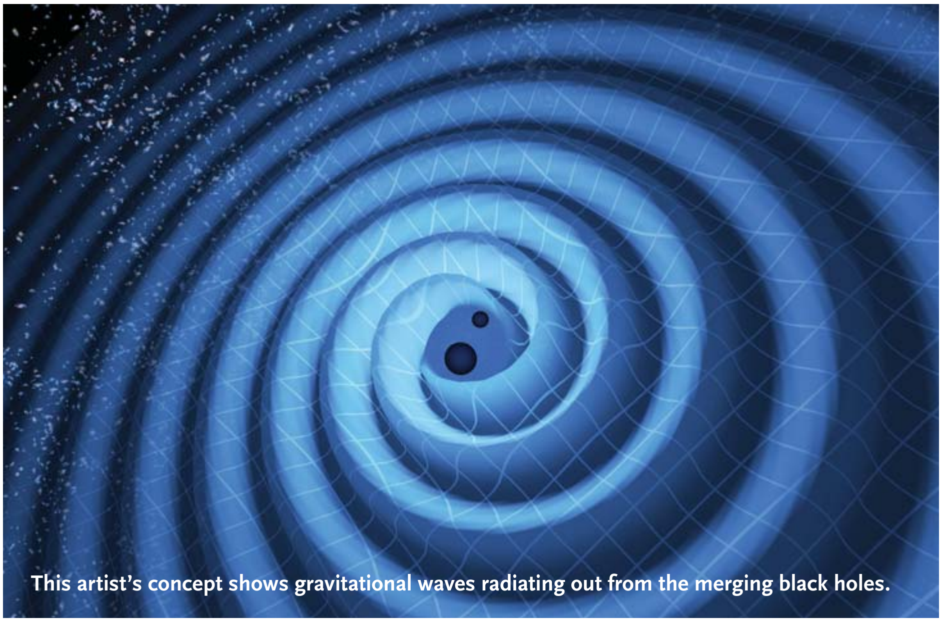
PHYSICS | LIGO Detects 2nd Black Hole Collision



LIGO / T. PYLE

This artist's concept shows gravitational waves radiating out from the merging black holes.

The Laser Interferometer Gravitational-Wave Observatory (LIGO) has detected another burst of spacetime ripples created by the violent merger of two stellar-mass black holes.

LIGO's first discovery, detected last September and announced in February (*S&T:* May 2016, p. 10), was an astounding achievement for science. The signal radiated outward from two surprisingly heavy black holes, each about 30 solar masses. As such the chirp was loud but short: it lasted only 0.2 second and allowed scientists to glimpse the last 10 cycles of the black holes' orbits before their collision.

This second signal, GW151226, came from two lesser black holes, roughly 7.5 and 14.2 times the mass of the Sun. The chirp was weak, barely visible above the noise, but lasted a full second and enabled researchers to witness the last 55 orbits of the black holes' inspiral. The signal reached LIGO on December 26, 2015, and was announced June 15th at the American Astronomical Society summer meeting in San Diego and in the June 17th *Physical Review Letters*.

The two black holes had been circling each other for eons before they finally crashed together 1.4 billion years ago. The bang was so furious — with an energy release equivalent to the entire mass of the Sun — that it sent shudders across the universe, distorting the length of LIGO's arms by 10 million-billionths of a centimeter. "That's like changing the distance between the Earth and the Sun by a fraction of an atomic diameter," says Gabriela Gonzalez (Louisiana State University), chair of the LIGO collaboration.

Given the new signal, scientists think the final black hole had a mass of approximately 20 solar masses.

LIGO's next observing run will last six months and increase LIGO's sensitivity by 15% to 25%. Given that the last, four-month run yielded two mergers, LIGO Executive Director David Reitze expects that the added sensitivity will unearth six to eight mergers over this fall's run. LIGO could potentially spot dozens of these events each year.

■ **SHANNON HALL**

SOLAR SYSTEM | Earth's Newfound Quasi-Moon

Our fair planet has a tiny companion, an asteroid that plays leapfrog with us in our annual journey around the Sun.

The asteroid, 2016 HO_3, is between 40 and 100 meters in size. Discovered as a 24th-magnitude blip on April 27, 2016, by the Pan-STARRS 1 survey based on Haleakala, Hawai'i, 2016 HO_3 occupies an orbit very much like Earth's. Calculations suggest that, although it evaded detection until this year, 2016 HO_3 has hung out in Earth's vicinity for a century or so and will stay for centuries to come.

2016 HO_3's orbit takes it alternately sunward and ahead of Earth for six months at a time, then slightly farther from the Sun and behind us. Its orbit is tilted relative to the ecliptic plane, resulting in a corkscrew twist over several decades. Too distant to be considered a true second moon, 2016 HO_3's journey brings it as close as 38 times the Earth-Moon distance (9.1 million miles or 0.1 astronomical unit) from our planet, and as far as 100 times the Earth-Moon distance.

"Since 2016 HO_3 loops around our planet, but never ventures very far away as we go around the Sun, we refer to it as a quasi-satellite of Earth," says Paul Chodas (NASA Jet Propulsion Lab). "In effect, this small asteroid is caught in a little dance with Earth."

Chodas explains that this body doesn't qualify as a "mini-moon" (*S&T:* Sept. 2015, p. 30) because our planet's gravity never truly captures it. "Captured objects are true satellites of Earth and will loop around with periods as large as a few months," he says. "Quasi-satellites loop around Earth with periods of almost exactly 1 year."

BLACK HOLES | How Dead Galaxies Stay Dead

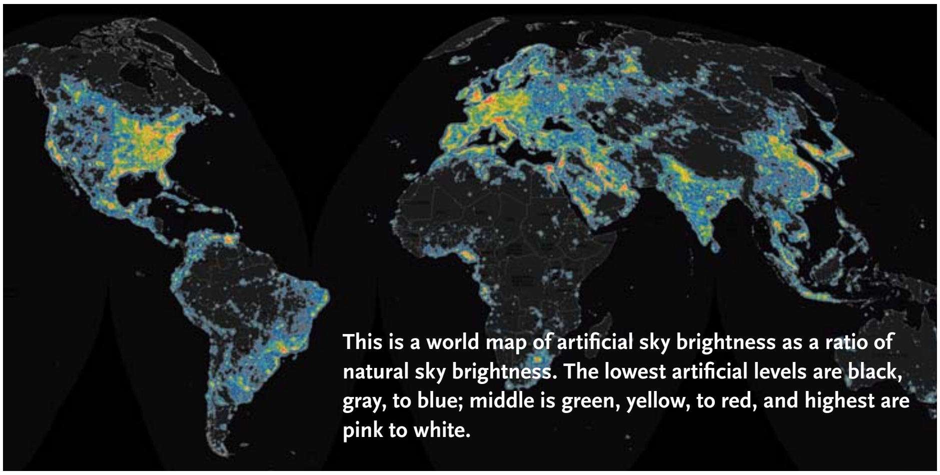
Astronomers have found further circumstantial evidence that supermassive black holes can prevent their host galaxies from forming stars. Galaxies create stars from cold gas. Yet although up to three-quarters of the old, "red-and-dead" galaxies still have enough gas to fuel star formation, only about 15% of them do so. Many astronomers think that jets or winds from the galaxy's central black hole heat up the gas and prevent it from collapsing into stars. Astronomers do see signs of this process in galaxies with the most enthusiastically gobbling black holes, but they've had trouble confirming this process is at work in more typical, quieter galaxies.

Now Edmond Cheung (University of Tokyo) and colleagues think they've done just that. The team found a galaxy, nicknamed Akira, that's in the midst of merging with a much smaller galaxy. Mergers often trigger bursts of starbirth. Yet although observations show that Akira has gas, it's not churning out stars. The team argues in the May 26th *Nature* that this inhibition might be due to the galaxy's active black hole. The researchers estimate that it could be putting out enough energy in small-scale jets or winds to literally stir up trouble for star formation and create the outflow of gas they detect.

■ **CAMILLE M. CARLISLE**

The asteroid 2016 HO_3 joins the small but growing list of objects tracked in a solar orbit near Earth. Asteroid 2003 YN_{107} was discovered by the LINEAR sky survey about a decade ago, when it followed a similar track, but the rock has since departed our neighborhood. Asteroid 2006 RH_{120} — the only true mini-moon yet discovered — made several distant looping passes of Earth from April 2006 to September 2007 before ejection. The Moon does a pretty good job at celestial goaltending, assuring such secondary hopefuls never hang around for long.

■ **DAVID DICKINSON**



This is a world map of artificial sky brightness as a ratio of natural sky brightness. The lowest artificial levels are black, gray, to blue; middle is green, yellow, to red, and highest are pink to white.

SCIENCE & SOCIETY | New Light Pollution Atlas

One-third of the human population cannot see the Milky Way at night due to the glow of artificial lights, according to an updated "New World Atlas of Artificial Night Sky Brightness" that quantifies the global impact of light pollution.

Moreover, more than 80% of the world's citizens and more than 99% of those in the U.S. and Europe live under some amount of artificial *skyglow*, the light directed upward and scattered by the atmosphere from electric lighting below. This is a problem even in isolated areas 100 km or more away from megacities.

Singapore is the most light-polluted country, where the entire population lives under skies so bright that their eyes can never fully adapt to night vision. The country least affected is Chad, with more than three-quarters of its population living under pristine skies.

Fabio Falchi (Light Pollution Science and Technology Institute, Italy) and an international team updated the atlas using newly available data from a low-light imaging sensor on the Suomi National Polar-orbiting Partnership satellite, which takes high-resolution photos from 800 km (500 miles) above Earth. The team also used new ground-level precision measurements from the U.S. National Park Service and thousands of citizen scientists around the world.

The atlas was first released in 2001, but this new release is more carefully calibrated and involves better models and computations. Christopher Luginbuhl (Flagstaff Dark Skies Coalition) cautions against comparing the two atlases, since the old version utilized a less precise set of satellite images. The new one appears in the June 10th issue of *Science Advances*. Read more about the report at **https://is.gd/lpatlas2016**.

Light pollution is a concern for everyone, not just astronomers. At its most extreme levels, it can disrupt our internal circadian rhythm, a cycle governing physiological processes including sleep and wake patterns, hormone production, and body temperature. Biological studies show that it is better to use bright light with high-blue content in the morning and dim light with low-blue content beginning at dusk.

Thoughtfully retrofitting older outdoor lighting can significantly improve efficiency, save lighting costs, and provide maximum protection for dark skies. However, unless blue-light emission is restricted, switching to LED street and area lighting can more than double the night sky's brightness as perceived by our dark-adapted eyes. "We need to slow down this LED juggernaut and think about it more carefully," says Luginbuhl.

Meanwhile, for those looking to assess their community's light pollution, STEM Laboratory (Tucson, Arizona) has developed a Light at Night Index (LANI) — a satellite-based evaluation of how efficiently communities in the U.S. use light at night.

■ **ANA V. ACEVES**

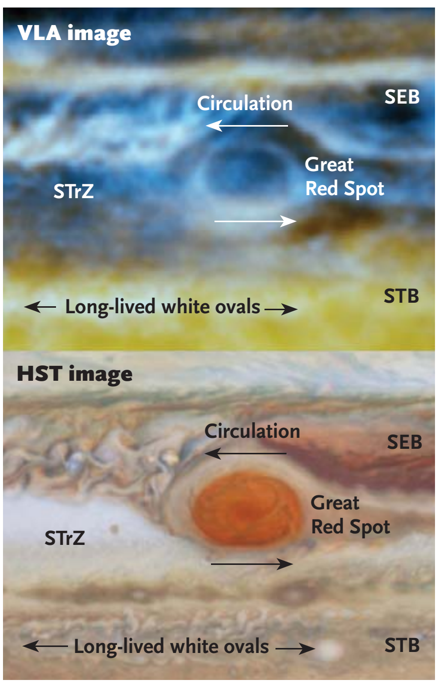
JUPITER | Deep Radio Atmosphere Probe

The Very Large Array (VLA) has probed about 100 km (60 miles) into Jupiter's cloud layers, giving an unprecedented look at the giant planet's atmosphere.

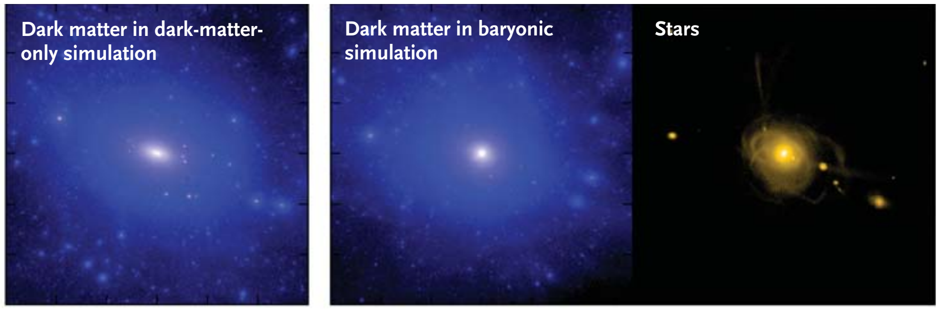
Because Jupiter rotates in less than 10 hours, conventional radio images become smeared in minutes. So researchers developed an innovative data-reduction technique to "unsmear" data from many hours of new, higher-resolution observations. The results, published in the June 3rd *Science* by Imke de Pater (University of California, Berkeley) and colleagues, give new insights into the structure and dynamics of the planet's atmosphere.

When they compared near-simultaneous maps of Jupiter as seen in radio and optical wavelengths (below), the researchers found the planet's belts generally lined up well. But the new radio images showed details unconnected to those seen in visible light. These locations mark where the overlying cloud layer of ammonia (NH_3) is thin and more transparent at radio wavelengths. The radio image spans 4 to 18 GHz.

■ **ANA V. ACEVES**



VLA: IMKE DE PATER ET AL. / NRAO / AUI / NSF; HST: NASA



A. R. WETZEL ET AL. / *ASTROPHYSICAL JOURNAL LETTERS* 2016

A dark-matter-only simulation *(left)* of cosmic structure development predicts that the Milky Way should have thousands of satellites. But when astronomers add gas and stellar physics *(center, showing dark matter, and right, showing stars)*, only a tenth as many dark-matter satellites form, and fewer than 10 of them form dwarf galaxies. Each box is about 2 million light-years across.

GALAXIES | Missing Dwarfs Never Were

New computer simulations may put to rest a longstanding cosmological mystery. Until now, calculations of galaxy formation predicted that the Milky Way should have at least thousands of little satellites swarming around it. Yet astronomers have detected only a few dozen dwarf galaxies around the Milky Way. This discrepancy is called the *missing satellites problem*.

Furthermore, if the expected swarm exists but is just too dim to detect, then the couple dozen we do see would presumably be the biggest ones. But compared with the largest dwarfs in the simulations, observed satellites are too small. This second conundrum is called the *too big to fail problem*.

New work suggests that the problem is the simulations, not the observations. Until a few years ago, simulations only included dark matter. It's much easier to calculate the evolution of structure when you're only dealing with gravity (which is the only force dark matter notices).

As part of their ongoing work with the Feedback in Realistic Environments (FIRE) simulations, Andrew Wetzel and Philip Hopkins (both at Caltech) and their colleagues are working on how gas and stellar feedback affects this process. On June 13th at the American Astronomical Society meeting in San Diego, Hopkins presented their latest results, called "The Latte Project: the Milky Way

COMETS | 67P Will Break Up and Make Up

Scientists now suspect that some comet nuclei regularly split in two and reunite later in life, a repeating process that might be fundamental to comet evolution overall.

Masatoshi Hirabayashi (Purdue University) and others studied the nucleus of Comet 67P/Churyumov-Gerasimenko, which has been home to the European Space Agency's Rosetta spacecraft since 2014. They found two straight cracks separated from each other by 750 m (2,500 feet) on the narrow neck that connects the comet's two large lobes.

As the team reports in the June 16th *Nature*, these cracks could be from an increasingly rapid rotation rate. Jets of gas and dust shooting into space cause the nucleus to spin faster. The team modeled what would happen as the spin rate quickened and found that it causes more internal stress and the formation of cracks in the same locations as those on 67P's surface. Eventually, the stress splits the nucleus.

Once that happens, the separated segments orbit each other for some time, ultimately merging again at a slow speed and in a new shape. This pattern could go on for the comet's lifetime.

Several other factors can cause a comet nucleus to spin faster, such as jetting action or gravitational torquing by the Sun or Jupiter. Icy compounds such as on FIRE." Latte has the highest resolution yet of any simulation of its kind, zooming in to a mere few light-years as it follows the development of a Milky Way–size galaxy and its legion of dwarfs.

The team ran two versions of the simulation: one with just dark matter, and one with dark matter plus gas physics plus stellar feedback. The researchers found that the souped-up version produced about 700 dark-matter satellites lurking around the big central galaxy, only a tenth as many as in the dark-matter-only version. And of these 700, only nine managed to form a stars-and-gas dwarf galaxy inside it.

The big galaxy itself keeps dwarfs from forming, Wetzel explains. As budding satellites fly through its hot halo of gas, they're ripped clean of their own gas by frictional drag, preventing star formation. The Milky Way–like galaxy also destroys the dark-matter clumps in which the dwarfs would have formed: as the satellites orbit the large stellar disk — which is completely absent in the dark-matter-only simulation — the disk's tidal forces yank on the satellites. If the satellites fly within two or three times the disk's radius, the tides wrench them apart.

In addition to solving both problems, Latte creates galaxies that look real enough to fool colleagues, Hopkins boasts.

■ **CAMILLE M. CARLISLE**

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ammonia and carbon dioxide can also affect spin when they go from frozen to gaseous states in a process called *sublimation* as the comet nears the Sun.

Other periodic comets are known to have a double-lobed shape. Of the seven comets astronomers have seen at high resolution, five are bi-lobed.

So could this be a common characteristic among periodic comets? "The conclusion that the other comets are necessarily bi-lobate is not so obvious as with 67P," said Uwe Keller (Max Planck Institute for Astronomy, Germany). He says other comets that undergo sublimation also have elongated shapes, but that not all elongated comets need to be of bi-lobate origin.

■ **ANA V. ACEVES**

IN BRIEF

Baby Planets Leave Gas Footprints. A new analysis of ALMA radio data confirms that gaps in the disk around the young star HL Tauri likely have been carved out by forming planets. Two years ago, astronomers used ALMA to capture a stunning image of gaps in the star's dusty disk. The disk spans 235 astronomical units, and gaps exist at around 32, 64, and 74 a.u. But ALMA's observations, taken at a wavelength of 1.3 mm, recorded emission only from cool dust; they don't reveal if gas fills the apparent gaps. If it does, then they're not carved out by forming planets and must arise some other way. Now Hsi-Wei Yen (Academia Sinica Institute of Astronomy and Astrophysics, Taiwan) and others report in the April 1st *Astrophysical Journal Letters* that, when they summed up the gas emission in different parts of the image, the gaps appear to be real. But HL Tau is only a million years old, and along with a recently discovered planet around the 2 million-year-old star CI Tau, it defies theorists' prediction that these worlds should take at least 10 times longer to accumulate.

■ **MONICA YOUNG**

LISA Pathfinder Surpasses Expectations. The European Space Agency's technology testbed for its upcoming space-based gravitational-wave detector is working even better than hoped, Michele Armano (ESA) and fellow team members report in the June 10th *Physical Review Letters*. LISA Pathfinder contains two test masses in freefall, which, when scaled up in the full-size 2030s mission, will be influenced by only gravitational waves. The first results exceeded engineers' goal by a factor of five, reaching femtometer scales (a femtometer is a million-billionth of a meter). For comparison, the charge radius of a proton is about 0.8 femtometer. Learn more and watch the press conference at https://is.gd/lisapathexceeds.

■ **DAVID DICKINSON**

Rolf G. Meier (1953–2016). On June 26th amateur astronomy lost a dedicated observer and successful visual comet hunter to brain cancer. As a teenager, Meier joined the Royal Astronomical Society of Canada's Ottawa Centre. He discovered his first comet — the first comet ever found from Canada — on the evening of April 26, 1978, after searching for only 50 hours. Comet Meier, initially designated 1978f and later C/1978 H1, is one of the largest comets ever found. Meier went on to find three more in the 1970s and 1980s. An engineer by day, he also pursued planetary photography with characteristic passion. He and his wife, Linda (herself an accomplished amateur astronomer), often observed together and hosted meteor watches at their home.

■ **DAVID H. LEVY**

First Chiral Molecule Discovered in Space. Molecules come in two "handed," or *chiral*, forms, one a mirror image of the other. All of life's chemistry seems to be based on chiral molecules of a certain handedness: the amino acids in proteins are left-handed, whereas the sugars that form the helical backbone of DNA are right-handed. Scientists don't know why. One idea is that the molecules on Earth started out with a preference for one chirality over the other, thanks to conditions in the cloud that formed the solar system — say, if polarized radiation from stellar nurseries destroyed slightly more molecules of one kind than the other. In the June 17th *Science*, Brett McGuire (National Radio Astronomy Observatory) and others report the first discovery of a chiral molecule in space, propylene oxide (CH_3CHCH_20). The molecule floats (probably on icy dust grains) near protostars in the giant molecular cloud Sgr B2(N). The team can't yet tell whether the propylene oxide is right- or left-handed, but they hope future observations of polarized radio waves will reveal its chirality. ✦

■ **MONICA YOUNG**

Pluto's Amazing Story

This distant world bristles with geologic diversity unmatched in the outer solar system.

J. Kelly Beatty

FIRST IN A SERIES

Sky & Telescope has prepared three installments to do the rich New Horizons results justice. This article addresses Pluto's surface. November's issue will explore Pluto's atmosphere and its solar-wind interactions, and December's examines Pluto's moons: Charon and its four smaller siblings.

Last July 14th, on the first anniversary of New Horizon's history-making dash through the Pluto system, Alan Stern was finally, *finally* on vacation. The mission's ubiquitous, high-energy principal investigator hadn't had one in three years, and the family's getaway was a well-deserved escape. The respite came at the conclusion of an intensive, three-day meeting of the mission's science team — one that proved enlightening yet frustrating. "Every day I became more depressed about everything we don't understand," Stern admits.

The problem (and it's a great one to have) is that Pluto and its big moon, Charon, have turned out to be far more complex than anyone could have imagined. "What the data revealed didn't surprise us," says James Green, who manages NASA's solar-system exploration division. "It shocked us."

Planetary scientists had spent the previous 75 years racking up hard-won observations from ground- and space-based telescopes. They realized, decades in advance of the spacecraft's arrival, that Pluto was more than far away — it was "far out." For example, there's the dramatic obliquity of Pluto's spin axis, swung over by 120° with respect to its orbital plane, and its consequent seasonal extremes. This tremendous tilt came about when something very large smacked into Pluto early in its history, knocking it askew and spewing out enough icy rubble to form Charon and four smaller moons.

They also knew, from a series of mutual eclipses and transits during the 1980s (*S&T:* June 1985, p. 501) and from Hubble Space Telescope observations, that Pluto and Charon have very different surfaces. The former is bright, tinged with orange, and blanketed with frozen nitrogen and methane, while the latter has a duller, grayer exterior overwhelmed by water ice.

These distinctions became more obvious as the spacecraft approached the Pluto system in early 2015, but the most revealing observations came in the frenetic hours surrounding the flyby itself. Unfortunately, owing to the slow, synchronized rotations of Pluto and Charon every 6.4 days, New Horizons saw only half of their sunlit hemispheres as it zipped by at 13.7 km per second (30,700 mph). The portions seen most poorly, last photographed when the spacecraft was still 3 days and 4 million km from the flyby, tantalize with lots of bright and dark markings but lack crisp detail. "It's like looking at the Moon through garden-variety binoculars," Stern says.

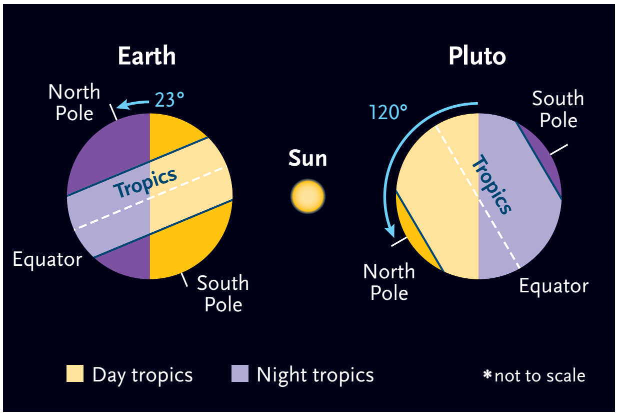
Worse, because Pluto's polar axis points only 39° from the Sun, most of the southern hemisphere was completely hidden in shadow. Some of that unseen territory won't bask in sunlight for another 100 years.

But make no mistake: thanks to New Horizons, we now know *vastly* more about Pluto and its family of moons. Here's a recap to showcase what we've learned about Pluto itself.

JAGGED SHORELINE Krun Macula (at lower right) rises 2½ km above the broad plain known as Sputnik Planitia. The icy surface is scarred by clusters of connected, roughly circular pits that are up to 13 km across and 2½ km deep.

NASA / JHU-APL / SWRI


15 km



SKY & TELESCOPE DIAGRAM / SOURCE: ALISSA EARLE

DIFFERENT TILTS The 23° obliquity of Earth's spin axis gives us predictable and reasonably moderate seasons. But Pluto's tilt of 120° creates climatic extremes not seen on any other solid body in the solar system. For example, its tropics (regions from which the Sun can appear directly overhead) encompass virtually the entire globe.

The Heart of Pluto

Roughly a month before the flyby, the spacecraft's Long Range Reconnaissance Imager (LORRI) spied a distinctive bright patch on the side of Pluto shaped like a heart. In fact, this brightening had been evident in Hubble images acquired during the 1990s. Having cultivated close relationships with Clyde Tombaugh (Pluto's discoverer) and his wife, Patsy, before they died, Stern and his team named it Tombaugh Regio — informally so, as the box below explains.

But when seen up close during the flyby, the heart clearly was broken in two, having a rougher eastern half butting against a remarkably smooth plain to its west. The latter, somewhat larger than Texas, was dubbed Sputnik Planum as a nod to Earth's first artificial satellite. Spectral scans by New Horizons reveal a composition dominated by frozen nitrogen and carbon monoxide.

Thanks to stereo imaging, it's now clear that this ice-covered plain is not a plateau, as first thought, but instead an enormous depression 3 to 4 km (about 2 miles) deep at its center. So it's almost certainly the site of a primeval impact roughly 1,000 km across — a basin big enough to wrap around the curvature of Pluto itself. There's no obvious rim, though geologists wouldn't expect one to remain after billions of years of exposure and erosion. But it is bordered by clusters of tall water-ice mountains — al-Idrisi Montes to the west and Hillary Montes and Norgay Montes to the south — that might be jumbles of crumpled upper crust or piles of impact ejecta.

(Recently, after realizing that Sputnik is not a plateau but a depression, mission scientists morphed its classification from Planum to Planitia.)

Little did the team know how crucial this low-lying plain has been to Pluto's geologic history. Even the spacecraft's closest, most detailed images show no impact craters — not one — anywhere within its confines. If Pluto were the same kind of eons-old ice ball found frequently in orbit around the outer planets (Jupiter's Callisto and Saturn's Rhea come to mind), Sputnik Planitia should have been heavily peppered with pits.

But given its dearth of craters, the team's geologists initially announced that its surface could be no older than 100 million years. Later, on inspection of the spacecraft's most detailed images, they sliced the age to no older than 10 million years. In geo-speak, this means Pluto is probably geologically active today.

The plain exhibits a pattern of interconnected polygons, 10 to 40 km across, with shallow depressions along their margins. "We saw that cellular pattern right away," recalls geophysicist William McKinnon (Washington University, St. Louis), and immediately likened it to a kind of patterned ground that undergoes constant renewal in Earth's polar regions.

Close inspection shows clusters of hills that stick up through the plain's surface. Up to a few kilometers across, they appear to be bobbing along in the icy floes and become concentrated where the polygonal slabs meet. The mission's geologists suspect that the mysterious hills are mountain-size chunks of water ice transported from the surrounding uplands, especially Tombaugh Regio. These "islands" appear to be afloat in Sputnik's sea of frozen nitrogen, analogous to ocean-going icebergs here on Earth. (It's entirely plausible: very cold pure water ice has a density of 0.934 g/cm^3, and that of frozen nitrogen is 1.027 g/cm^3.)

New Horizons' best images show that floes of nitrogen ice are indeed sliding into Sputnik Planitia from the higher elevations in neighboring Tombaugh Regio — in ways very reminiscent of glacial flows on Earth, observes investigator Orkan Umurhan (NASA Ames Research

What's in a Name?

As of early August, all of the names used by scientists for specific features on Pluto and its moons remained informal and unofficial. Usually, the International Astronomical Union's Working Group for Planetary System Nomenclature (WGPSN) approves thematically appropriate categories for feature names on a planetary body well ahead of time. But that didn't happen for New Horizons. Instead, the mission's scientists conducted a public poll for names (see ourpluto.org), ostensibly with a nod from the IAU, and the informal names used to date derived from that effort. WGPSN officials were not amused, especially because the various monikers used for specific features have never been submitted for formal approval. However, some degree of détente should have emerged on August 8th, when the two groups were scheduled to meet.

Center). They pass through narrow canyons and carry along dark ribbons of material that mimic the debris streams and moraines created by terrestrial glaciers. Along Sputnik's northern margin, the flows seem to be moving toward the shoreline and, in places, diving out of sight beneath a jumble of mountains.

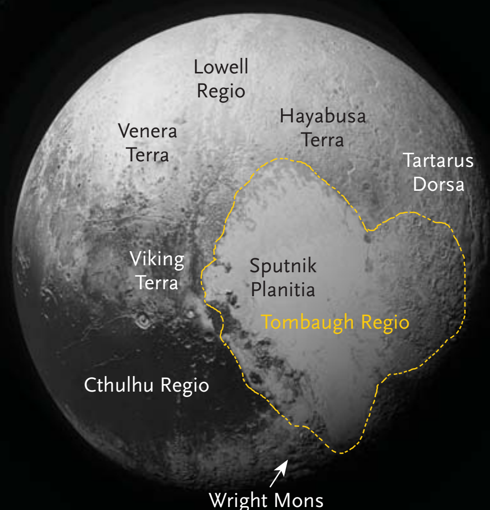
Pluto might be mostly silicate-based rock by mass, but no rocks lie on its surface. Instead, everything is ice of one form or another — surface temperatures range from 37K in the bright interior of Sputnik Planitia to 50K in the Sun-warmed dark expanses of Cthulhu Regio. Spectral maps acquired by the spacecraft's LEISA instrument (short for Linear Etalon Imaging Spectral Array), show this to be a ubiquitously icy landscape consisting of water (H_2O), nitrogen (N_2), methane (CH_4), and carbon monoxide (CO); abundance maps appear on page 20.

Water ice lies exposed only spottily, but it's the only one of these four that is strong enough to support topography. If it's not turning up in spectra, then most likely its presence is masked by a veneer of something else.

Stirrings from Within

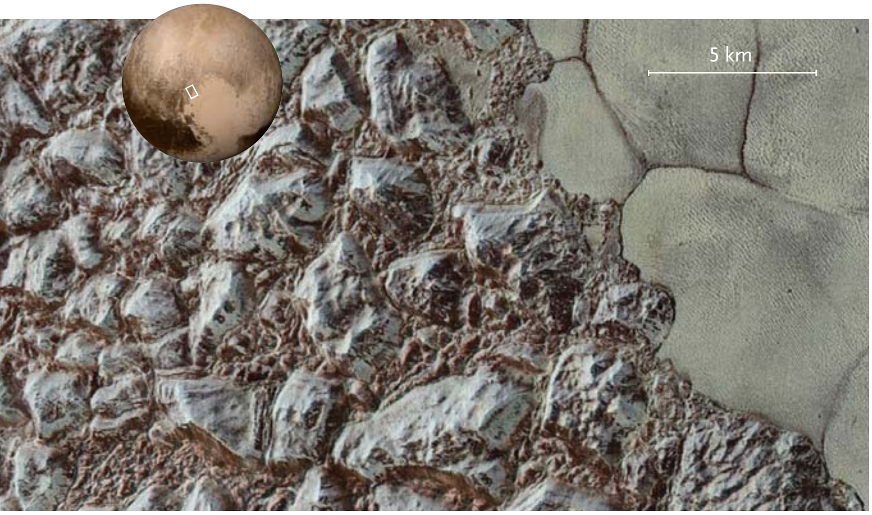
Sputnik Planitia's youthfulness begs the question: Could Pluto still be churning inside? Yes, insist geochemists who've run the numbers. First, they note that rock makes up 75% of Pluto's diameter and two-thirds of its mass. This means trace elements in the core are still releasing heat through radioactive decay, and that heat

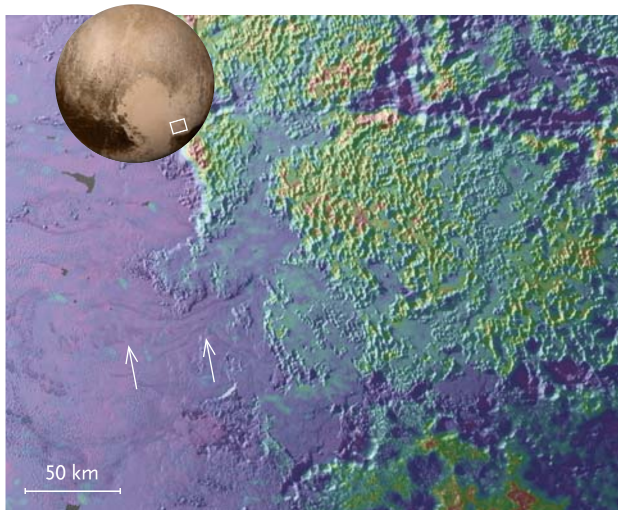
SO FAR AWAY Because Pluto rotates slowly, every 6.4 days, New Horizons saw the portion of its globe seen worst *(above)* when still 3 days and 4 million km from its flyby. The tantalizing details were not resolved any better than this.



MANY-SPLENDORED WORLD Seen in enhanced color at high resolution, Pluto displays a wild variety of terrain types — from bright, super-smooth Sputnik Planitia to ancient, organics-covered Cthulhu Regio.

NASA / JHU-APL / SWRI (3)





NASA / JHU-APL / SWRI (2)

BEAUTIFUL BADLANDS ***Left:*** **The rugged peaks of al-Idrisi Montes sit against the northwestern shore of Sputnik Planitia.** ***Right:*** **Even though much of Pluto never gets warmer than 50 kelvin, New Horizons scientists have spotted evidence of massive, recent downslope glacial flow (arrowed) from eastern Tombaugh Regio, at right, into Sputnik Planitia. Altitudes span 6 km in this color-coded view and range from pink (low) to orange (high).**

has to escape to the surface somehow. Second, frozen nitrogen melts at just 63K and should flow readily even when solid at Sputnik Planitia's surface temperature of 37K (–393°F).

The polygons provide the key evidence: they're the tops of solid-state "bubbles" percolating up from below. Sputnik Planitia is, in effect, a giant solid-state lava lamp that uses convection to deliver interior heat to the surface. Recent calculations by Alexander Trowbridge (Purdue University) and others show that convection will occur if the layer of nitrogen ice has a depth of at least 435 m (¼ mile).

Also, the bigger the polygons, the deeper the ice should be. On this basis, Trowbridge's team argues that the plain's convecting layer of frozen nitrogen should be at least 10 km thick in its center and thinner along its outer margin. But that would require the underlying basin to be implausibly deep, counters McKinnon. He and others believe the convection cells should get sluggish as they encounter the cold ice near the surface, an effect that would widen the polygons. So they maintain the ice layer need only be 3 to 6 km deep.

Whichever model is correct, both groups agree that the upwelling convection pushes the topmost ice along at rates of a few centimeters per year, meaning that the surface of Sputnik Planitia renews itself very rapidly — in just 500,000 to 1,000,000 years. No wonder there aren't any craters!

En route to the surface, the heat from deep inside should have melted Pluto's water-ice mantle at its base, creating a global layer 50 to 150 km thick. But does that deep-seated reservoir still exist? Two lines of evidence argue that it does.

First, if the mantle were solid throughout, overlying pressure should gradually transform the frozen water to a higher-density variant, known as Ice II. This conversion reduces the needed volume for all that ice, and Pluto should have contracted by up to 13 km in radius. We'd see that expressed topside as a dramatic series of compressional fractures — but they're aren't any.

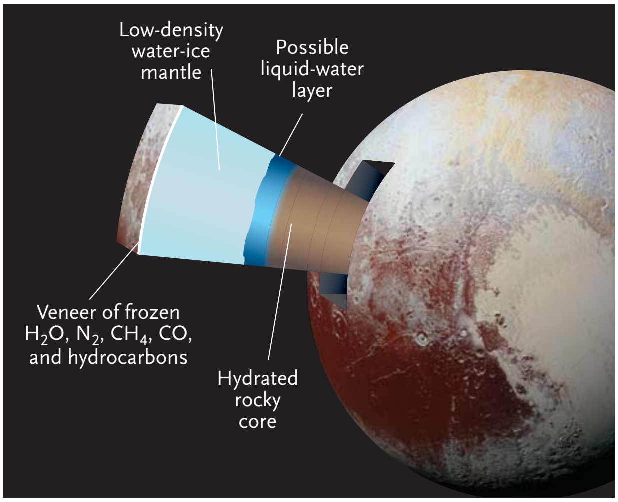
Second, just the opposite seems to be happening. An analysis by Noah Hammond (Brown University) and two colleagues argues that the assorted cracks seen in Pluto's surface result from *extension*, not compression, created because the globe has gradually expanded. "A subsurface ocean that was slowly freezing over would cause this kind of expansion," Hammond explains.

The New Horizons images reveal another pair of features that could have resulted from internal stirrings. Each is big, round, and tall, with a deep hole at its center. One, dubbed Wright Mons, is about 150 km across and 3 or 4 km high, with a central depression at least 5 km deep. To its south, lurking in the shadows along the day-night terminator, is a similar mound, Piccard Mons, that's half again wider and taller.

On Earth, we'd call these volcanoes. But Pluto's interior isn't hot enough to melt rock. Instead, a type of eruption called *cryovolcanism* could have occurred if a buried reservoir of liquid water, mixed with ammonia to lower its melting temperature, were squeezed under

(A LITTLE) MORE TO COME

Roughly 6 gigabytes (80%) of the New Horizons results are in hand. But there's still a smattering of low-priority data to retrieve from the spacecraft, now some 3 astronomical units past Pluto and 5.4 billion kilometers from Earth.



HEART OF STONE Despite its icy exterior, most of Pluto's mass consists of rocky material in its core. New studies suggest a liquid-water layer up to 150 km deep should exist at the base of the thick ice mantle.

pressure out onto the surface. The resulting ooze might have the consistency of toothpaste, notes Kelsi Singer (Southwest Research Institute), who has analyzed the two massive mounds. They can't be huge piles of nitrogen ice, she explains, because that isn't strong enough to support the weight of such tall structures. So they likely consist of water ice.

Interestingly, the flanks of these putative cryovolcanoes don't exhibit any craters (though one vague feature might be an impact, Singer says). Therefore, they're old but not primordial — likely having formed within the last billion years.

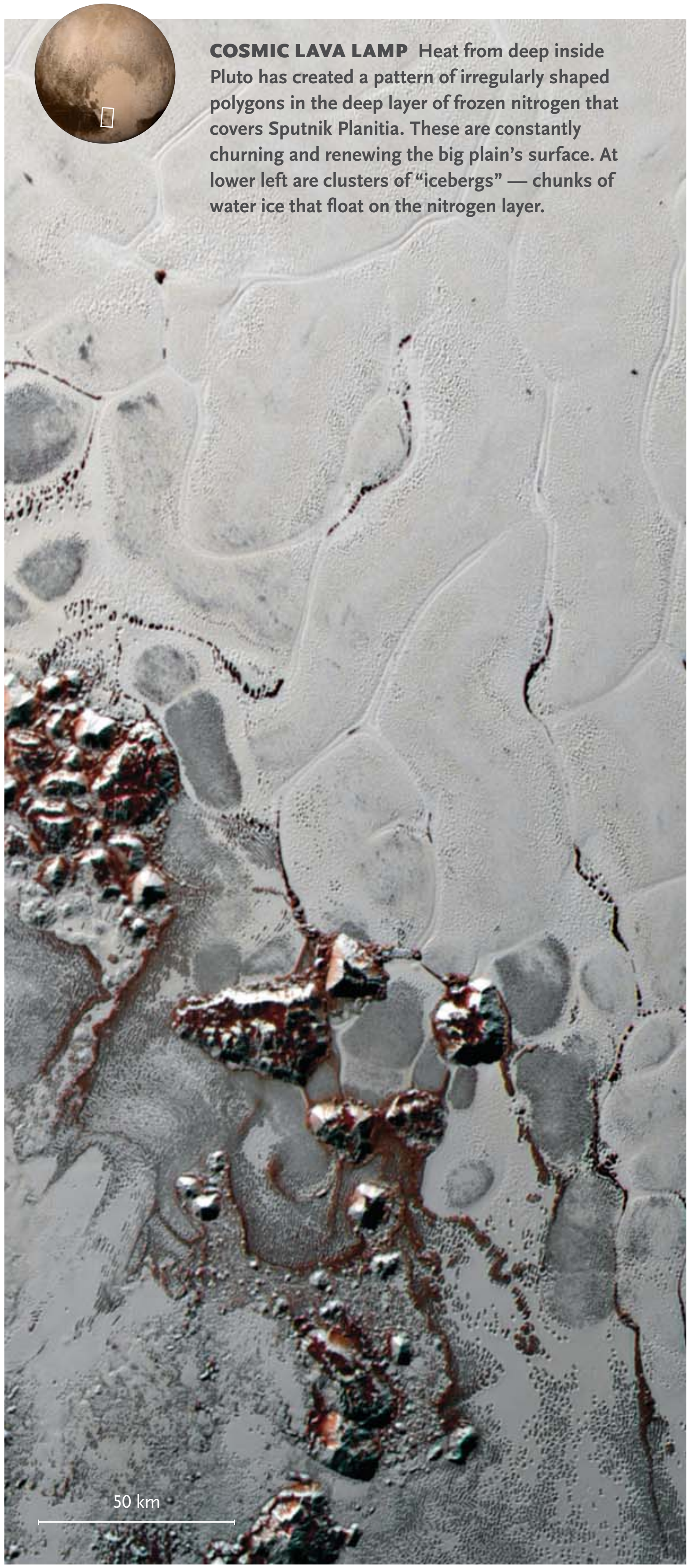
Confusing Complexity

There's more to Pluto than youthful cryovolcanoes and ice floes. In fact, much of the surface seen in the best New Horizons images is heavily cratered and thus quite old, some of it apparently dating to 4 billion years ago.

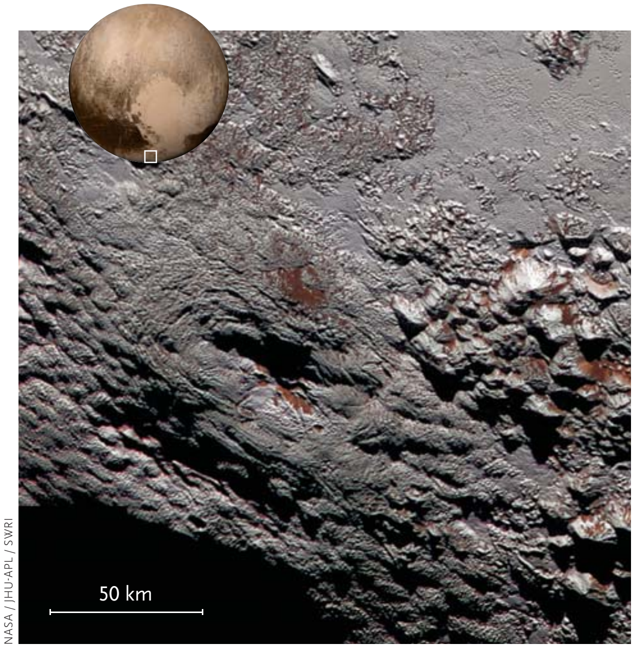
But even the old terrain is geologically complex. "Even now we have terrain types we just don't understand," admits Jeff Moore (NASA Ames Research Center), leader of the mission's geology and geophysics team. Instead, as he admitted at the conclusion of the recent science-team meeting, "We're sorting hypotheses according to whether they're more or less likely."

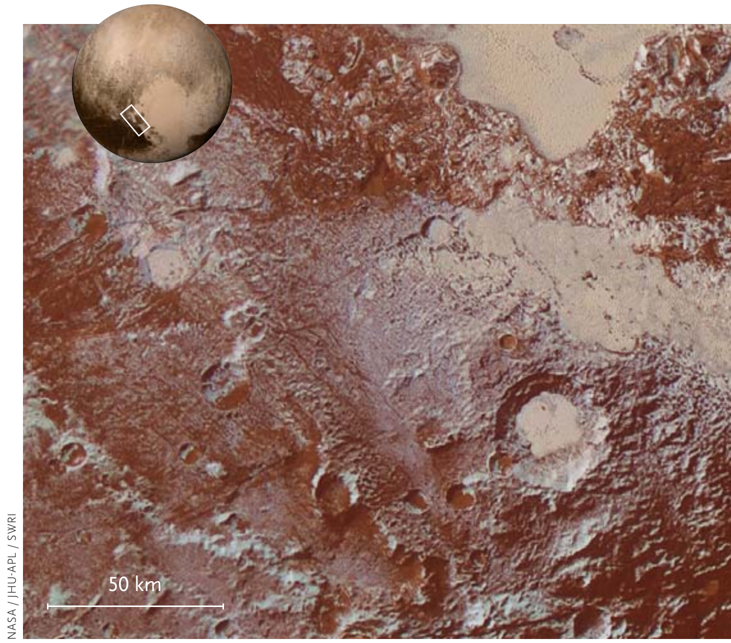
Here's a sample of what Moore dubs Pluto's "not yet explained" terrains, many of which are detailed in March 18th's *Science:*

• **Pitted uplands:** The southeastern corner of Tombaugh Regio sports a 100-km-wide plateau peppered with close-spaced pits up to 25 km across. In some spots the pits interconnect to form long troughs in undulating terrain. The pits' walls slope at up to 30°, a hint that they've formed in rigid material.



COSMIC LAVA LAMP Heat from deep inside Pluto has created a pattern of irregularly shaped polygons in the deep layer of frozen nitrogen that covers Sputnik Planitia. These are constantly churning and renewing the big plain's surface. At lower left are clusters of "icebergs" — chunks of water ice that float on the nitrogen layer.





WRIGHT'S STUFF *Left:* This roundish feature, called Wright Mons, appears to be a volcano about 150 km across that has gradually disgorged a thick, pasty water-ice slush from Pluto's interior. *Center:* A vast stretch of ancient, heavily cratered Cthulhu Regio along Pluto's equator has likely been covered with a veneer of complex, reddish-black organic matter.

• **Bladed terrain**: Northeast of the pitted uplands lie several 100-km-wide swells covered with blade-shaped ridges arrayed roughly parallel to one another. These outcrops, several hundred meters high and spaced 5 to 10 km apart, sometimes merge to form Y-shaped intersections.

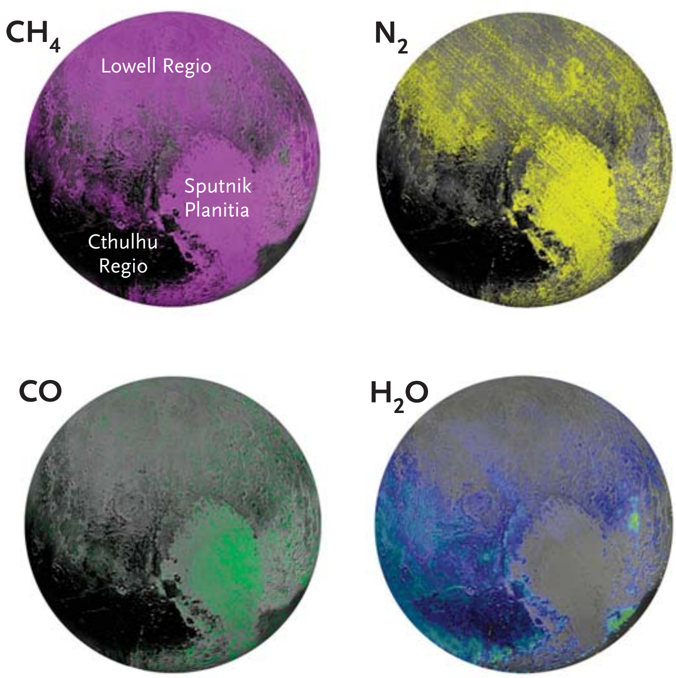
• **Washboard terrain:** Images of the region north and northwest of Sputnik Planitia often show expanses of parallel ridges and grooves that trend northwest to southeast and are spaced about 1 km apart. This washboard pattern doesn't mask underlying features, suggesting that it might be a thin coating that's been selectively deposited or eroded.

• **Cthulhu Regio:** An expanse of very dark terrain starts to the south of Tombaugh Regio and extends westward nearly halfway around the planet's equator. Patchy dark areas continue around the midsection on the side of Pluto seen only from great distances. It's apparently not a distinct surface type but rather a veneer of reddish-black material draped over the underlying topography.

"Our notion is that there's a latitude band for a reason," Stern comments. This largely ice-free belt corresponds nicely to the region within 13° of the equator that receives a lot of sunlight but has never been subjected to continuous darkness.

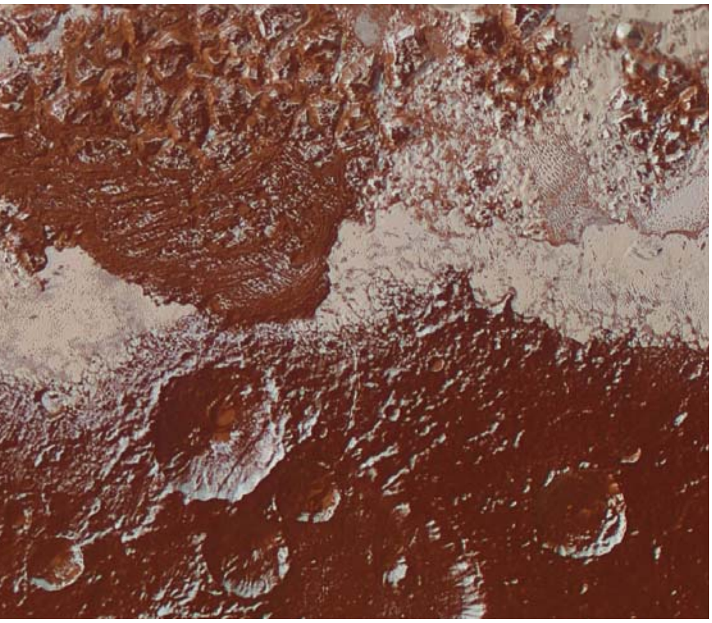
Prior to the spacecraft's arrival, astronomers knew that Pluto exhibited a wide range of bright and dark markings. Investigator Richard Binzel (MIT) was among those who used the long series of mutual events during the 1980s to painstakingly map this world's bright and dark areas in broad detail.

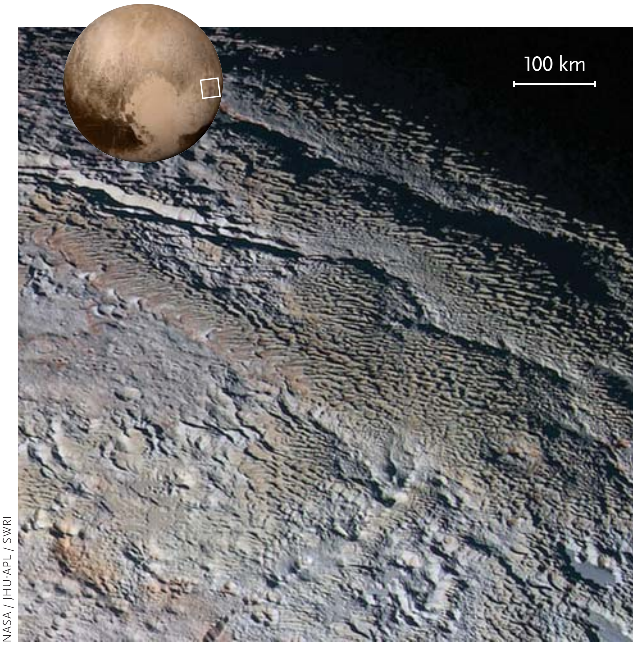
But the mission's scientists weren't prepared for the extreme contrasts revealed by New Horizons. According to an analysis by Bonnie Buratti (Jet Propulsion Laboratory) and others, the *albedo,* or reflectivity, of Pluto's surface runs the gamut from only 8% (nearly black) to



ICY MIX Four kinds of ice occur on Pluto's surface, but they appear in complex patterns and under disparate circumstances that aren't well understood.

NASA / JHU-APL / SWRI / W. GRUNDY





NASA / JHU-APL / SWRI

BLADED SNAKESKINS ***Right:*** **Mission scientists initially referred to this region of Tartarus Dorsa as a "snakeskin terrain." Note the repetitive, blade-like hills, about 5 to 10 km apart, that cover several rolling mounds and valleys. Some of the ridges meet in Y-shaped junctions — but their origin remains a mystery.**

virtually 100%. More remarkable is how closely these extremes can occur to one another. "I was surprised," says Binzel, "by the abrupt dark-bright boundary between Cthulhu Regio and Sputnik Planitia."

The surface is actually quite colorful overall. Laboratory simulations by Dale Cruikshank (NASA Ames) and others suggest that solar ultraviolet light — weak as it is so far from the Sun — has gradually transformed Pluto's coating of exotic ices into long-chain hydrocarbons, known as *tholins,* which can range in color from yellow to red to brownish black.

Frozen N_2, CH_4, and CO are likely mixed together in varying proportions across the globe. Nitrogen registers only weakly in LEISA's surface spectra, but it's the dominant gas in Pluto's thin atmosphere and likely the most dominant ice exposed on the surface. Meanwhile, methane has a widespread but spotty distribution. Carbon monoxide, also a challenge to detect, appears most concentrated in Sputnik Planitia.

In fact, this big, bright plain stands apart as the one area where New Horizons detected N_2, CH_4, and CO together. There's suspicion that, despite its low elevation, Sputnik Planitia's brilliantly reflective surface absorbs so little sunlight that it creates a convenient "cold trap" where these ices can readily condense.

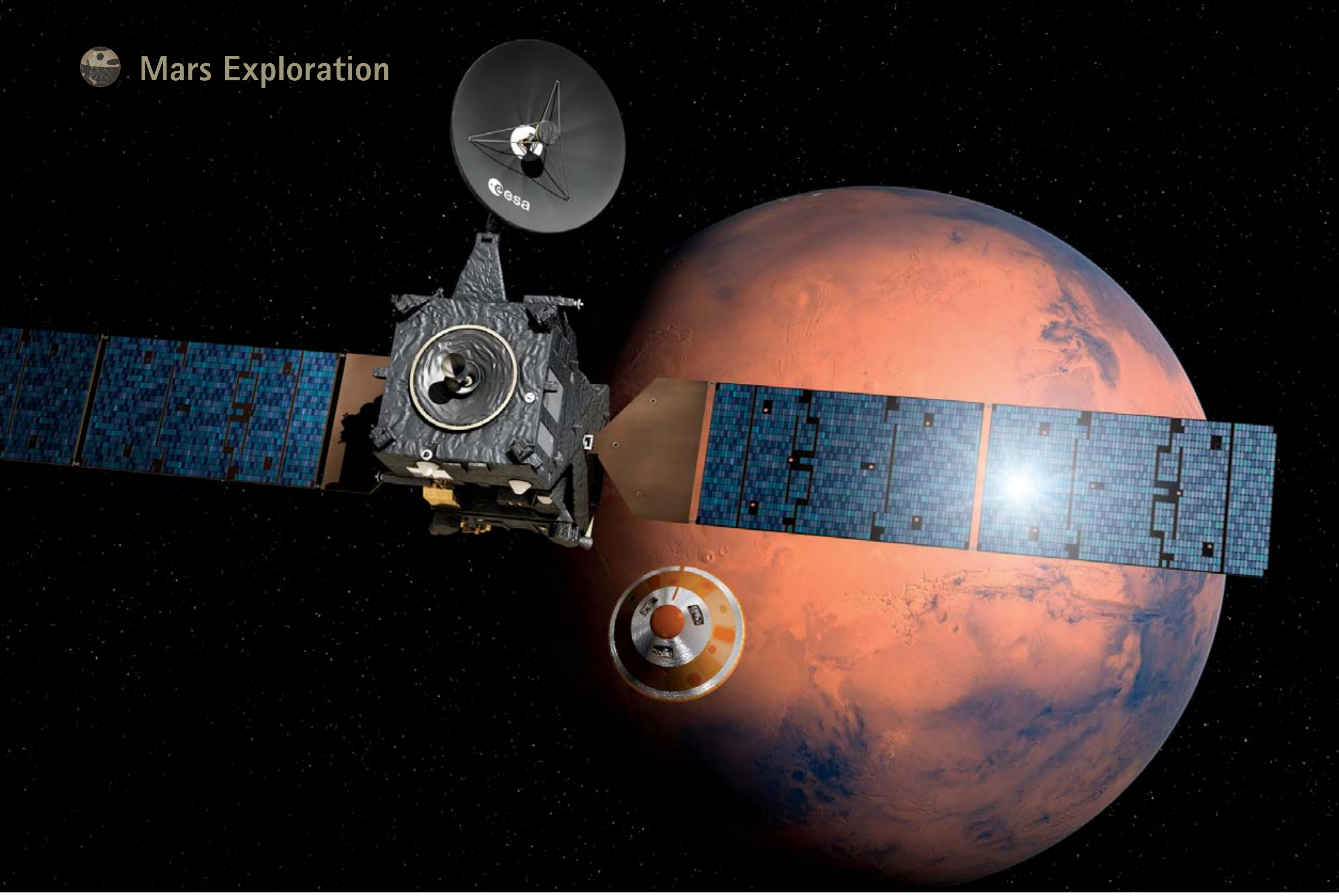
But elsewhere it's a compositional mishmash, and the complicated topography doesn't help. For example, methane ice coats many crater rims but is often absent from their floors. Nitrogen registers strongly on some crater floors, yet little is evident across the broad, bright polar expanse called Lowell Regio.

"Complicated" seems to fit no matter where the New Horizons scientists look. "Pluto has opened up a bunch of questions involving exotic materials and strange behaviors that we haven't thought about until now," says Moore. In fact, he adds, the sheer diversity of shapes, colors, and chemistry reminds him of another planet that's been a challenge to unravel: "Pluto is the new Mars." ✦

Senior Editor ***Kelly Beatty*** *has never seen Pluto through a telescope, but he spent a week at the mission control center for New Horizons during the spacecraft's historic flyby.*

2014 MU_{69} or Bust!

On July 1st, the New Horizons team got the good news they'd been hoping for: NASA managers have approved and intend to fund a Kuiper Belt Extended Mission that will allow the spacecraft to operate through 2021. That's enough time to plan, execute, and analyze results from a close flyby of Kuiper Belt object 2014 MU_{69}, an object situated 43.3 astronomical units (6.49 billion km) from the Sun. The encounter will take place on January 1, 2019, though the team took some critical first steps last October and November: a series of engine firings to redirect the spacecraft toward the roughly 45-km-wide body. "We'll also be taking images of about 20 other KBOs that New Horizons will pass distantly," notes principal investigator Alan Stern.



D. DUCROS / ESA

Looking for LIFE on MARS

Camille M. Carlisle

HELLO MARS The ExoMars Trace Gas Orbiter (TGO) and its "entry, descent, and landing demonstrator module," named Schiaparelli, appear in this artist's illustration as they'll be after the spacecraft releases the lander on October 16th. Three days later, Schiaparelli will head to the Martian surface and TGO will fire a braking rocket to begin orbiting the planet.

The first phase of the ExoMars mission arrives at the Red Planet this month to search for evidence of past or present life.

We obsess over Mars. Since the dawn of the Space Age, scientists have sent (or tried to send) more than 40 spacecraft to the Red Planet. Half have failed. In fact, only NASA has managed to land anything that operated on the surface for more than 2 minutes.

The European and Russian space agencies are hoping to change that. Their ExoMars mission is about one thing: life. The goal is to examine Mars for evidence of *exobiology*, or life beyond Earth — hence the mission's name. It will also be sensitive to signs of active geology.

ExoMars has two phases. The first involves an orbiter-lander combo that arrives at the Red Planet in mid-October; the second will be a full-fledged rover that launches a few years from now. When phase one arrives, the lander, named Schiaparelli, will detach and plunge to the surface. Meanwhile, the main spacecraft, called the Trace Gas Orbiter (TGO), will be captured by the planet's gravity and, over the next year, settle into a circular, near-polar orbit 400 kilometers (250 miles) above the surface, flying just above NASA's Mars Reconnaissance Orbiter.

Just a Whiff

Once it begins science operations in December 2017, TGO will search for signs of life by studying changes in the atmosphere and on the surface. It's designed to detect and characterize trace gases, which are any compound that makes up less than 1% by volume of Mars's atmosphere — everything besides carbon dioxide (an overwhelming 96%), argon, and nitrogen. This most-wanted list includes water vapor and methane (CH_4).

Scientists now know that methane exists on Mars, and they've seen hints of a seasonal cycle in its levels (see page 25). But methane is a pretty pickle of a find, because unless it's replenished it should only survive in the planet's atmosphere for about 400 years before being broken down by sunlight. On Earth, most methane comes from microbes called *methanogens,* raising the hope that Earth's smaller sibling might host alien life. But methane can also come from geological processes, such as the reaction of hot water and the mineral olivine (called *serpentinization*) or from sunlight's ultraviolet rays breaking up micrometeoroid dust deposited on the surface.

Disentangling where the methane and other trace gases come from will be no easy task. Isotopic ratios will matter — how much carbon-13 versus carbon-12 methane contains could favor either a biotic or abiotic source, for example. Yet researchers care not so much about each trace compound on its own but rather how it changes with respect to others, and how these abundances vary (or don't) with location, season, and local time. Sulfur dioxide (SO_2), for example, might indicate a geologically recent volcanic eruption, but that depends on what other simultaneous changes the orbiter detects.

After TGO has established a broad picture of what's in the atmosphere, it will home in on the details, such as the ratio of hydrogen to deuterium ("heavy hydrogen"). It will also characterize the whole atmosphere, specifically its pressure and temperature, as well as levels of aerosols, water vapor, ozone (O_3), and other compounds, then figure out the circulation patterns to track these things back to their sources.

A Spectrometric Mission

To achieve these goals, the orbiter carries a camera, two spectrometer packages, and a neutron detector.

With the camera, the mission team will create stereo surface maps and look for changes that correlate with any variations detected in the atmosphere.

The spectrometer suites will exploit sunlight to study

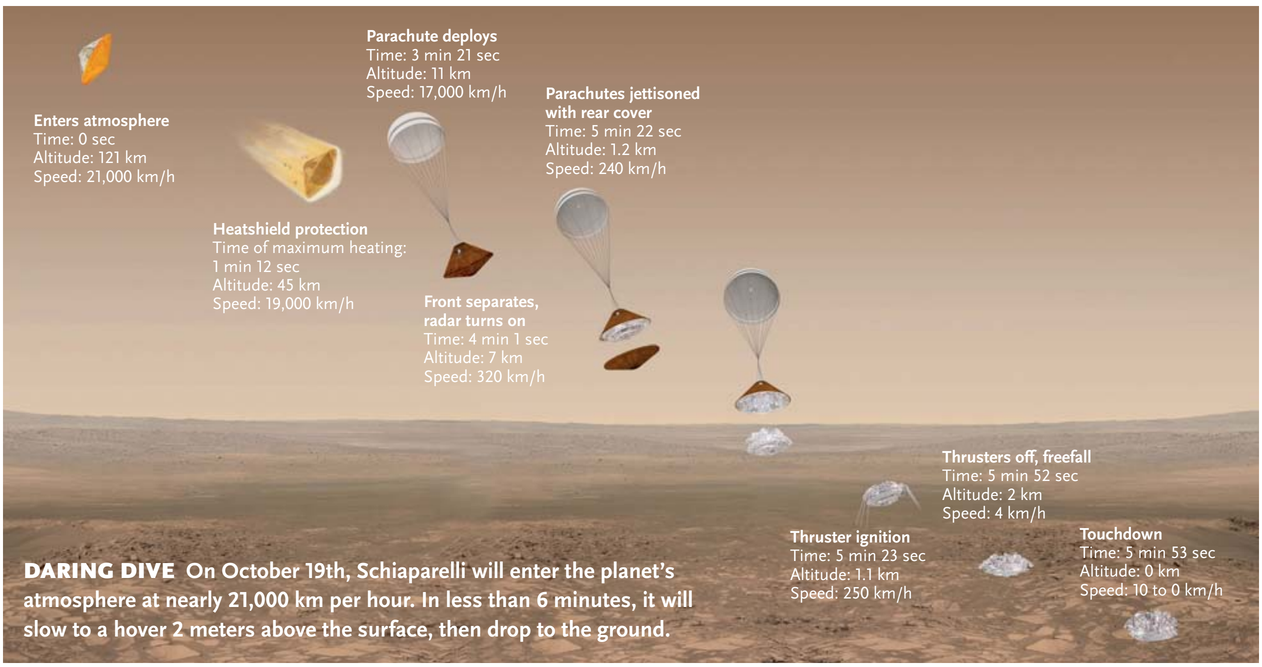
ExoMars Trace Gas Orbiter: Fast Facts

Spacecraft	3.2 m × 2 m × 2 m, solar wingspan 17.5 m
Power	solar, 2 lithium-ion batteries for eclipses
Communication	2.2-m high-power antenna, 3 low-power antennas for communication with Earth; Electra UHF transceiver for rover and lander contact

Science instruments

- *spectrometer suites:* Atmospheric Chemistry Suite (ACS); Nadir and Occultation for Mars Discovery (NOMAD)
- *camera:* Colour & Stereo Surface Imaging System (CASSIS)
- Fine Resolution Epithermal Neutron Detector (FREND)

Nominal mission ends 2022



DARING DIVE On October 19th, Schiaparelli will enter the planet's atmosphere at nearly 21,000 km per hour. In less than 6 minutes, it will slow to a hover 2 meters above the surface, then drop to the ground.

ESA / ATG MEDIALAB

Mars. As TGO loops around the planet, the spacecraft will study sunlight as it reflects off the surface, scatters in the air above the horizon, and passes through the atmosphere to the craft when it's flying through Mars's shadow. TGO will circle Mars every 2 hours, so it will be eclipsed by the planet 12 times a day (with a few exceptions due to the spacecraft's migrating orbit). During these frequent occultations, the spacecraft will depend on two lithium-ion batteries instead of its solar panels, which wingtip-to-wingtip span 17.5 meters (57.4 feet), or nearly the length of a bowling lane.

The fourth instrument, the neutron detector, will determine how much water ice exists within the top meter of the planet's surface. This detection will be an indirect one. When cosmic rays slam into the surface, they free neutrons from the atoms there. These neutrons scatter every which way, like the splat of a paint-gun pellet. Some of them even make it all the way to space, where TGO will catch them. The distribution of their velocities reveals how much hydrogen comprises the material they passed through. Since most hydrogen will be in water molecules, scientists (fairly safely) assume that any hydrogen they detect is a proxy for water.

Water ice is a big deal for long-term Mars exploration. Its abundance will influence future landing-site selections, both robotic and crewed. For instance, those working on NASA's Journey to Mars initiative — which aims to launch the first crewed mission to the Red Planet in 2035 — are currently exploring strategies for extracting water ice and other resources from the rust-stained Martian soil.

ExoMars Schiaparelli: Fast Facts

Diameter	1.65 m (without heat shield)
Height	1.8 m
Mass	600 kg
Power	battery
Communication	UHF link (2 antennas) with TGO

Science instruments

• *science payload:* Dust Characterisation, Risk Assessment, and Environment Analyser on the Martian Surface (DREAMS)

• *entry/descent tests:* Atmospheric Mars Entry and Landing Investigation and Analysis (AMELIA); Combined Aerothermal and Radiometer Sensors Instrument Package (COMARS+); Descent Camera on Schiaparelli (DECA)

• Instrument for Landing — Roving Laser Retroreflector Investigations (INRRI)

WHY "SCHIAPARELLI"?

The lander's name honors the Italian astronomer Giovanni Schiaparelli (1835–1910), who mapped the Red Planet's surface and drew the famous *canali* — dark lines that started a debate about Martians' existence.

Touchdown

The second part of ExoMars 2016 is Schiaparelli. It's a lander, not a rover — it's just going to sit there. But it *is* a technology testbed for the upcoming rover.

Schiaparelli will separate from TGO on October 16th. Three days later, it will enter the upper atmosphere in a daredevil dive of nearly 21,000 km/h (13,000 mph). As it plummets, the flying-saucer-like lander will measure the atmosphere's density, pressure, and temperature. Engineers will also use the dive to test the heat-shield design.

In less than 6 minutes, Schiaparelli will fall about 120 km and, thanks to aerobraking, a 12-meter-wide parachute, and three clusters of hydrazine thrusters, will slow to a standstill hover 2 meters above the surface (see illustration, page 23). Then the thrusters will cut and drop it to the ground. A crushable bottom, similar to a car's crumple zone, will absorb the thud.

Once on the surface, Schiaparelli will operate on battery power for 2 to 8 Martian days, or *sols*, which are 24.7 hours long. It will monitor local weather conditions, including humidity, dust, and wind speed, as well as electric fields near the surface, which might help maintain or even increase the atmosphere's dust levels (scientists don't yet know, because they've never measured these surface fields).

Airborne dust could pose a problem. Due to orbital mechanics, the lander arrives in the middle of the planet's storm season. Plus, its landing site in Meridiani Planum — roughly 50 km from where NASA's Opportunity rover is exploring the crater Endeavour — lies close to a track frequented by dust-laden winds. But storms usually occur in two peak periods, and Schiaparelli should arrive after the first peak. Regardless, engineers have designed it to handle blustery conditions.

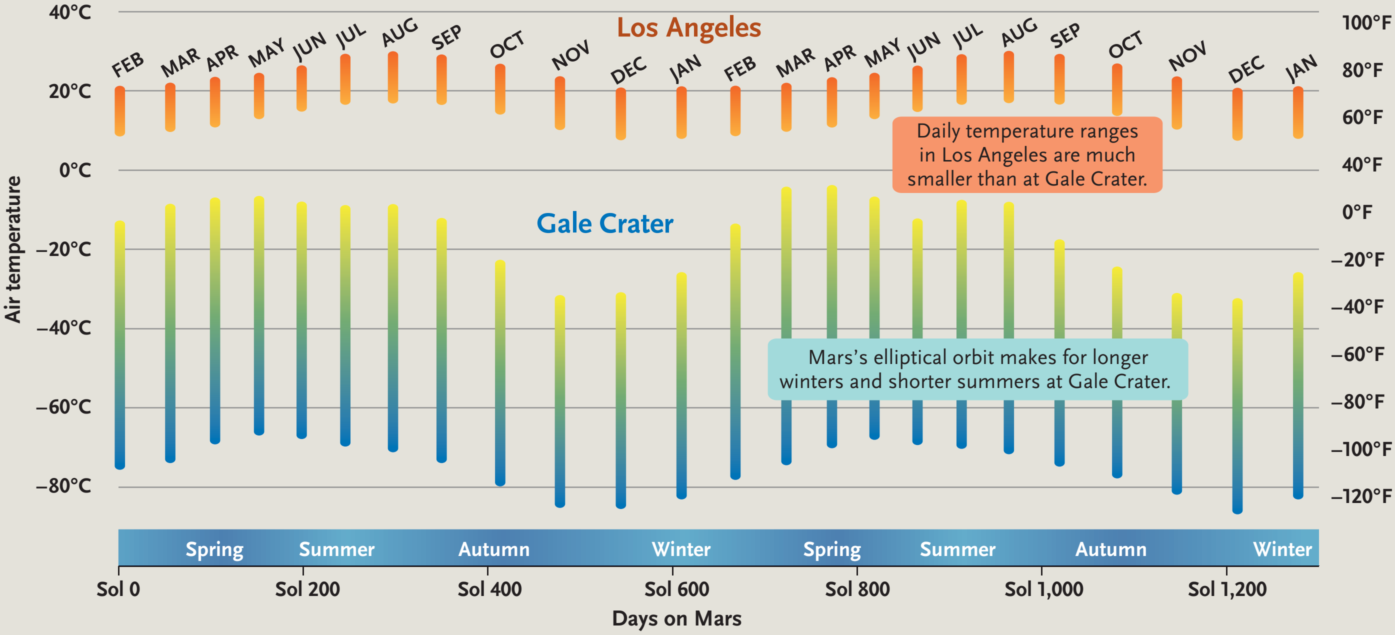
All this is merely ExoMars's first act; next comes the rover. Originally scheduled for a 2018 launch, the rover has been delayed to 2020 (*S&T:* Sept. 2016, p. 9). When it does reach the Red Planet, it will drill into the surface and collect samples, both to conduct exobiological and geochemical research and as a test for an upcoming international sample-return mission.

ExoMars won't be the only project heading to the Red Planet that year. NASA's Mars 2020 rover will also cache samples and look for hints of past life. In addition, it will test technology to extract oxygen from the atmosphere's carbon dioxide, in preparation for human exploration.

And the Mars race extends beyond Europe, Russia, and the United States. Japan, India, the United Arab Emirates, China, and even the private company SpaceX (cooperating with NASA) are all exploring ways to reach the Red Planet or its moons within the next decade. Our obsession with Mars continues. ✦

Science Editor ***Camille M. Carlisle*** *would never, ever, ever go to Mars.*

Seasonal Temperature Ranges at Gale Crater (with temperatures in Los Angeles at equivalent seasonal points)



Curiosity Sees Seasonal Trends on Mars

Curiosity recently completed its second Martian year, even though it landed in Gale Crater almost four years ago. That's because the Red Planet takes 687 days to complete one orbit around the Sun. During this time, the rover has detected seasonal changes much like Earth's yearly rhythm.

Curiosity has measured temperature variations ranging from about 60°F (16°C) on a summer afternoon to −148°F (−100°C) on a winter night. Daily ranges are much larger than on Earth. In addition, the air in Gale is very dry, with water content around 40 parts per million (ppm), or a few hundredths of a percent by volume, compared with Earth's typical reading of 20,000 ppm (a couple of percent). During the southern hemisphere's summer, relative humidity — a measure of how close water vapor is to saturating the air — is low. But in the winter, even though there is little water content in the air, the temperature drops so much that humidity actually goes up to 70%. That's because for a given amount of water vapor, the colder the air is, the closer it is to being saturated, making the relative humidity higher.

The rover has detected methane, too. Methane is the most abundant hydrocarbon in the solar system, but it must be replenished — either by biotic or abiotic activity — because it is easily destroyed by sunlight's ultraviolet rays. So when methane was first found on Mars in 2004, scientists were skeptical.

But when Curiosity detected a spike of 7 parts per billion by volume (ppbv) during its first autumn (*S&T:* Apr. 2015, p. 14), it confirmed methane's presence in the atmosphere. Scientists are still unsure where the compound came from.

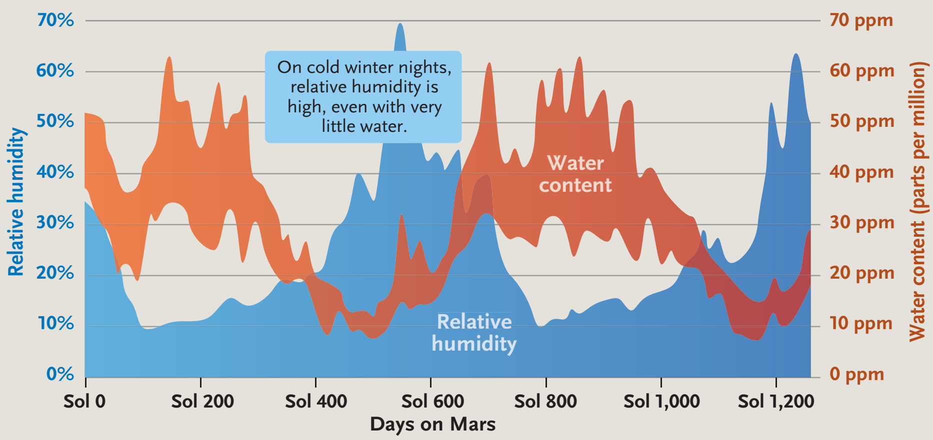
The rover has also measured a methane "background." The levels over the last two Martian years fall mostly between 0.3 and 0.8 ppbv, and possibly follow seasonal patterns. Although scientists checked carefully, the methane spike that happened during the first autumn did not repeat during the second autumn. This indicated it was an episodic event that might not occur again.

The mission continues to monitor methane levels, which appear to be even lower in autumn than in other seasons. If confirmed, the low autumnal level could be a delayed reaction to summer's high doses of ultraviolet radiation from the Sun.

HIGHS AND LOWS Much like those in Los Angeles, temperatures on Mars follow a seasonal pattern. These data are for Gale, which lies just south of the equator. Each bar is an average over 1/12 of the planet's year.

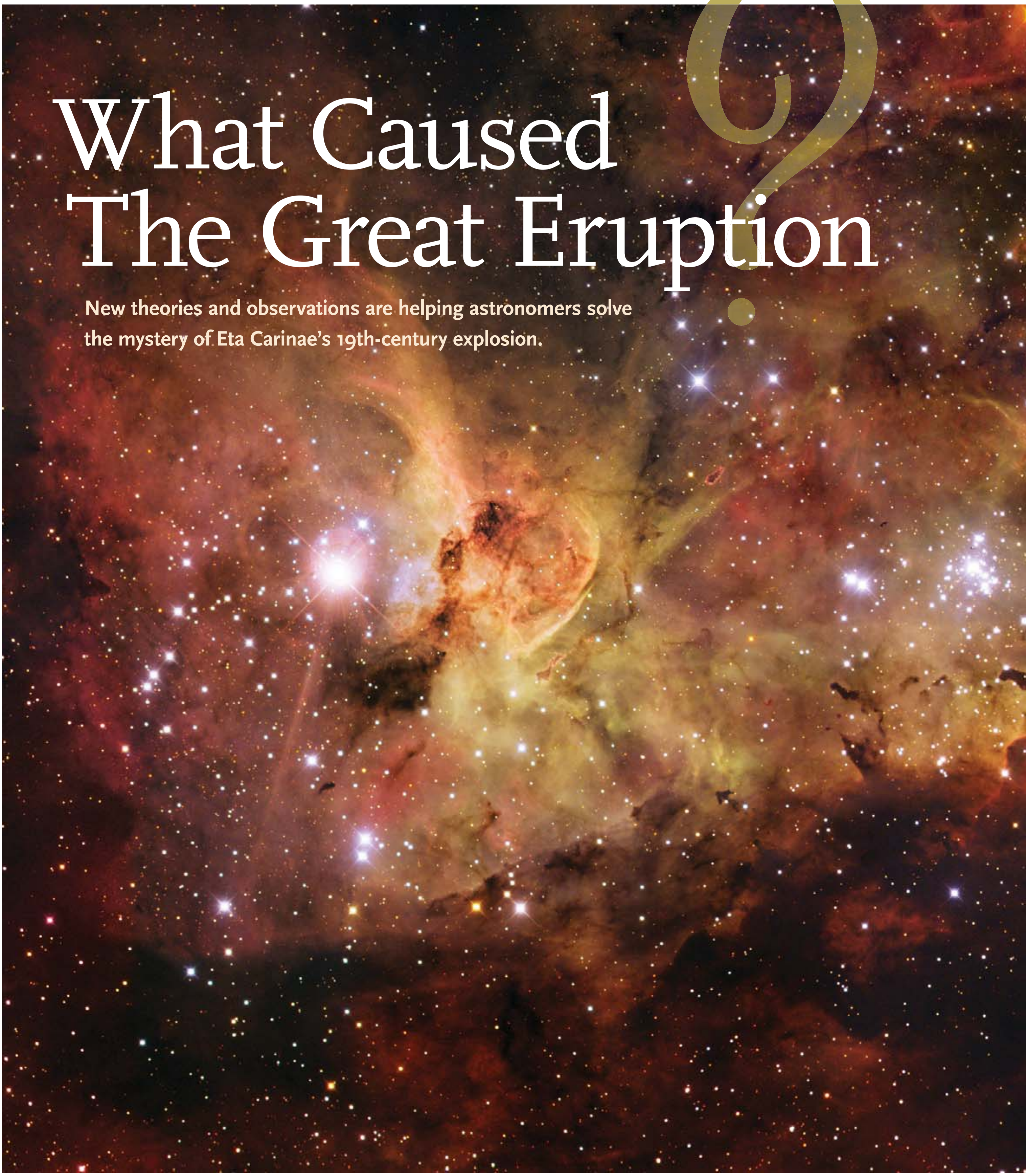
Ana V. Aceves *is S&T's editorial intern.*

Ranges of Atmospheric Water Content & Relative Humidity at Gale Crater



NOT A MUGGY WINTER The air in Gale is most humid in winter, even though the water content is lowest at that time of year (see text). The average water content of 40 ppm is 1/500 that of the 20,000 ppm that is typical on Earth.

S&T: GREGG DINDERMAN, SOURCE: NASA / JPL-CALTECH / CAB (CSIC-INTA)(2)



What Caused The Great Eruption?

New theories and observations are helping astronomers solve the mystery of Eta Carinae's 19th-century explosion.

KEITH COOPER

When John Herschel looked up at the sky late one summer evening almost two centuries ago, he knew it didn't look right.

The great British astronomer had been living with his family on the Feldhausen estate near Cape Town, South Africa, cataloging the clusters, double stars, and nebulae of the Southern Hemisphere. As he stepped outdoors into the mild evening air on December 16, 1837, he scanned the sky and noticed a star in the constellation Argo Navis that seemed wrong. Herschel had frequently observed this star, then known as Eta Argus, at magnitude 1.4 throughout his time in South Africa. This evening it had brightened dramatically, outshining even Orion's magnitude-0.13 star, Rigel.

Unbeknownst to Herschel, the star was undergoing an incredibly violent process — now called the Great Eruption — and today astronomers are still trying to figure out what happened. Herschel returned to England the following year. Had he remained in South Africa, he would have seen Eta Argus grow even more dazzling. By 1843, it had become second only to brilliant Sirius.

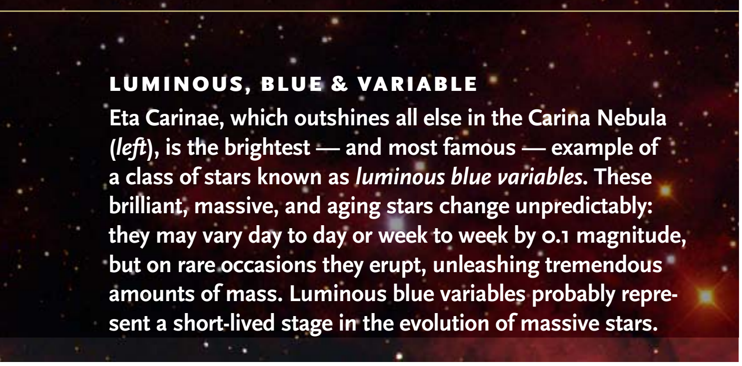
Eta Argus blazed for more than a decade but began fading dramatically in 1858, dimming to 8th magnitude. The star experienced a brief resurgence between 1887 and 1894 in what is commonly referred to as the Lesser Eruption, when it just about reached naked-eye visibility. Today, it lingers at magnitude 4.5 — not too shabby for a star some 7,500 light-years away.

In modern nomenclature, the star is called Eta Carinae. Its constellation, the ancient and unwieldy Argo Navis (*S&T*: March 2015, p. 36) has long since been broken into three more manageable pieces, with Carina being the mythical ship's keel. Modern instruments show that Eta Carinae is actually a binary system, with a primary star about 100 times the Sun's mass that's classed as a *luminous blue variable* (LBV) — an aging star prone to violent outbursts. Its companion, unseen amidst the primary's glare, contains roughly 30 times the mass of the Sun, but without direct observations, astronomers don't know much more about it. The secondary could be an *O*-type main-sequence star or perhaps an evolved Wolf-Rayet star. The two companions orbit each other every 5.5 years in an oval-shaped orbit.

Fewer than 20 LBVs are known in our galaxy, and a significant fraction display evidence of past eruptions. Astronomers witnessed one such outburst during the 17th century when the LBV P Cygni ejected about 0.1 solar mass of material.

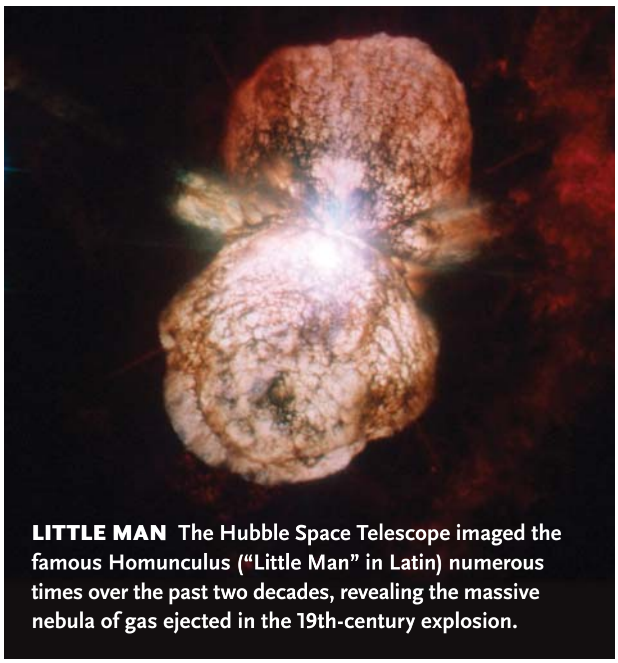
Although such an outburst could potentially explain Eta Carinae's flare around 1890, no such outburst has approached the scale of the Great Eruption, when Eta Carinae threw between 10 and 40 solar masses' worth of gas and dust into the Homunculus. This twin-lobed nebula now stretches 0.6 light-year long. The star's luminosity increased to 10 million times that of our Sun during the eruption, generating almost as much radiation over the course of two decades as a typical supernova.

Yet, unlike in a supernova, Eta Carinae survived. Numerous scenarios have tried to explain why. One popular idea proposed that, if the star were spinning fast enough to squash itself into an oblate shape, then a regular LBV-style outburst would concentrate at the



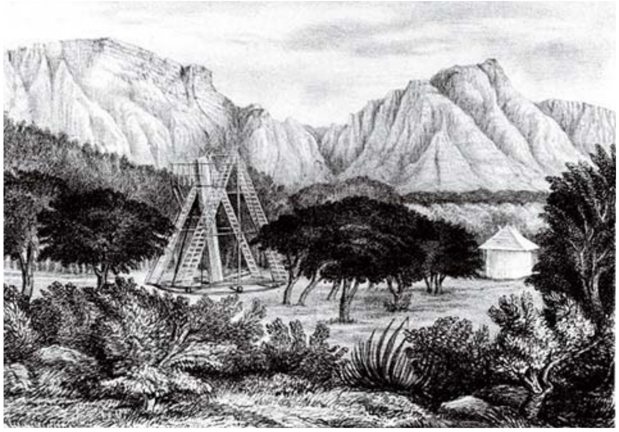
LUMINOUS, BLUE & VARIABLE Eta Carinae, which outshines all else in the Carina Nebula (*left*), is the brightest — and most famous — example of a class of stars known as *luminous blue variables*. These brilliant, massive, and aging stars change unpredictably: they may vary day to day or week to week by 0.1 magnitude, but on rare occasions they erupt, unleashing tremendous amounts of mass. Luminous blue variables probably represent a short-lived stage in the evolution of massive stars.

ESO / IDA / DANISH 1.5-M / R. GENDLER, J-E. OVALDSEN, C. THÖNE & C. FERON



LITTLE MAN The Hubble Space Telescope imaged the famous Homunculus ("Little Man" in Latin) numerous times over the past two decades, revealing the massive nebula of gas ejected in the 19th-century explosion.

ESA / HUBBLE & NASA



SCIENCE PHOTO LIBRARY

UNDER SOUTHERN SKIES John Herschel erected a 20-foot telescope on the Feldhausen estate near Cape Town, South Africa, during the 1830s.

star's poles and become extra-powerful. Yet even in the most extreme case, it was hard to see how this mechanism could rival the energy and mass expelled by Eta Carinae. So that idea, among others, fell by the wayside.

Today astronomers deliberate between two main alternatives, a pre-supernova explosion or a stellar merger — and the debate is far from settled.

The False Supernovae

During the late 1990s, as various teams undertook systematic searches for supernovae, they began turning up so-called supernova imposters — stars that appear to explode, sometimes even more than once, yet somehow survive. Several of the imposters eventually did explode for real, most notably the supernovae known as SN 2006jc and SN 2009ip. In fact, had we witnessed Eta Carinae's Great Eruption in another galaxy, it may well have looked like a supernova imposter.

"But we still don't have a theoretical model that explains them," admits Nathan Smith (University of Arizona). Smith has been chasing supernova imposters for almost a decade. Although their origin remains a mystery, he and others have found a characteristic feature to distinguish their quarry: narrow emission lines.

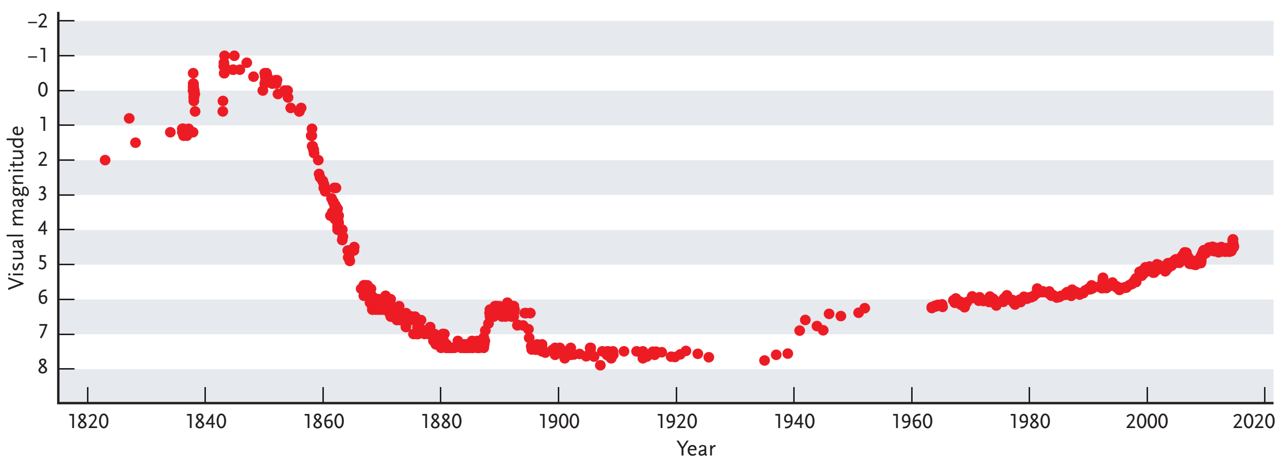
When a massive star's outer layers erupt in an imposter explosion, the outflow of hot, dense hydrogen gas emits light at specific wavelengths, known as emission lines. Because the gas is moving relatively slowly, the emission lines are narrow — unlike the broad lines characteristic of a true supernova. If the same star really does go supernova later, its shockwave will ram into the back of the older material, reheating it and again releasing narrow emission lines. In fact, the obscuring gas may be so dense that it hides the supernova's broad lines, making it difficult to differentiate imposters from the real thing.

Imposter events tend to occur late in a star's life, sometimes just years before a true supernova, so it's likely that the fault lies with the aging process. As a stellar core begins to run out of hydrogen for nuclear reactions, it must instead use the elemental ashes of prior fusion for fuel — this is how stars forge increasingly heavier elements in their centers. Within these heavy-fusion regions, Smith explains, bubbling and swirling motions due to convection and turbulence could mix the gas in just the right way to create violent instabilities — in other words, the potential for explosions.

Yet if imposter explosions precede the real thing, why is Eta Carinae still shining happily 173 years after the peak of its Great Eruption? "There's some missing ingredient that we don't understand," says Smith.

Crashing Stars

Then again, perhaps it's not just a missing ingredient but an entirely different recipe. Simon Portegies Zwart (Leiden University, The Netherlands) and Edwin van den Heuvel (University of Amsterdam, also in The Netherlands) recently proposed a game-changing alternative:



OVER THE CENTURIES Eta Carinae flashed its way to celebrity in 1837 before plunging back into obscurity two decades later. More recently, the system has edged its way back into naked-eye view. E. FERNÁNDEZ-LAJÚS ET AL., ASTRONOMY & ASTROPHYSICS 2009 / HTTP://ETACAR.FCAGLP.UNLP.EDU.AR that the Eta Carinae system was once home to not two stars, but three, and that the Great Eruption occurred when the inner duo merged.

Portegies Zwart sets the scene by asking us to picture a typical hierarchical triple — in this case, an inner binary system separated by an astronomical unit (a.u.; the distance between Earth and the Sun) and a third, outer star riding an inclined orbit at 25 a.u.

"What ultimately drives the merger is the interaction between the outer star and the inner binary," Portegies Zwart explains.

Portegies Zwart and van den Heuvel think the source of the stellar interactions is the *Lidov-Kozai mechanism*, named after its independent discoverers, Soviet space dynamicist Michail Lidov and Japanese astronomer Yoshihide Kozai. The idea is that when the outer member of a triple system is in a highly inclined orbit, it nudges the inner binary, changing the shape and inclination of the inner stars' orbits. The resonance between the three bodies eventually forces the inner stars to collide.

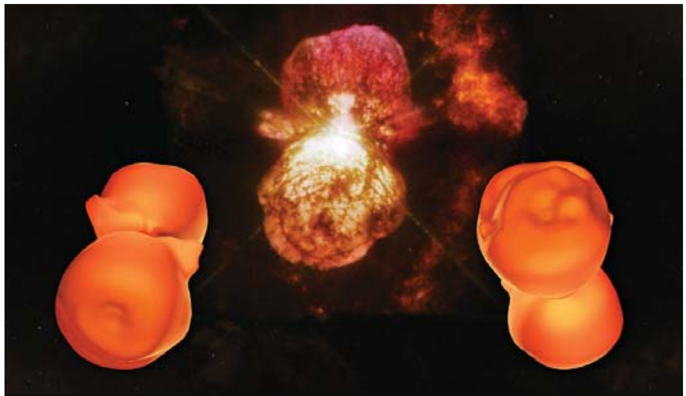
Portegies Zwart and van den Heuvel suggest that this merger sparked the initial brightening that Herschel witnessed in late 1837. The subsequent peak in 1843 occurred when the outer star — now the secondary object in the system — punched through the bloated envelope around the newly merged star, ejecting material and releasing a huge amount of energy.

This scenario predicts that the orbital plane of the two surviving stars should be aligned with the equatorial plane (and the "skirt") of the Homunculus Nebula.

The theory also predicts that the inner merger should have given the binary system a good "kick," sending it flying through space at 50 kilometers per second (more than 100,000 mph). The obscuring Homunculus Nebula complicates efforts to measure the motion of Eta Carinae's binary; astronomers will need extremely accurate astrometry over several decades to verify the kick. However, astronomers have seen several other LBVs speeding across the sky, so mergers might indeed occur frequently among such stars.

But if explosive stellar mergers are common, then why haven't we seen other Eta Carinae–like outbursts? A recent Spitzer Space Telescope project led by Rubab Khan (NASA Goddard) searched nearby galaxies for analogs of the modern (post-outburst) Eta Carinae; these would appear as luminous objects enveloped in dusty shrouds. Khan's team turned up only five Eta Carinae twins — two in M83 and one each in M51, M101, and NGC 6946. The dust-enshrouded phase might be so short, Smith says, that Eta Carinae–like objects appear rarer than they are.

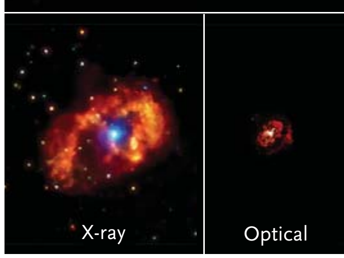
Astronomers had previously proposed that interactions among a triplet system might have created the Great Eruption. But merger scenarios in particular



IN THREE DIMENSIONS Wolfgang Steffen, Thomas Madura, and colleagues fed spectroscopic observations into the *Shape* software to build their 3D model of Eta Carinae (*insets*). The "wings" seen in their model are unrelated to the "skirt" seen in the Hubble image, which is invisible in the spectroscopic observations. Instead, Madura thinks the protrusions formed as the fast stellar wind of the binary's secondary star collided with the outer nebula.

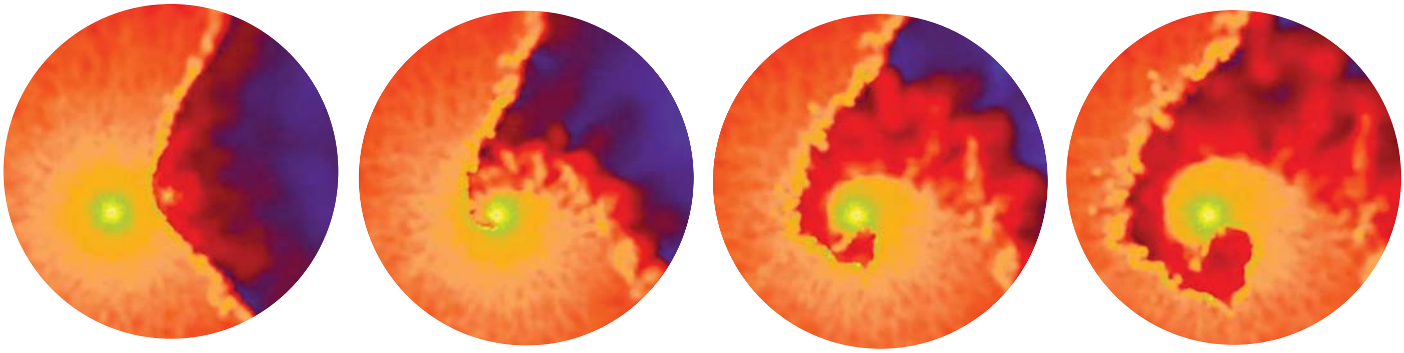
NASA GSFC CI LAB

HOT STUFF The 10 million-degree gas surrounding Eta Carinae lights up in X-rays. This image reveals an outer horseshoe-shaped ring, a hot inner core, and a hot central source. Long-term monitoring has revealed a regular flash of X-rays from this central source every 5.5 years, a period that matches the orbit of the central binary stars.



TO SCALE The X-ray-emitting gas around Eta Carinae, imaged by Chandra, dwarfs Hubble's view of the Homunculus, seen here for the same field of view.

X-RAY: NASA / CXC / GSFC / K.HAMAGUCHI ET AL.; OPTICAL: NASA / STSCI



haven't been explored in detail, and Smith is intrigued by Portegies Zwart's model.

"I've seen Simon's paper and I've talked to him about this," Smith says. "It seems a pretty easy way to get the amount of energy and mass that you need."

Yet while Smith agrees that mergers may explain some supernova imposters, he still harbors doubts about whether a merger could have caused the Great Eruption. Under normal circumstances, he points out, the Lidov-Kozai mechanism ought to act quickly upon a star system, within a matter of hundreds of thousands of years. Eta Carinae is around 3 million years old, so the merger should have happened long ago. However, Portegies Zwart suggests that gravitational tides (the same forces that long ago locked the Moon's face toward Earth) played an important role in delaying the merger, arguing that with one effect working against the other, it could quite easily take millions of years to nudge the inner stars into a collision.

The Winds of Eta Carinae

Thomas Madura (San Jose State University) and colleagues are taking a different angle to understanding Eta Carinae: rather than studying the stars themselves, they're studying the stars' winds as the outflows interact with the surrounding Homunculus Nebula. Whatever explosion created the nebula, the stellar winds blew it out and sculpted it, so understanding the winds is part and parcel to explaining the nebula's origins.

Back in 2013, while perusing the posters at the 221st meeting of the American Astronomical Society in Long Beach, California, Madura chanced across an eye-catching study. The poster, presented by student David Clark (National Autonomous University of Mexico), described visualization software called *Shape*, which Clark had used to produce a 3D model of the planetary nebula NGC 7026.

Madura and colleagues had just finished using the X-Shooter spectrograph on the European Southern Observatory's Very Large Telescope in Chile to accumulate a wealth of data on the motions of molecular hydrogen within Eta Carinae's nebula. Madura realized that, with the help of Clark's advisor, Wolfgang Steffen (also at National Autonomous University of Mexico), *Shape* could transform that data into a 3D model of the Homunculus. Following a year's worth of emails and Skype conferences between the teams, the model took shape.

"We were pretty surprised by some of the features that we found," says Madura. The 3D-printed model showed trenches and protrusions on the nebula's surface that appear to originate from deep within the nebula, where winds pouring out from the two stars meet.

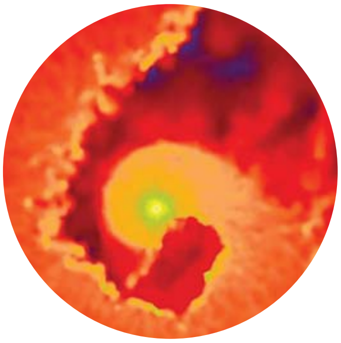
As the winds collide, the gas heats up to more than 10 million degrees and radiates X-rays. The X-ray emission peaks without fail every 5.5 years, when the secondary star's orbit reaches its closest point to the primary star. Using NASA's Rossi X-ray Timing Explorer, as well as the X-ray Telescope aboard the Swift satellite, Madura and colleagues have peered through the cloak of the Homunculus Nebula to monitor the winds over almost a decade. They've also done 3D computer simulations, which follow the nimble outflow from Eta Carinae's smaller companion as it punches a tunnel through the primary star's denser, slower wind. The tunnel's extent, as measured from the simulations, matches the trenches and protrusions seen on the nebula's surface.

"One of the reasons why the nebula has the shape that it has is because it is expanding at different speeds at different latitudes," Madura says. Material along the equatorial plane of the Homunculus floats outward at 50 to 100 km/s, while the ends of each lobe reach speeds between 500 and 600 km/s. Meanwhile, the stellar wind from the binary's secondary star hurtles out at 3,000 km/s. That wind may already have caught up to the Homunculus, blowing out the protrusions seen in Madura's observations.

Based on the simulations that reproduce the positions and shapes of the protrusions, Madura calculates that the two stars orbit each other on a plane that's within 10° of the Homunculus' equatorial plane — as Portegies Zwart's merger scenario predicts.

"I'm personally more inclined towards the merger event," Madura says, though he agrees with Smith that some of the details still need to be worked out.

Explore the 3D models of Eta Carinae observations and simulations at https://is.gd/etacarinae_models.



CLOSE APPROACH These simulation snapshots look down on the orbital plane of the two stars in the Eta Carinae system. The view spans 320 a.u. (47.8 billion km). Lighter colors indicate greater densities, with the highest densities occurring near the primary star and in the region where the stellar winds interact. The faster wind from the smaller star carves a spiral cavity into the denser wind from the primary star. This structure expands outward along with the primary's stellar wind at 440 km/s (1 million mph). Detailed simulations such as this one are necessary to understand how the colliding stellar winds shape the Homunculus Nebula, enabling researchers to trace the nebula's evolution back to the time of the Great Eruption.

NASA GSFC / T. MADURA

Beyond Eta Carinae

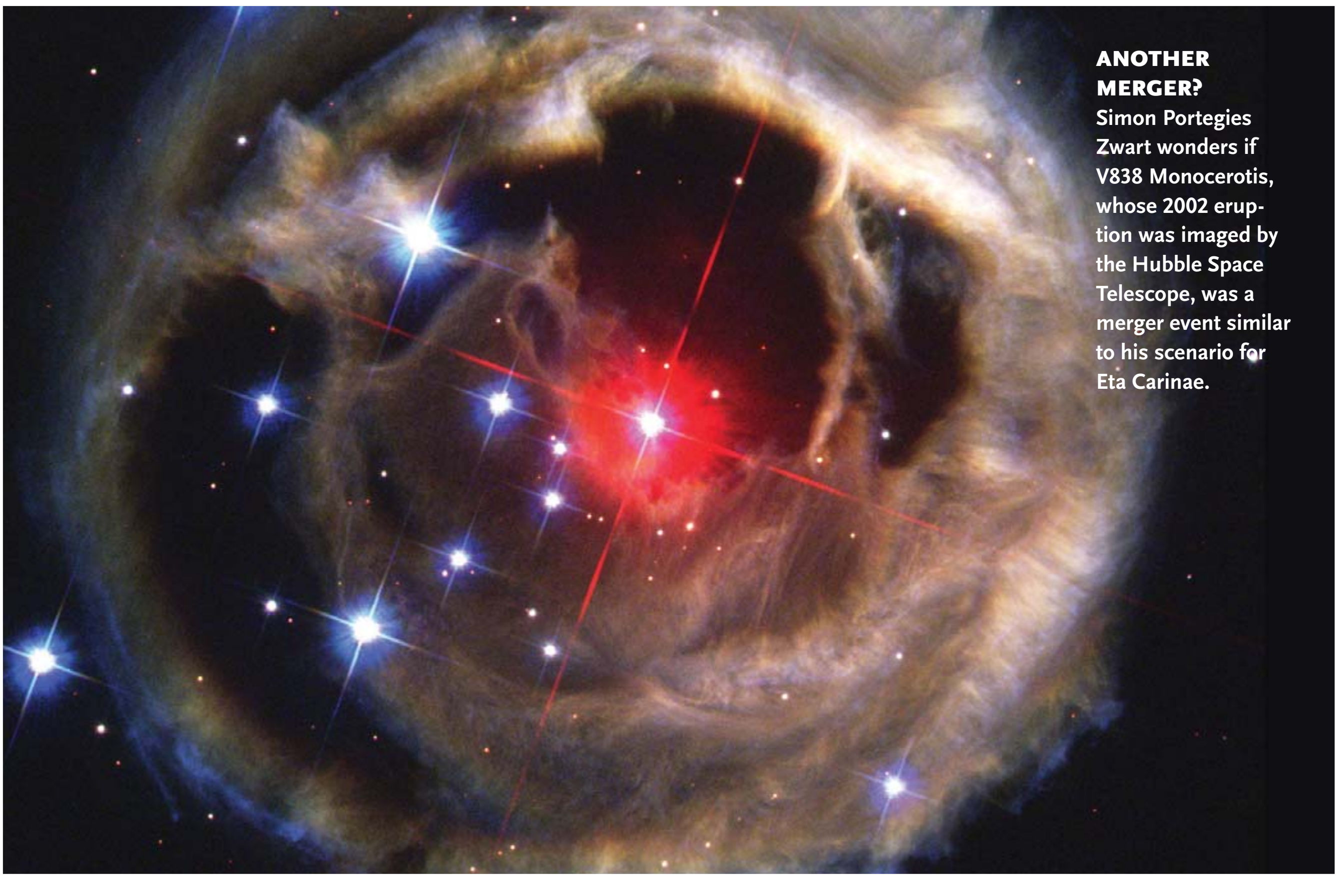
Madura is now asking NASA for funding to crash stars together in a supercomputer simulation. Though not directly related to Portegies Zwart's work, such calculations could end up supporting it. Madura wants to see if mergers in Eta Carinae–like systems can reproduce the intricacies seen in the surrounding winds.

"It's something I've wanted to do for a long time," he says. "We want to start from first principles and see if we can explain the shape of the Homunculus and see whether the winds start to catch up with the nebula to create these protrusions that we observe."

Meanwhile, Portegies Zwart wants to start looking at other objects like Eta Carinae, such as V838 Monocerotis. This star, whose unexpected 2002 outburst was captured in dramatic Hubble images, shows an intriguing resemblance to Eta Carinae. "V838 Monocerotis is very high on my wish list for further study," Portegies Zwart says.

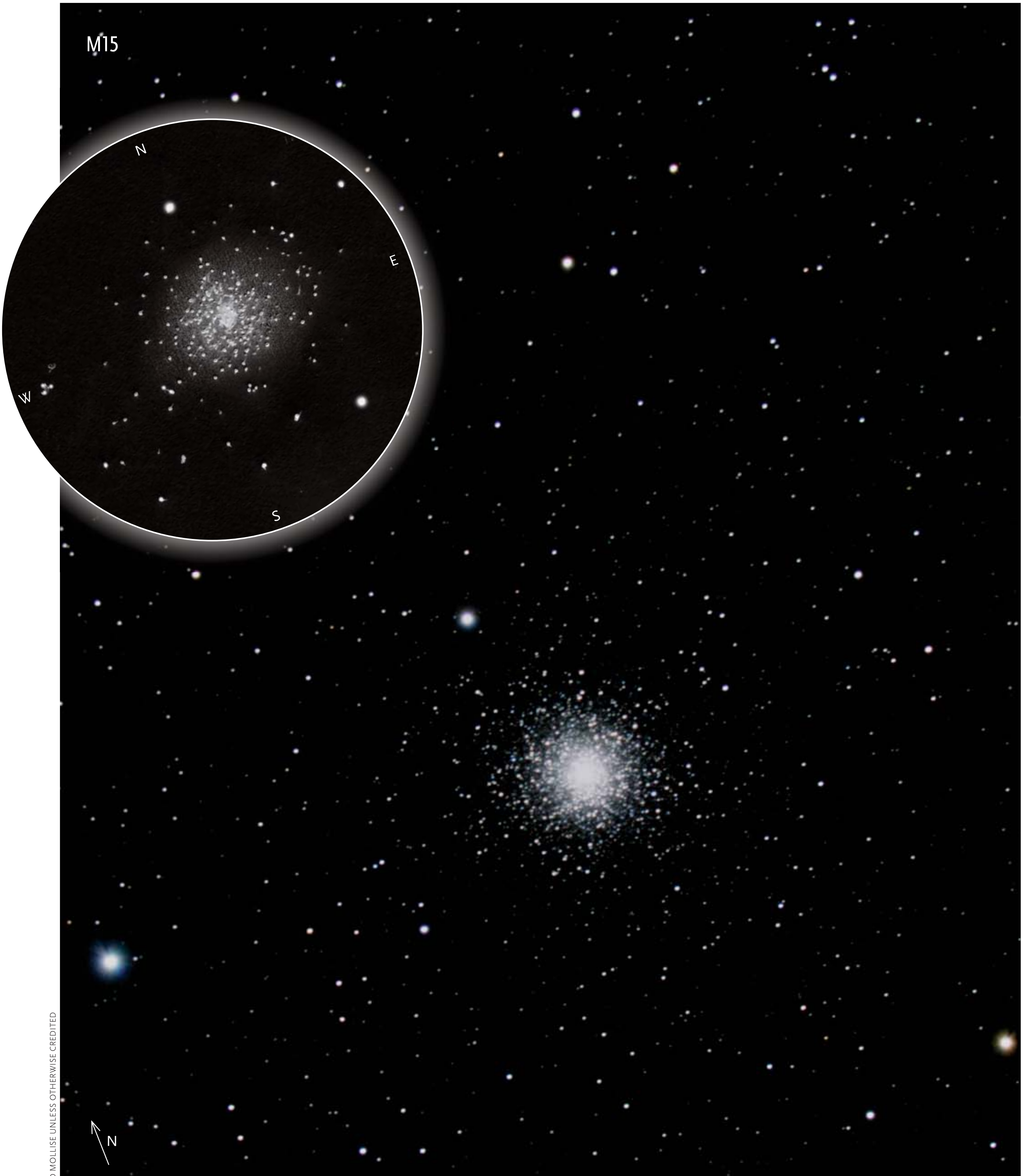
Still, Eta Carinae itself will remain an attractive target for astronomers for a long time to come. "It went from this very boring star that nobody cared about to suddenly being the second brightest star in the sky," Madura says. "When that happens, I think it's impossible to avoid catching people's interest." ✦

***Keith Cooper**, a British freelance science journalist, was editor of* Astronomy Now *magazine from 2006 to 2015. You can follow him via @21stCenturySETI on Twitter.*



ANOTHER MERGER? Simon Portegies Zwart wonders if V838 Monocerotis, whose 2002 eruption was imaged by the Hubble Space Telescope, was a merger event similar to his scenario for Eta Carinae.

NASA / ESA / H. E. BOND (STSCI)



PUMP, PUMP IT UP Globular clusters almost always reward the seeker, even when viewed under compromised suburban skies with a smaller scope. *Inset:* The author captured the view of M15 as seen through his 10-inch f/5 Dobsonian reflector at 96×.

The Backyard Sky: FALL

SAY GOODBYE TO SUMMER WITH THESE SEASONAL SIGHTS.

Rod Mollise

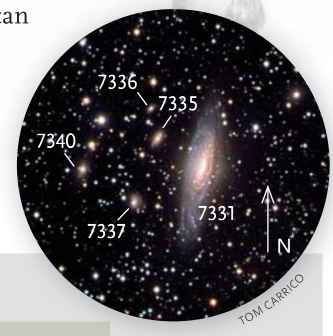
The great wheel of the sky has rolled on, and we now greet the constellations of autumn. Backyard observers tend to mourn the passing of the summer objects. Those wonders are bright and interesting even when set in a suburban sky, while the deep-sky objects of fall tend to be more subdued. This may be true, but the autumn sky is still full of marvels — if you know how to observe them.

Before diving into fall's dim "water" constellations, let's visit sprawling Pegasus. The flying horse's great globular star cluster, **Messier 15**, shines at magnitude 6.4, bright enough to be easily visible even in compromised skies. It's also easy to find, located a mere 4° northwest of magnitude-2.4 Epsilon (ε) Pegasi (Enif), "the Horse's Nose." You probably won't have difficulty locating M15, but you may not be impressed when you do; at least, not at first.

One of the tricks to seeing deep-sky objects well in light pollution is increasing magnification, which tends to spread out background sky glow and increase contrast. Although this also dilutes light from the object, it sometimes improves contrast. If anything illustrates this point, it's M15. At 78×, the cluster looks okay in my 10-inch Dobsonian reflector, showing an intensely bright core surrounded by a few resolved stars. Still, the impression is "fuzz-ball." It's better at 156×, but adding a 2× Barlow to my 8-mm eyepiece makes all the difference.

At 312×, M15 becomes a rich ball of suns with streams of stars extending a considerable distance from the core. The cluster's at its best with at least 10 inches of aperture, but it's also pretty in my 4-inch refractor when I push it to 200×. At that magnification, quite a few stars pop in and out of view.

NGC 7331, also known as the Deer Lick Galaxy, is so much dimmer than M15 you'd think it would be an impossible catch from the average American



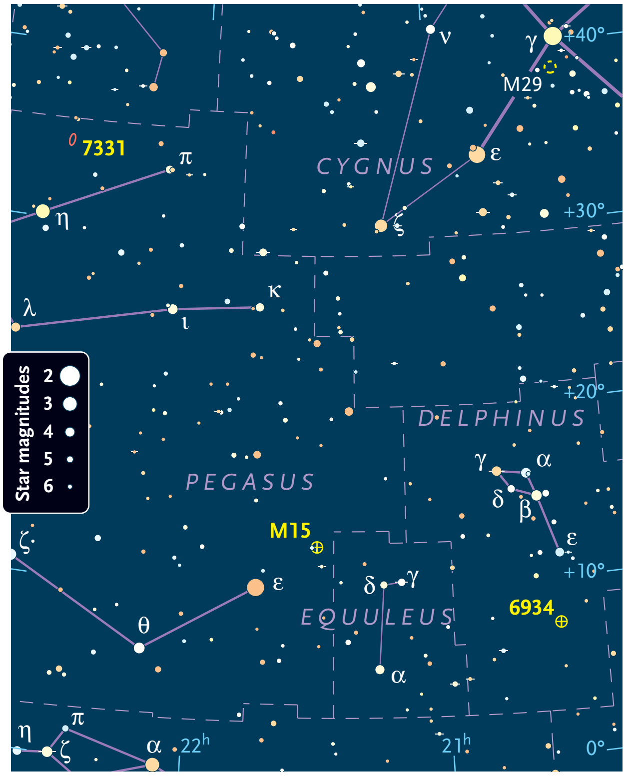
WILD HERD Under the best observing conditions, you may be able to discern the bright core of spiral galaxy NGC 7331. The tiny companion galaxies generally require 12 inches of aperture or more, but don't let that rule deter you from going after them.

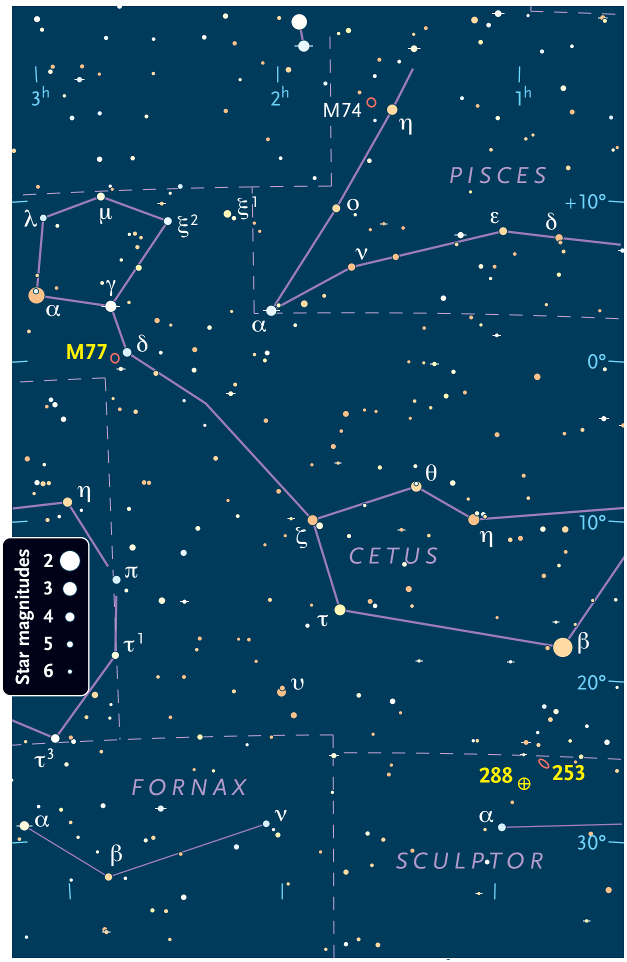
Finding Your Fall Favorites

Object	Type	Con	Mag(v)	Size/Sep	RA	Dec.
Messier 15	Globular Cluster	Pegasus	6.4	18′	$21^h\ 30.0^m$	+12° 10′
NGC 7331	Galaxy	Pegasus	9.5	11′ × 4′	$22^h\ 37.1^m$	+34° 25′
NGC 7293	Planetary Nebula	Aquarius	7.3	25′ × 13′	$22^h\ 29.6^m$	–20° 50′
Messier 77	Galaxy	Cetus	8.8	7′ × 6′	$02^h\ 42.7^m$	–00° 01′
NGC 253	Galaxy	Sculptor	7.6	29′ × 7′	$00^h\ 47.6^m$	–25° 17′
NGC 288	Globular Cluster	Sculptor	8.1	13′	$00^h\ 52.8^m$	–26° 35′
Messier 30	Globular Cluster	Capricornus	6.9	12′	$21^h\ 40.4^m$	–23° 11′
NGC 6934	Globular Cluster	Delphinus	8.9	7.1′	$20^h\ 34.2^m$	+07° 24′
NGC 457	Open Cluster	Cassiopeia	6.4	20′	$01^h\ 19.6^m$	+58° 17′

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.

CONSTELLATION DRAWINGS JOHANNES HEVELIUS





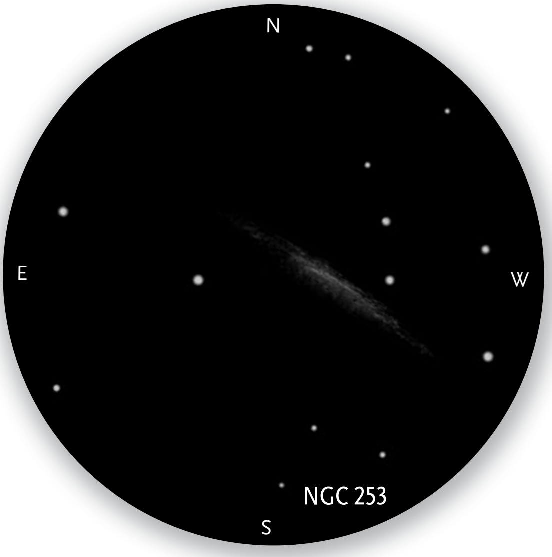
suburb. However, I don't believe I've ever failed to at least detect the Deer Lick on any decent night when I've turned my 4- and 5-inch telescopes to its location northwest of prominent Eta (η) Pegasi (Matar).

But just because you can see a galaxy doesn't mean you can see much of it. On many nights NGC 7331 is just a strongly elongated smudge. If you wait for a superior evening, however, and visit the galaxy when it's riding high, it can surprise you, as it did me on a night when it showed off a bright central region, a well-defined disk, and traces of its prominent, sweeping spiral arm. My best views that night came with the 10-inch at medium power, around 150×.

In addition to big NGC 7331, numerous small and dim island universes dot the same field of view, including NGC 7335, NGC 7336, NGC 7337, and NGC 7340, which range in magnitude from 13.4 all the way down to 15.0. These galactic tinies are normally invisible in my 10-inch from home, but on the same night I caught NGC 7331's spiral arm, I was amazed to detect the two brightest sprites, magnitude-13.6 NGC 7335 and magnitude-14.6 NGC 7337. Why is the big galaxy the "Deer Lick"? Legend has it that it celebrates Tomm Lorenzin's epic night of observing in Deer Lick Gap, North Carolina.

STELLAR SHELL NGC 7293, popularly called the Helix Nebula, is a planetary nebula, composed of expanding, concentric shells of gas cast off by a dying star.

CHRISTIAN VAN DEN BERGE



SILVER DOLLAR Discovered by Caroline Herschel in 1783, NGC 253 is a spiral galaxy seen edge-on from our vantage point on Earth. With a surface brightness of 13.3, it's one of the brightest galaxies in the night sky; try for it with binoculars under dark skies. *Sketch:* Although not quite as bright as the Andromeda Galaxy, the Silver Dollar should be within reach of 6-inch scopes from the suburbs. This sketch records the view through a 10-inch f/5 reflector at 59×.

But you can also imagine the little NGCs as cosmic deer loitering at the great salt lick of NGC 7331.

Let's step off the banks now and into the watery realm of the constellations Aquarius, Cetus, Capricornus, and Delphinus. Aquarius is on the dim side, with its brightest star, Beta (β) Aquarii, shining only at magnitude 2.9. "Dim" also describes one of its most famous objects, **NGC 7293**, but keep in mind that "dim" doesn't always mean "impossible."

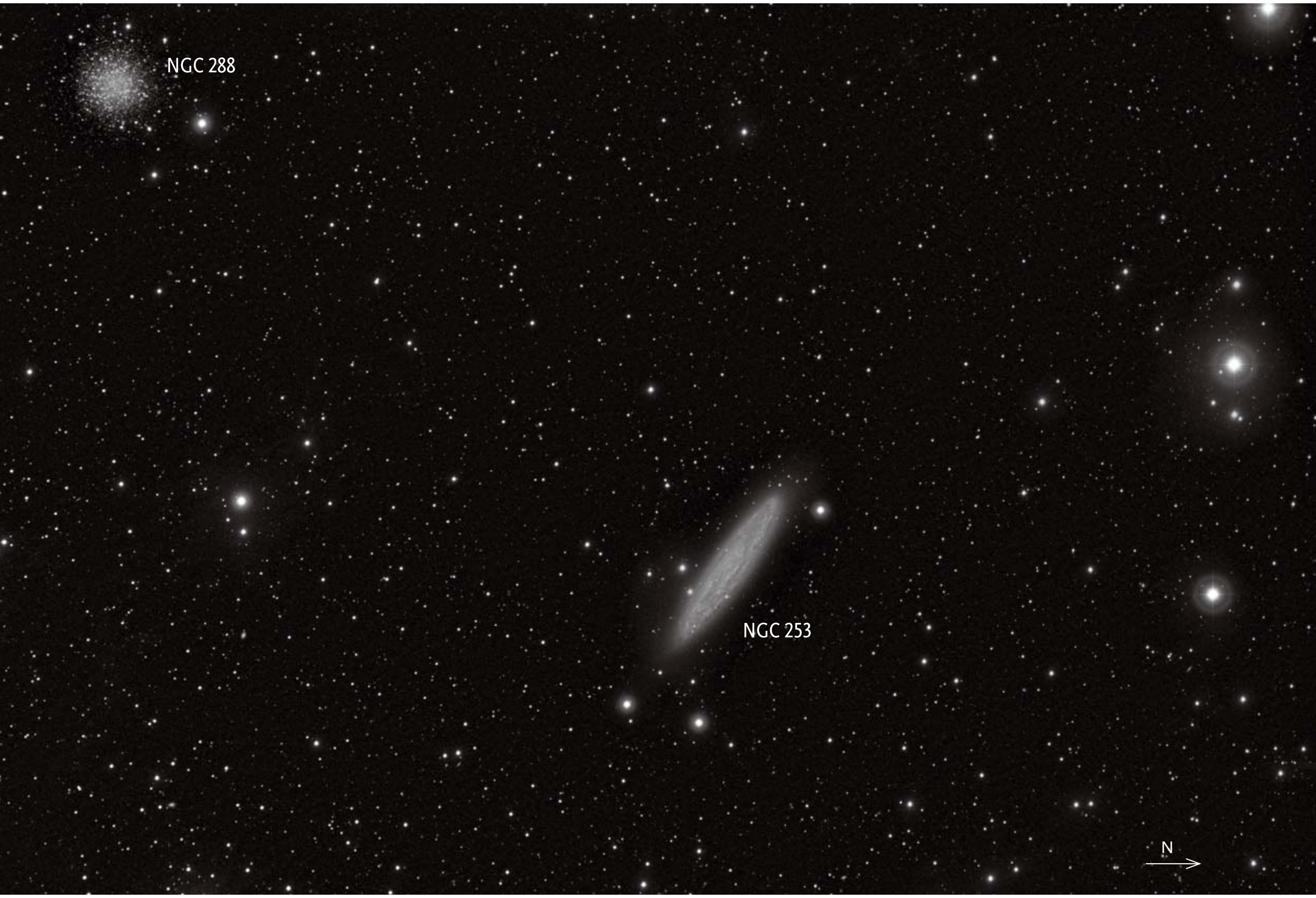
NGC 7293, more commonly known as the Helix Nebula, is a planetary nebula, the corpse of a long-dead star. It's not overly faint at magnitude 7.3, but its large size means its light is spread out over a wide area, reducing its surface brightness and making it a tough target. Even worse, at a declination of almost –21°, it's always fairly low for northern observers; even from my Gulf Coast home in Alabama it never gets much higher than 30°.

One evening, I noticed the Helix was near its 30° culmination. That was the good. The bad was that it hovered just outside the area of my sky's most severe light pollution. I thought I'd give it a try with the 5-inch refractor anyway, but I didn't expect to see a thing. Nevertheless, a low-power eyepiece revealed its circular form to me. Even at 30× the nebula was obvious, if not particularly bright.

Pumping up the magnification to 112× and adding an O III filter almost made the nebula into a showpiece. The darker center, the donut hole of this ring-shaped planetary, wasn't easy, but I could see it. Straining, I even made out two slightly brighter arcs opposite each other in the nebulosity. Lesson learned: always go for the "tough stuff" and be sure you have an O III or light-pollution reduction (LPR) filter on hand.

Want to see a galaxy on a poor night? Cruise on over to lackluster Cetus, the Whale. Once your telescope's centered on the correct field the only way you can miss **Messier 77** is to mistake it for a star. This magnitude-8.8 galaxy is relatively small, so use at least 100× to pick it out of the sparse star field.

At medium magnification in my backyard telescopes M77 resembles a small, unresolved globular star cluster, its bright center surrounded by a small amount of haze. It's obvious on any night in my 5-inch refractor, and I can often catch a look at it with an 80-mm scope. Look



JOSEPH BRIMACOMBE

TWO FOR THE PRICE OF ONE Globular cluster NGC 288 lies 1° 45′ south-southeast of NGC 253. Eight inches of aperture should pull a few stars out of the cluster's haze.

for the magnitude-9.0 field star 11′ northeast of the galaxy; it makes the view a little more attractive than it would be otherwise.

For my money, **NGC 253**, the Silver Dollar Galaxy, in the quiet constellation Sculptor southeast of Aquarius, is one of the most spectacular objects in the sky. Unfortunately, at a declination of –25°, it's low from mid-northern latitudes. More fatally, like the Helix, it's large, so it looks dim despite its reasonable 7.6 magnitude. In order to get a good view of a large object, you need to frame it with plenty of sky around it to provide contrast. The catch is that in the suburbs, using low power to expand the field of view increases the intensity of the background sky glow, so you're again left with a low-contrast view.

My solution for NGC 253 is wide apparent-field eyepieces that allow me to keep the magnification high but still place some contrast-enhancing sky around the galaxy. On an average night in my 5-inch at 56×, the galaxy is a barely visible dim streak. After concentrating on the view for a few minutes, however, I usually begin to see a little detail in the disk. In the 10-inch scope on superior evenings, I can pick out dust patches and hints of the galaxy's tiny, bright nucleus.

Are you up for a challenge? **NGC 288** is less than 2° south-southeast of NGC 253, but this globular cluster is often overlooked by backyard observers. At a declination of –26° 35′, it's

A YEAR OF BACKYARD SKY

This installment completes our "Backyard Sky" series. If you've missed any of these articles, look for them here:

Spring: April 2011, page 34
Winter: January 2015, page 36
Summer: July 2015, page 62

even lower in the night sky than NGC 253. It's also loosely concentrated, looking almost like an open cluster, which makes it appear fainter than its 8.1 magnitude and size would suggest. Yet, its reputation for being tough is mostly undeserved, as you'll find once you track it down. On a good night, NGC 288 is visible in my 5-inch as a large, dim, elongated glow at 56×. At 70×, it's not only more obvious, but a sprinkling of tiny stars wink in and out of view.

Messier 30, lurking in Capricornus, is large and bright if not quite spectacular. This globular will always be the Goat Cluster for me, and not just because it's situated in the Sea-Goat. One night, I was observing it from my light-polluted yard. The sky was as good as it ever gets and the cluster was showing off quite a few resolved stars to my 6-inch reflector. As I stared, I began to make out two adjacent strings of suns extending from M30's core that brought to mind, amazingly, the horns of a goat. So that's it for me: M30 is the Goat Cluster.

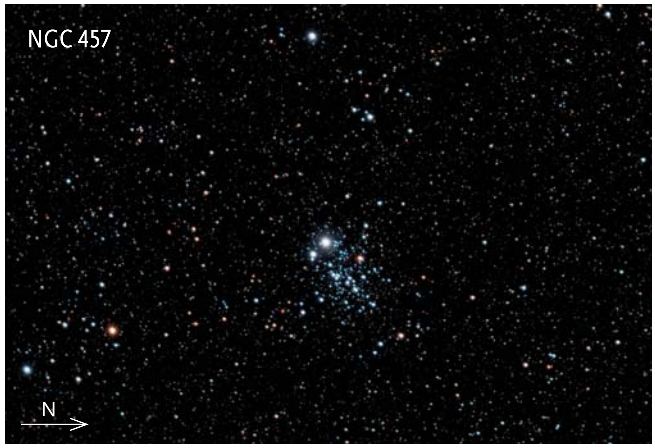
There are a few non-Messier globulars scattered across the autumn sky, too. One of my favorites is **NGC 6934**. Wading over to Delphinus, the Dolphin, you'll find this small fuzz-ball 4° south of Epsilon Delphini, the dolphin's tail star. In order to resolve any stars at all in NGC 6934, I found high power mandatory. This yellowish cluster took magnification well but didn't become a ball of stars even at 312× in the 10-inch. It did give up a few suns, though they tended to flicker in and out of view like fireworks popping off.

Let's end tonight's deep-sky voyage on bright and beautiful **NGC 457** in Cassiopeia. This open cluster, the famous E.T. or Owl Cluster, is a spectacular coda and lovely even in an 80-mm telescope. As soon as you land on the starry group, you'll understand why observers see an extraterrestrial or an owl (or maybe a dragonfly) here. The cluster's lines of stars make a distinct stick figure. You'll also notice E.T. looks comically goggle-eyed; bright yellow Phi (φ) Cassiopeiae forms one of his eyes, which is considerably brighter than the other eye.

As the autumn stars sink and the sapphires of winter begin to rise, I hope you've enjoyed this four-part series of seasonal backyard star tours. You certainly don't have to stop here, though. With a few tricks up your sleeve and a little planning, a lifetime of wonders awaits you and your telescope in the humble backyard. ✦

MARTIN GERMANO

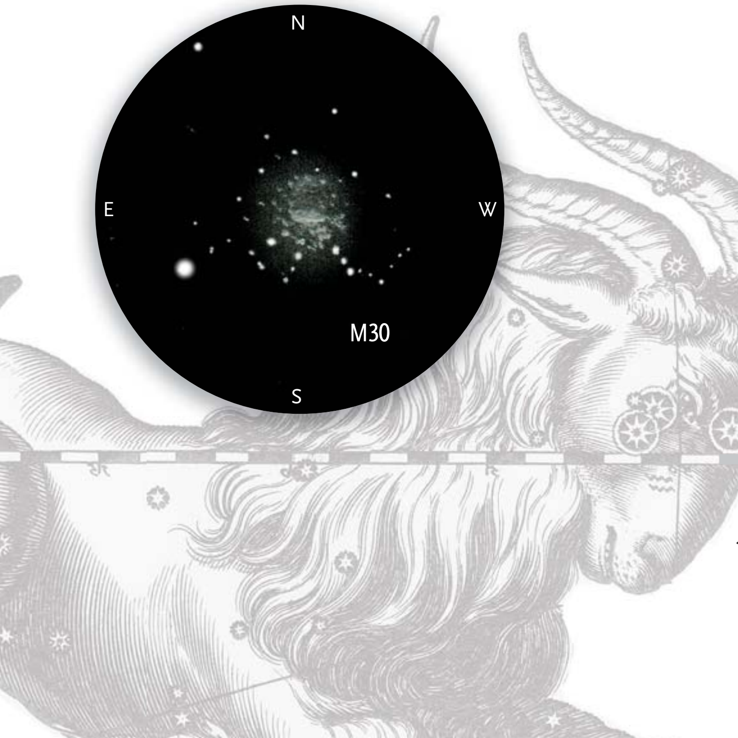
HIGH POWER MANDATORY To resolve the stubborn stars of NGC 6934, you'll need to use as much aperture and magnification as possible. As the author notes, even at 312× in the 10-inch, the cluster refused to give up many individual sparklers.



JASPAL CHADHA

GOOGLY EYES The uneven but bright eyes of a celestial owl — or Hollywood alien, depending on your imagination — peer out of open cluster NGC 457.

GOAT CLUSTER Studying globular cluster M30 in his 10-inch reflector at 156×, the author saw the curving horns of a goat. What do you see?



Veteran observer and scope junkie ***Rod Mollise*** *attended his first star party when he was just 5 years old. Dad had to help carry the C14. Read his amusing and informative online postings at* ***http://uncle-rods.blogspot.com***.

Book Review
S. N. Johnson-Roehr

Success Story

The Far End of the Journey: Lowell Observatory's 24-inch Clark Telescope

Kevin Schindler
Lowell Observatory, 2016
141 pages, ISBN 978-0692549186, $45.00, hardcover.

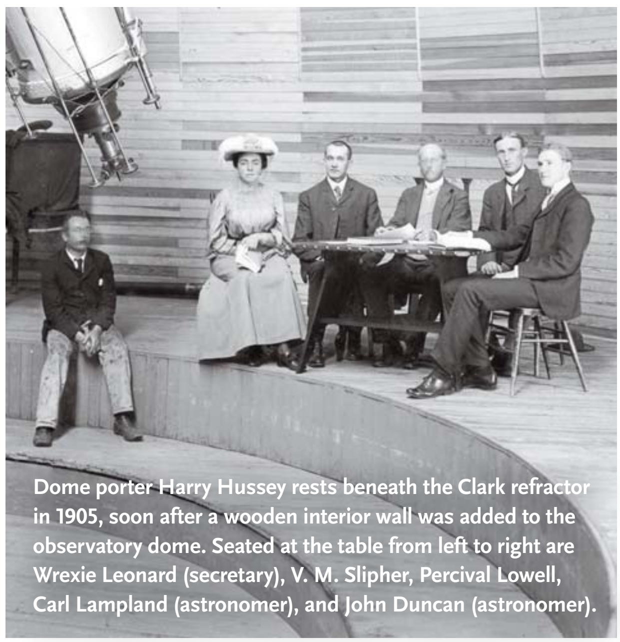
Glass to be 24 inches clear aperture and up to A.G.C.'s best. Mounting to be Greenwich Equator or on German plan, to be decided by P.L. Telescope to be fitted with every ordinary appliance for visual work, including illumination of field, any or all of P.L.'s present appliances to be used. All included to cost $20000 and to be finished ready for shipment not later than June 1, 1896. A.G.C. to go out with glass, his fare out and back to be paid by P.L. — Signed Alvan G. Clark, Percival Lowell, April 25, 1895

WITH THE ABOVE agreement written and signed, Alvan Clark & Sons, the well-regarded telescope makers of Cambridgeport, Massachusetts, began work on one of their most notable refracting telescopes. Commissioned by Boston native Percival Lowell to aid his research on Mars, the 24-inch refractor was destined for the dark skies of the American southwest. In 1897, the telescope was erected under a wooden bucket dome outside the city of Flagstaff, Arizona, on a mesa that would soon be known as "Mars Hill." In addition to supporting Lowell's planetary studies, the refractor served as the lynchpin in several major observing campaigns in the following decades, including V. M. Slipher's measurements of recessional velocities of galaxies that revealed the expanding nature of the universe and the Aeronautical Chart and Information Center's lunar mapping program in the 1960s.

Like most of the great refractors, the telescope on Mars Hill had transitioned from active research instrument to educational tool by the 1980s. Later efforts expanded the outreach program, putting the refractor at the center of the observatory's initiative to build a dedicated visitor center to share the observatory's history with the public. Tens of thousands of visitors — including amateur astronomers who want to experience the view through the storied scope for themselves — arrive at Mars Hill every year.

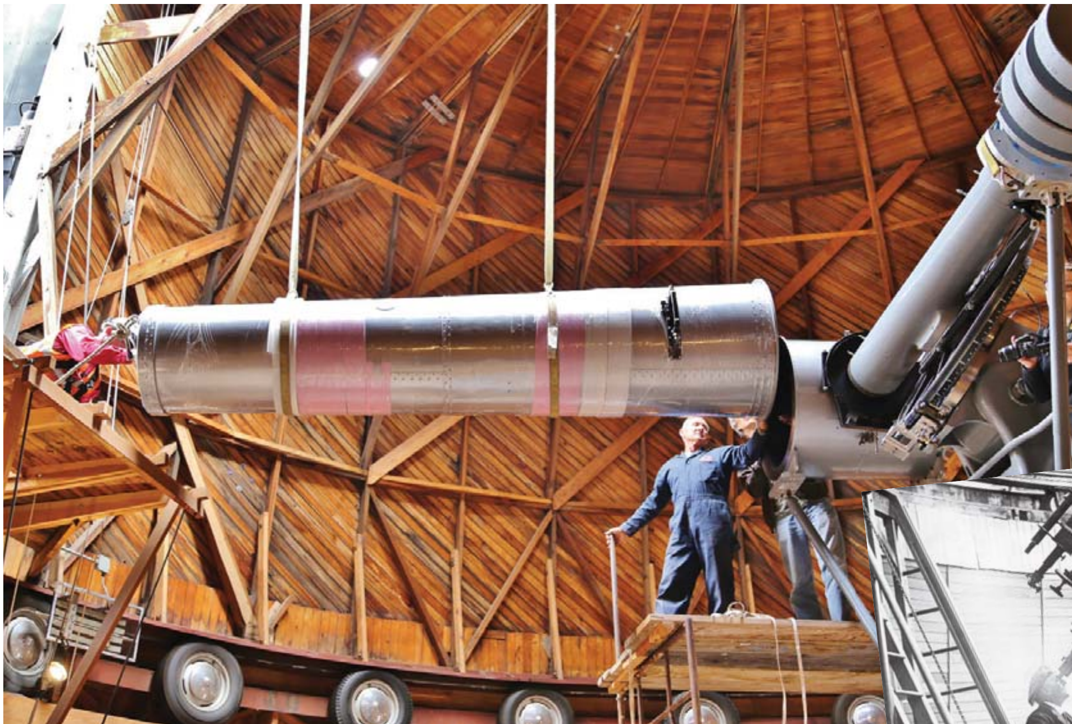
But time was catching up with the century-old refractor. By the early 21st century, it was clear to its caretakers that it was time to make a hard decision: either repair the scope or shut it down. After what must have been a very thorough gut check, a team of Lowell staff embarked on a surprisingly short but successful fundraising journey. The campaign brought in nearly $300,000, enough to underwrite a 20-month renovation project. Led by Ralph Nye, the Director of Technical Services, the Lowell team disassembled, repaired, cleaned, and re-erected the Clark under its bucket dome (*S&T:* March 2016, p. 34).

These few paragraphs hardly do justice to the role the 24-inch refractor played in the history of astronomy, nor do they adequately express the scale and wonder of the restoration project that brought the gleam back to the telescope's optical tube and lens. Luckily, Kevin Schindler's *The Far End of the Journey: Lowell Observa-*



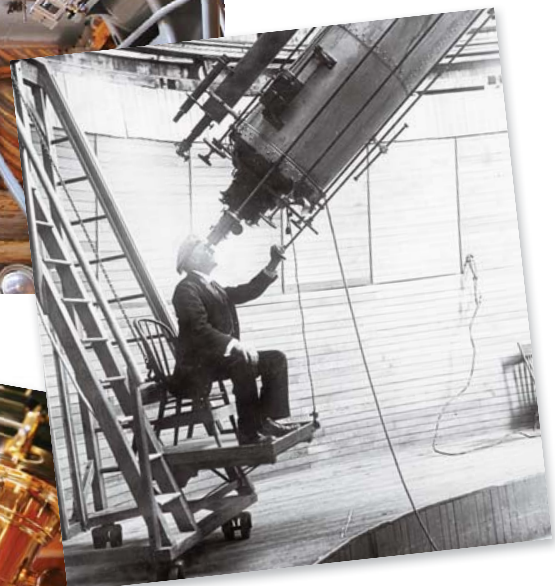
Dome porter Harry Hussey rests beneath the Clark refractor in 1905, soon after a wooden interior wall was added to the observatory dome. Seated at the table from left to right are Wrexie Leonard (secretary), V. M. Slipher, Percival Lowell, Carl Lampland (astronomer), and John Duncan (astronomer).

LOWELL OBSERVATORY



LOWELL OBSERVATORY

Left: **Lowell Observatory's Director of Technical Services, Ralph Nye, supervises the reinstallation of the rear tube section of the Clark telescope during its renovation.**



Below: **Jauntily attired Percival Lowell sits on an observing ladder that can still be seen in the Clark dome. He's using the refractor to study Venus during an afternoon observing session on October 17, 1914.**

tory's 24-inch Clark Telescope, does both — and much more. In eleven chapters, each lavishly illustrated with reproductions of historical photos, correspondence, newspaper clippings, observing logs, mechanical diagrams, and other astronomical ephemera, Schindler presents a deep timeline of the telescope's life, from its conception to its rebirth. There's a lovely interplay between prose and picture throughout the book; the illustrations populate the dome with workers, telescope operators, and observers, highlighting their intentions, their jealousies, and their ingenuity. Carefully considered asides link the observatory's past to the reader's present (who knew Diana Gabaldon was descended from Godfrey Sykes, designer of the observatory's unique wooden dome?), making the story even more relevant.

Schindler appears to have pitched *The Far End of the Journey* to multiple audiences. For readers unfamiliar with the great leaps of knowledge that depended on observations made at Lowell, the book provides an accessible introduction to the history of American astronomy and its instruments. Readers well-versed in Lowell's (controversial) obsession with Mars will discover there's always something new to learn. (For me, the construction, maintenance, and restoration of the wooden dome was particularly interesting.)

Publicity materials describe *The Far End of the Journey* as a coffee-table book. It's true that the book makes a good living-room ornament — it's well-designed, full of sharp images, and raises my intelligence cred with the neighbors — but it's far more than that. The book not only holds the story of a remarkable instrument, but

Left: **The brass sections of the refractor, including the eyepiece assembly, were disassembled, cleaned, repaired, clear-coated, polished, and reassembled.**

RICHARD BOHNER / LOWELL OBSERVATORY (2)

also serves as a model historic preservation document. If you want to list an observatory on the historic register to prevent its demolition, or wish to raise funds to restore your community's equivalent of the Clark refractor, read this book. Schindler provides a road map to success, laying out a cohesive argument for preservation and renovation. By the end of the book, he's proven the Clark played a significant role in at least three major scientific campaigns, connected the telescope to notable historical figures, from astronomers and astronauts to politicians and poets, and shown that it still contributes to outreach and education. If you can do the same for your observatory, you're well on the way to saving its life. ✦

S&T *Observing Editor* ***S. N. Johnson-Roehr*** *loves reading even more than she loves astronomy.*

In This Section

NGC 7293, commonly called the Helix Nebula, lies about 700 light-years from Earth in Aquarius; see page 32.

PHOTOGRAPH: ESO

OCTOBER 2016

3 **DUSK**: The thin crescent Moon hangs about 4° above or upper right of Venus, very low in the west-southwest.

5 **DUSK**: The waxing crescent Moon shines a bit higher this evening, standing 5° or 6° right of Saturn in the southwest. Look 6° below Saturn for twinkly Antares.

13 **NIGHT**: Algol shines at minimum brightness for roughly two hours centered at 10:00 p.m. PDT (1:00 a.m. EDT October 14th); see page 51.

16 **EVENING**: Algol shines at minimum brightness for roughly two hours centered at 9:49 p.m. EST (8:49 p.m. CDT).

18–19 **NIGHT**: The Moon occults Aldebaran for the southern half of North America and Central America; see page 48.

20–22 **MORNING**: The modest Orionid meteor shower peaks early on the morning of October 21st. Activity should be strong for several nights before and after, but the waning gibbous Moon will wash out the region of the Orion radiant.

25 **MORNING**: The waning crescent Moon rises just after Regulus, the star that marks the forefoot of Leo. By dawn, the pair will be about halfway up the sky in the east-southeast.

26 **DUSK**: Look for Saturn approximately 5° upper left of much brighter Venus in the southwest.

27 **DUSK**: Saturn, Venus, and Antares are fairly close this evening, forming a vertical line 7° tall in the southwest. Bring binoculars. Red Antares is only 7° high a half hour after sunset for skywatchers near latitude 40° north.

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

	◀SUNSET	MIDNIGHT	SUNRISE▶
Mercury		Visible through October 14	E
Venus	SW		
Mars	S SW		
Jupiter		Visible beginning October 7	E
Saturn	SW		

Moon Phases

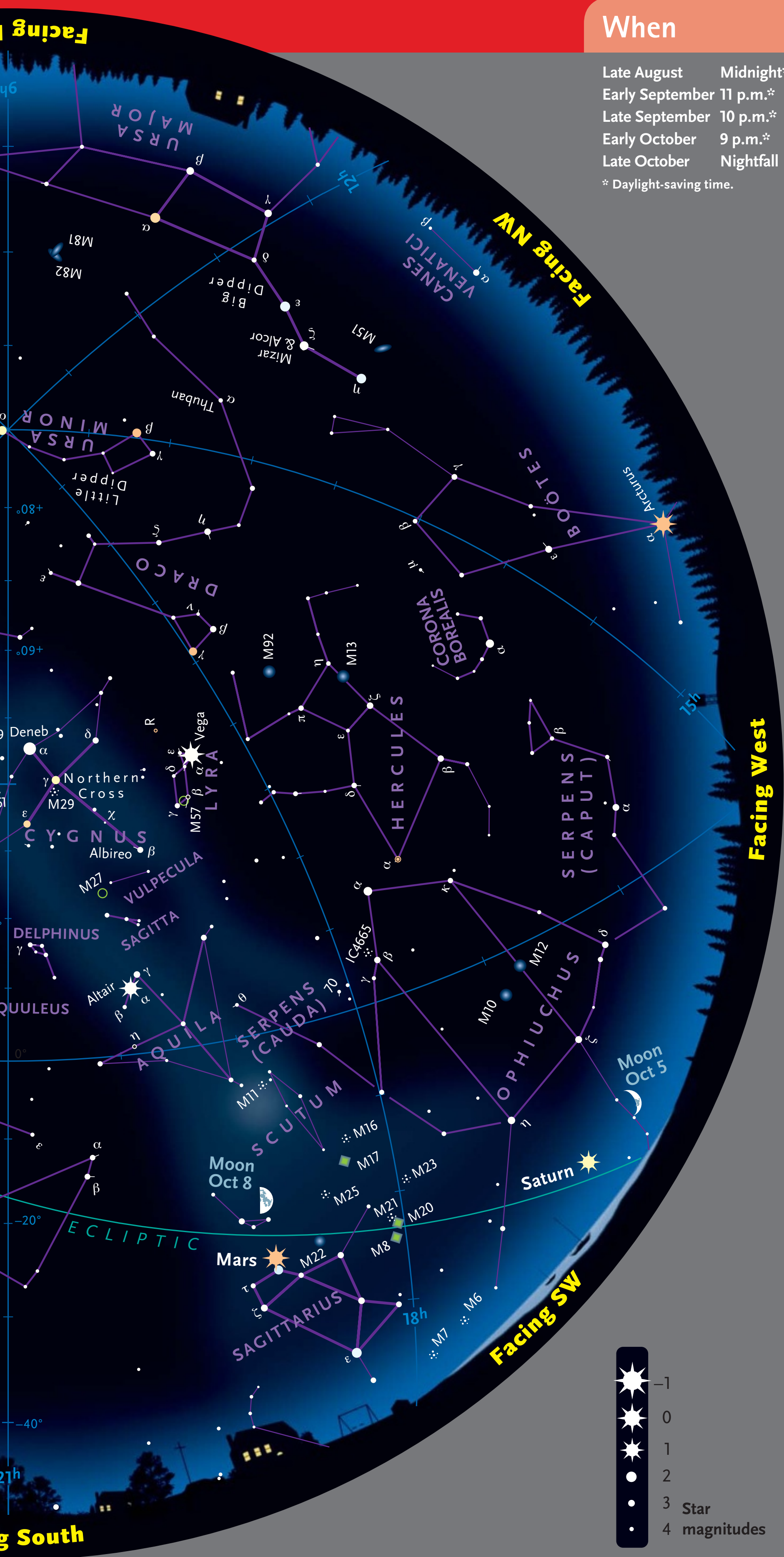
First Qtr October 9 12:33 a.m. EDT	Full October 16 12:23 a.m. EDT
Last Qtr October 22 3:14 p.m. EDT	New October 30 1:38 p.m. EDT

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 / 30	24 / 31	25	26	27	28	29

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.



When

Late August	Midnight*
Early September	11 p.m.*
Late September	10 p.m.*
Early October	9 p.m.*
Late October	Nightfall

* Daylight-saving time.

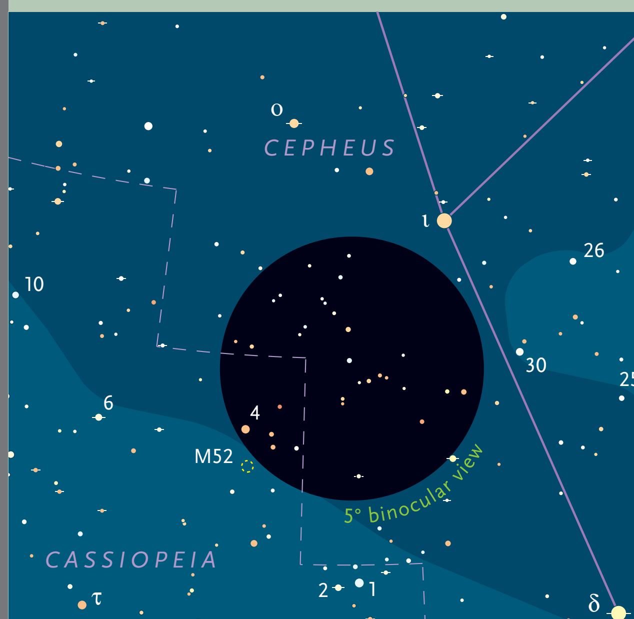
A King's Gift

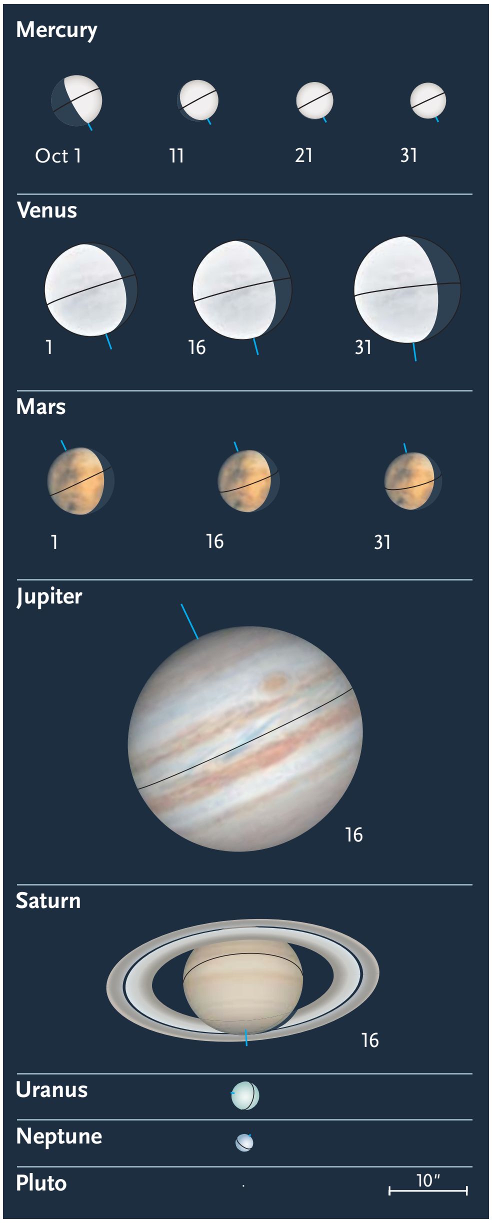
One of the great delights of stargazing is discovering unexpected wonders. As a beginning observer, I was constantly stumbling across new objects and hitting the atlases to figure out what I was seeing. I still relish those moments of discovery, and binoculars seem to deliver them consistently. It's so quick and easy to see what lies just beyond the next star — and then one field beyond that.

My latest find is a rich stream of suns in the eastern reaches of the constellation Cepheus, King of Ethiopia in Greek mythology. A chain of bright stars runs northeast to southwest, halfway between Iota (ι) Cephei and 4 Cassiopeiae, with a kink to the southeast like a shark's dorsal fin. In light-polluted skies or small instruments, that's about all that can be seen. But as conditions improve and apertures rise, the main band breaks out into loops and whorls of smaller stars, which are attended by a glittering multitude of still-fainter lights. The collective effect is to fill an 5° × 2° ellipse with a dense crowd of stars that rivals the better binocular clusters.

The brighter members of this field are *B*- and *K*-type main sequence and subgiant stars, ranging from 500 to 3,000 light-years away. The easily visible ones are larger and more luminous than our own Sun — royalty among the masses of smaller stars that swarm the Milky Way.

If this stellar wonderland has a name, I've been unable to discover it. In my mind it's a glittering hoard of diamonds, gold coins, and jeweled necklaces that King Cepheus is presenting to Queen Cassiopeia. The sky is full of similar treasures, named and nameless, waiting to be chanced upon by any who dare to look. Let's dare. ✦



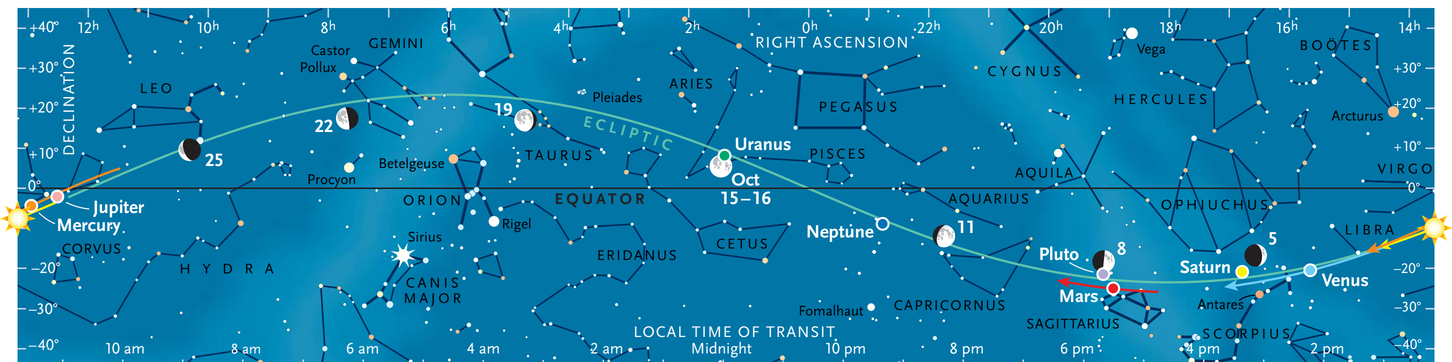


Sun and Planets, October 2016

	October	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$12^h 29.4^m$	–3° 11′	—	–26.8	31′ 57″	—	1.001
	31	$14^h 21.6^m$	–14° 06′	—	–26.8	32′ 13″	—	0.993
Mercury	1	$11^h 27.3^m$	+5° 08′	18° Mo	–0.8	6.6″	60%	1.017
	11	$12^h 24.9^m$	–0° 37′	12° Mo	–1.1	5.4″	90%	1.255
	21	$13^h 27.8^m$	–7° 54′	5° Mo	–1.3	4.8″	99%	1.389
	31	$14^h 30.1^m$	–14° 38′	2° Ev	–1.3	4.7″	100%	1.439
Venus	1	$14^h 25.3^m$	–14° 38′	31° Ev	–3.9	12.1″	85%	1.376
	11	$15^h 13.2^m$	–18° 41′	33° Ev	–3.9	12.6″	83%	1.319
	21	$16^h 03.0^m$	–21° 58′	35° Ev	–3.9	13.2″	81%	1.259
	31	$16^h 54.6^m$	–24° 17′	37° Ev	–4.0	13.9″	78%	1.197
Mars	1	$18^h 09.7^m$	–25° 49′	84° Ev	+0.1	8.8″	85%	1.067
	16	$18^h 54.8^m$	–25° 02′	80° Ev	+0.2	8.1″	85%	1.155
	31	$19^h 40.9^m$	–23° 24′	75° Ev	+0.4	7.5″	86%	1.245
Jupiter	1	$12^h 17.9^m$	–0° 45′	4° Mo	–1.7	30.6″	100%	6.450
	31	$12^h 41.3^m$	–3° 14′	27° Mo	–1.7	31.2″	100%	6.319
Saturn	1	$16^h 40.2^m$	–20° 43′	63° Ev	+0.5	15.9″	100%	10.449
	31	$16^h 51.5^m$	–21° 08′	36° Ev	+0.5	15.4″	100%	10.826
Uranus	16	$1^h 23.2^m$	+8° 04′	179° Ev	+5.7	3.7″	100%	18.951
Neptune	16	$22^h 45.0^m$	–8° 53′	137° Ev	+7.8	2.3″	100%	29.222
Pluto	16	$19^h 03.7^m$	–21° 28′	82° Ev	+14.2	0.1″	100%	33.319

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

A Study in Cepheus

A meditation on a small section of the celestial globe.

When I started writing this particular column, I didn't know I'd soon be delightfully interrupted by an illustration that would change my focus: the illustration you see here, from *Sky & Telescope*'s beautiful and masterful new celestial globe. With its help, I'd like to concentrate on just one small region of the sky: part of the mysterious Cepheus Milky Way.

Spur and triangle. When I was young I marveled at the dark cut across much of the Milky Way not far northeast of Deneb. But I was also drawn beyond that murk to where a flood of Milky Way glow resumed with a spur that made a pool of radiance inside the square formed by Alpha (α), Beta (β), Iota (ι), and Delta (δ) Cephei. I was equally attracted to the passage of the main stream by one corner of the square — a corner that featured a curious compact triangle of naked-eye stars.

You can see these features first, before you check them out in the sky, here on the celestial globe created by Roger Sinnott, Kelly Beatty, Gregg Dinderman, and Wil Tirion.

The bright spur to Kurhah. Let's start with that bright spur or promontory of glow, which goes all the way to Xi (ξ) Cephei (Kurhah). The little line sticking out of its dot on the globe indicates that Kurhah is a double star. It consists of a lovely pairing of a 4.3-magnitude spectral type *A*3 star and a 6.5-magnitude *F*7 companion just 8″ away. Can you detect a subtle contrast in the stars' hues?

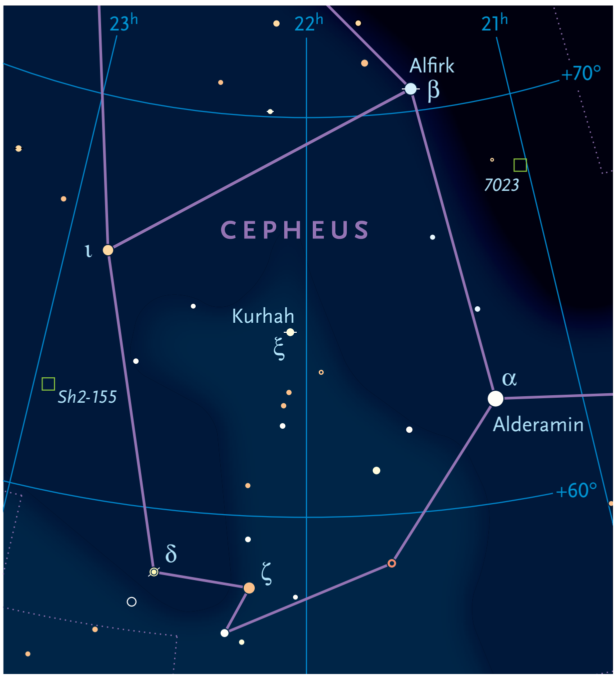
The two vast stars of the spur. Only about 1¼° southwest from Kurhah, marked by a tiny circle on the globe, is one of the largest stars known — VV Cephei. It normally shines at about magnitude 4.9 but dims a few tenths of a magnitude every 20 years while its hot blue companion star passes behind it. If we placed VV Cephei where the Sun is, it would fill the solar system almost all the way out to Saturn.

Amazingly, a star of similar size lies at the base of the milky spur: Mu (μ) Cephei, popularly known as Herschel's Garnet Star. This is said to be the reddest star visible to the naked eye in the northern heavens, but to see it truly ruddy, make sure to use binoculars or a small-aperture telescope. Mu Cephei usually ranges between about magnitude 3.9 and 4.5 (irregularly, but with an average period of about 755 days). Extreme values for its magnitude have been 3.4 and 5.1.

And don't overlook Mu Cephei's amazing neighborhood. Extending at least 2° south from Mu is the visually elusive but photographically spectacular nebula IC 1396. It's accompanied by a fine open cluster and by a truly marvelous and easy triple star, Struve 2816 (magnitudes 5.6, 7.7, and 7.8).

The Delta Cephei triangle. The radiant spur is wonderful but no more so than the tiny triangle formed by Zeta (ζ), Epsilon (ε), and Delta Cephei. Delta is the prototype star of the Cepheids, those "flickering yardsticks" which help us measure — and discover — the universe. Watch Delta Cephei vary from 3.5 (a bit dimmer than Zeta) to 4.4 (a bit dimmer than Epsilon), and return to maximum again in its period of 5 days, 8 hours, and 48 minutes. But Delta is also a gorgeous double star. The orange primary shines 41″ from a 6.3-magnitude blue secondary star.

Lurking just 43′ to Delta's southwest is a challenging treat of the triangle. Krueger 60 consists of a magnitude 9.8 and 11.3 pair of red dwarfs with 44-year orbital period and only a few arcseconds apart. These two, only 13.2 light-years away, are among the least massive stars known. The dimmer of the two is a flare star, which sometimes brightens by several magnitudes for a matter of mere minutes. ✦



S&T ILLUSTRATION

Tower of Light

Saturn, Venus, and Antares fall into line near the end of October.

At dusk this October, Venus shines brilliantly low in the southwest. It needs almost the entire month to close the gap between itself and Saturn before passing dramatically between the fairly closely paired Saturn and Antares.

Meanwhile Mars, still a bit brighter than Saturn, continues to move eastward, away from the Saturn-Antares duo, to glow like a firespark in the south-southwest at nightfall.

At dawn in the first week of October, lustrous Mercury remains alone low in the east. But Jupiter soon comes into view and passes very close to Mercury's right on October 11th. As the month progresses, Mercury disappears into the sunrise while Jupiter rises earlier and reaches higher.

DUSK

Venus, low in the southwest after sunset, creeps a little higher as October progresses, improving by month's end to about 10° high 45 minutes after sunset for observers around latitude 40° north. Telescopes reveal the gibbous disk of Venus changing only gradually, growing from 12″ to 14″ wide while its phase decreases from about 86% to 78% lit.

A few days into the month and well into Libra, Venus passes below the wide double star Alpha (α) Librae (Zubenelgenubi). They're less than 1° apart on the 5th. Around October 20th Venus crashes through the "fence" of stars that forms Scorpius's head, brushing very close to the bright and unpredictable variable star Delta (δ) Scorpii (Dschubba).

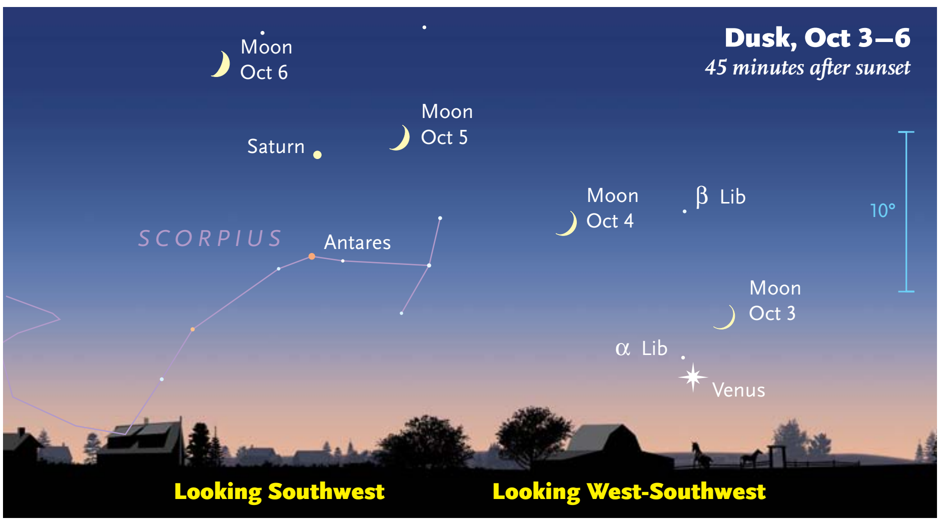
Venus is 3° upper right of Antares on the American evenings of October 25th and 26th. The most exciting event, however, happens on the 27th, when Venus passes midway through the gap between **Saturn** and Antares, forming a nearly vertical line with them low in twilight. In this tower of bright objects, Saturn shines at magnitude +0.5, Venus at –4.0, and Antares at +1.0. Thus Venus burns 100 times brighter than Antares. Poor Antares is also the lowest of the three by that day — it's already less than 10° high only 30 minutes after sunset.

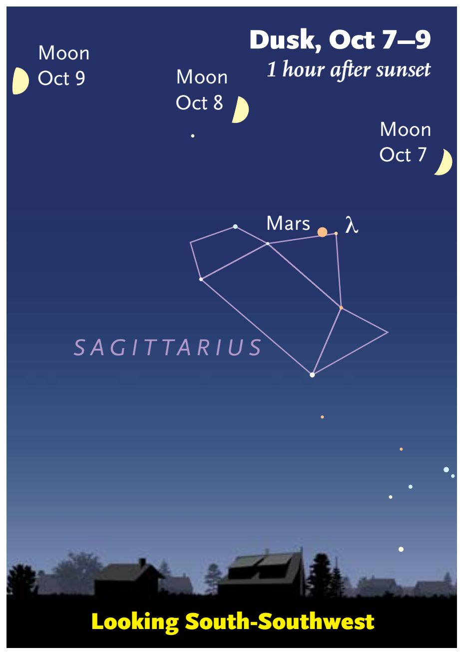
Saturn was closest to Antares back on September 11th, when it was 6° north-northeast of the star. The ringed planet is moving, slowly but surely, eastward and away from Antares, but at the end of October they're still close, only 7° apart.

Saturn's globe is less than 16″ wide this month and subtly shrinking, but its rings remain open and beautiful at 26° from edge on. At the start of October, however, Saturn stands only about 20° high in the southwest an hour after sunset. By month's end it's only half that.

EVENING

Mars fades from magnitude +0.1 to +0.4 in October. The fire-colored planet races across most of Sagittarius during the month. It starts October lower left of M8, the Lagoon Nebula. Mars is farthest

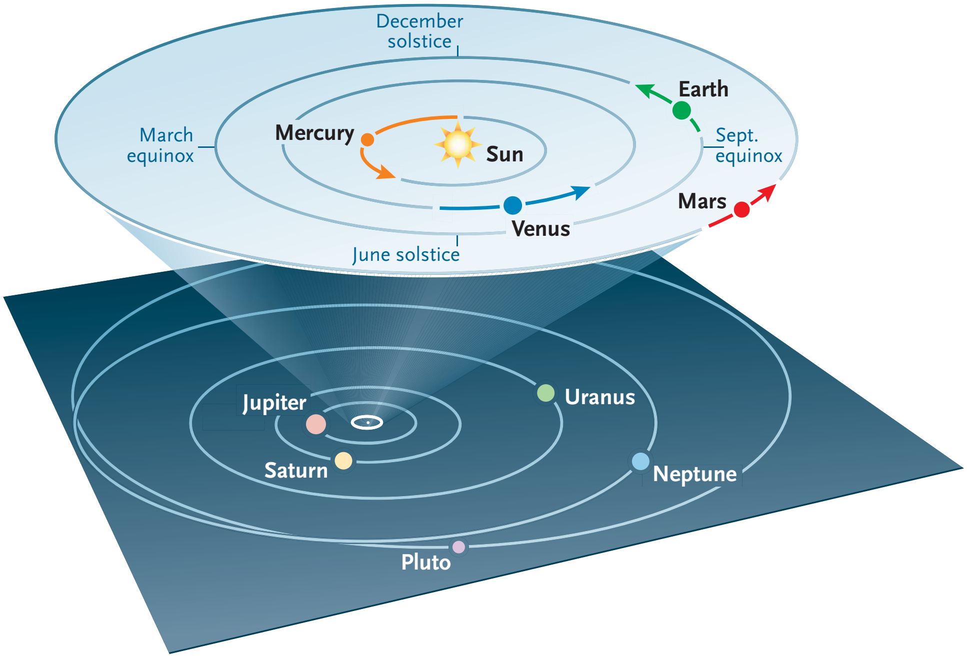




These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist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

ORBITS OF THE PLANETS

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



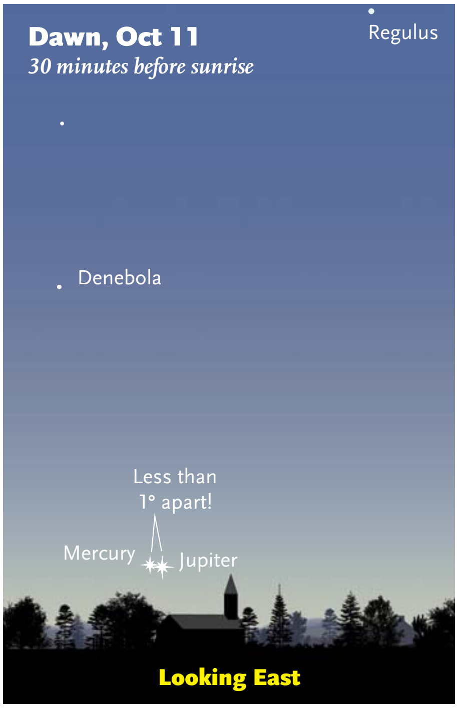
south of the ecliptic on October 3rd. On the 6th it passes just 0.2° south of Lambda (λ) Sagittarii, the top star of the Sagittarius Teapot. During the second half of October, it passes over the Teapot's bright handle and treks a few degrees below the dimmer Teaspoon asterism. But good telescopic viewing is just a memory; Mars shrinks to less than 8″ wide over the course of the month. The Red Planet reaches perihelion, its closest to the Sun in space, on October 29th.

Magnitude-14.2 **Pluto** resides dimly in the bowl of the Sagittarius Teaspoon; see the finder chart in the July issue, page 48.

NIGHT

Uranus comes to opposition in Pisces on October 15th, so it's technically visible all night long this month. At magnitude +5.7, with a 3.7″-wide disk, however, the ice giant is best seen when high — in other words, in the middle of the night.

Neptune, in Aquarius and several hours ahead of Uranus, shines two magnitudes fainter and appears less than 2⁄3 as wide, but transits during more convenient hours. Finder charts for Uranus and Neptune are on page 50.



DAWN

Mercury and **Jupiter** trade roles in the October dawn. The month starts with only Mercury visible, just past the peak of its finest morning apparition of the year for observers at mid-northern latitudes. It shines about 8° above the due-east horizon 45 minutes before the first sunrise of the month. By about October 8th Jupiter emerges below it, moving higher each day as Mercury gets lower. On the American morning of October 11th, magnitude –1.1 Mercury beams just 0.8° left of magnitude –1.7 Jupiter. Bring binoculars or a telescope and hope for very clear air; they'll be only about 5° above the horizon in the bright sky 30 minutes before sunrise. Telescopes may reveal Mercury's 90% illuminated disk to be only 5″ wide compared to Jupiter's 31″.

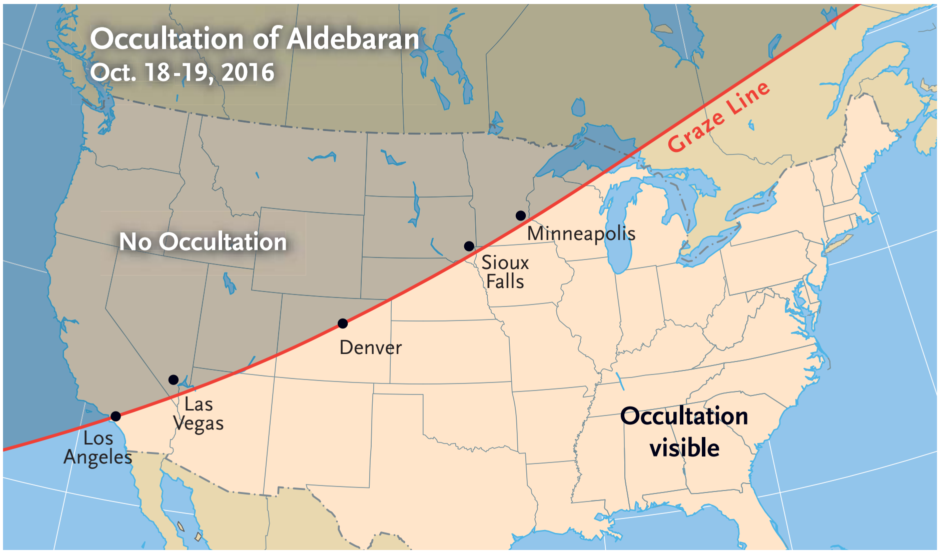
Mercury appears lower each morning thereafter, becoming lost in the sunrise by mid-month before dropping through superior conjunction with the Sun on October 27th. In contrast, Jupiter continues to climb, rising almost 2½ hours before the Sun at month's end.

MOON PASSAGES

The crescent **Moon** waxes above and right of Venus on the evening of October 3rd, right of Saturn on October 5th, and upper left of Saturn on October 6th. The first-quarter Moon lies rather far upper right of Mars on October 7th, then similarly far upper left of it the next night. A widely visible occultation of Aldebaran by the waning gibbous moon occurs on the night of October 18–19; see p. 48. At dawn on October 28th, a hair-thin waning crescent hangs very close to the lower left of Jupiter. ✦

Moon, Aldebaran Meet Again

This time, a grazing occultation crosses Los Angeles and Denver.



S&T: LEAH TISCIONE / DATA: IOTA

Most people in North and Central America are positioned for the Moon's October 18–19 coverup of Aldebaran. It happens in a dark sky late at night. Maps of the graze line with street-level precision are in the webpage for this event at the end of the article.

Have you caught any occultation of Aldebaran yet in the current series? They're happening every 27 or 28 days, once per lunar month. But most occur for parts of the world where you are not, or in the daytime, or with the Moon too close to the Sun. And then, when everything comes together right, it's often cloudy.

Skywatchers in much of North America have their next chance late on the night of October 18–19. The waning gibbous Moon (86% sunlit) will cross Aldebaran after midnight for the East, in late evening for the Southwest. The map above shows the area of visibility. Aldebaran will disappear on the Moon's bright limb, for which you'll need a telescope at high power, then will reappear from behind the Moon's invisible dark limb up to an hour or more later. For the reappearance, binoculars may be enough.

Here are some times:

Halifax, *disappearance* 3:06 a.m., *reappearance* 4:08 a.m. ADT; **New York**, *d.* 1:44 a.m., *r.* 2:50 a.m. EDT; **Washington, DC**, *d.* 1:36 a.m., *r.* 2:44 a.m. EDT; **Atlanta**, *d.* 1:18 a.m., *r.* 2:27 a.m. EDT; **Miami**, *d.* 1:11 a.m., *r.* 2:26 a.m. EDT; **Toronto**, *d.* 1:48 a.m., *r.* 2:37 a.m. EDT; **Chicago**, *d:* 12:37 a.m., *r.* 1:20 a.m. CDT; **Kansas City**, *d:* 12:28 a.m., *r.* 1:08 a.m. CDT; **Austin**, *d:* 12:03 a.m., *r.* 1:03 a.m. CDT; **Phoenix**, *d:* 11:13 a.m., *r.* 11:42 a.m. MDT; **San Diego**, *d:* 10:14 p.m., *r.* 10:36 p.m. PDT.

Times and other info are listed for 1,000 locations in the predictions link below.

A Populated Graze Line

The most interesting place to be will be in a strip a few hundred yards wide along the graze line, as told in the August issue (page 50) for the event that happened on July 29th. This time the graze happens 500 miles farther north. It runs right across Los Angeles and Denver, about 50 miles southeast of Las Vegas, and about 30 miles southeast of Minneapolis. The narrow graze zone is plotted to street-level accuracy (along with how to correct for your elevation) on the special webpage set up or this event at the link below.

Along that line, you'll probably see Aldebaran disappear and reappear several times in the darkness just barely off the Moon's dazzlingly sunlit north polar region. Most of these events will not be instantaneous, as hills and valleys on the Moon's northern limb slide across the face of the giant star. Aldebaran is 20 milliarcseconds wide, or 40 meters at the Moon's distance.

The graze "could be an interesting opportunity for public outreach," notes David Dunham of the International Occultation Timing Association, "a rare astronomical phenomenon visible with binoculars by thousands of people who live in the graze zone. In spite of the bright Moon, this is one of the better Aldebaran events in the current series for populous parts of North America."

Enjoy these events while you can. We're halfway through the current series; it began on January 29, 2015, and ends on September 3, 2018. After that the Moon will occult no 1st-magnitude star until 2023 (Antares, on August 25th of that year), and the next Aldebaran series won't start until 2033.

FOR MORE INFORMATION

IOTA has set up a special web page for the October 18–19 graze, with maps, predicted lunar-limb profiles, and other information, at **occultations.org/Aldebaran/2016October.**

Detailed predictions for Aldebaran and the Hyades star 71 Tauri, along with the Moon's altitude, are listed for 1,000 cities and towns at **lunar-occultations.com/iota/bstar/bstar.htm.**

Alan MacRobert

The Two Top Miras

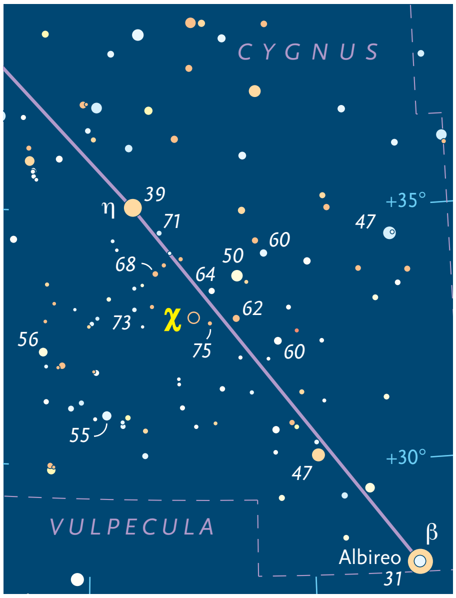
Chi Cygni high overhead, and Mira rising up late at night, are the two brightest Mira-type stars in the sky: aging red giants that slowly pulse and fade through very large brightness swings with periods of many months. This class is also known as the long-period variables, dating from back when no other kinds of variable stars with long periods were known. This fall you can watch these two leaders of the Mira menagerie progress through opposite behaviors, on opposite sides of the sky.

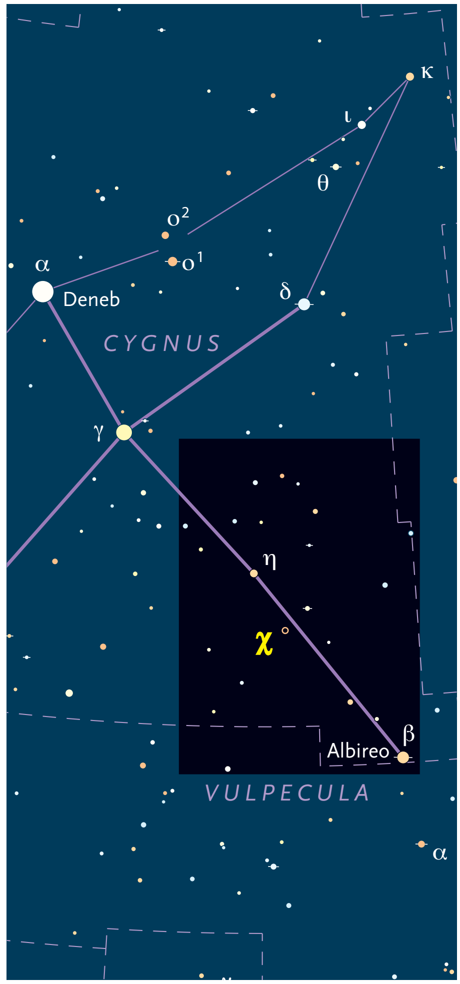
Chi Cygni starts out bright. The American Association of Variable Star Observers predicts that it will peak in mid-September, then fade for the next 7 or 8 months. Chi Cyg tends to alternate between bright and faint maxima. It reached 4th magnitude last time, so this time it will probably top out at 5th or 6th. But who knows?

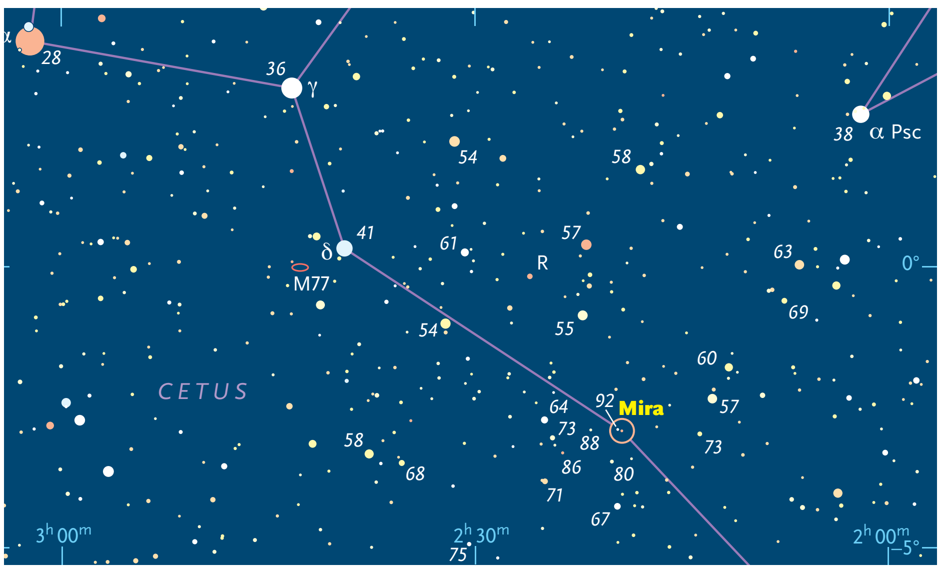
Mira, on the other hand, should bottom out in late October around magnitude 9.4. That's brighter than the *maxima* of many variables that amateurs follow. A magnitude-9.2 orange star lies just 2 arcminutes east of it, as shown on the bottom chart, offering a convenient comparison. Mira variables tend to brighten faster than they fade; the AAVSO predicts that Mira itself should climb to 3.4 by late February, making it easy to the naked eye.

On these charts, comparison-star magnitudes are given to the nearest tenth with the decimal point omitted. At the eyepiece, find the comparison star that looks just a little brighter, and the one just a little fainter, than the variable itself. Interpolate the variable's magnitude carefully between them. Then spend some time examining whether this first impression is really the best. Visual variable-star work is rather exacting; strive for the greatest accuracy you can eke out.

On what date will falling Chi and rising Mira cross in brightness?

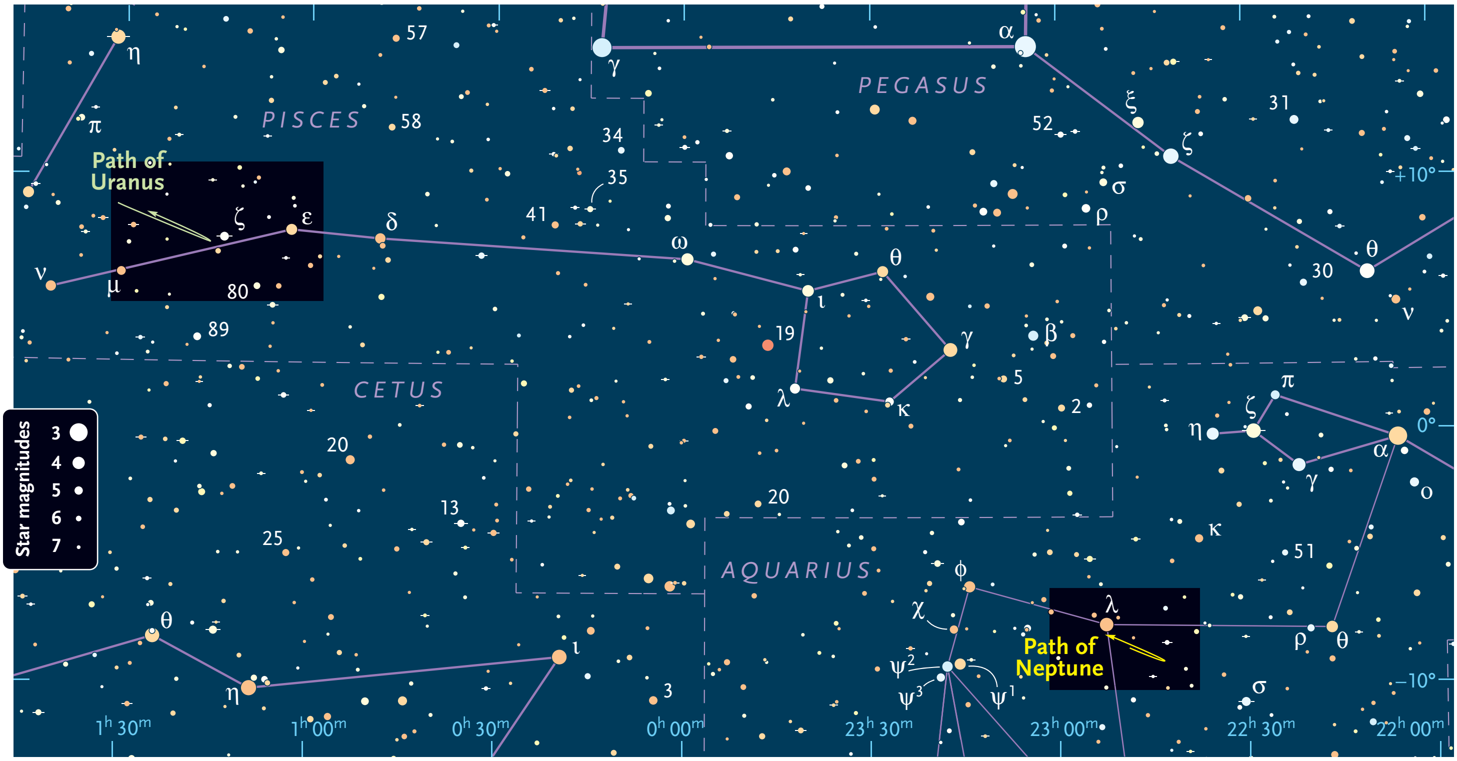






Top: **Chi (χ) Cygni, high overhead these evenings, is the brightest star of spectral type *S*. It should peak at 4th to 6th magnitude in September, then start fading. The black rectangle shows the area of the enlargement. (For deeper comparison-star charts, go to aavso.org and at "Star Name Here," type Chi Cyg.)** ***Right:*** **Mira is in good view in the east by about 1 or 2 a.m. in September, 11 p.m. or midnight in October, 9 or 10 p.m. in November, and so on. In late October, you may catch it matching the 9.2-magnitude star 2′ east of it. This winter, it should become easy to spot naked-eye.**

Uranus & Neptune Enter the Evening Sky

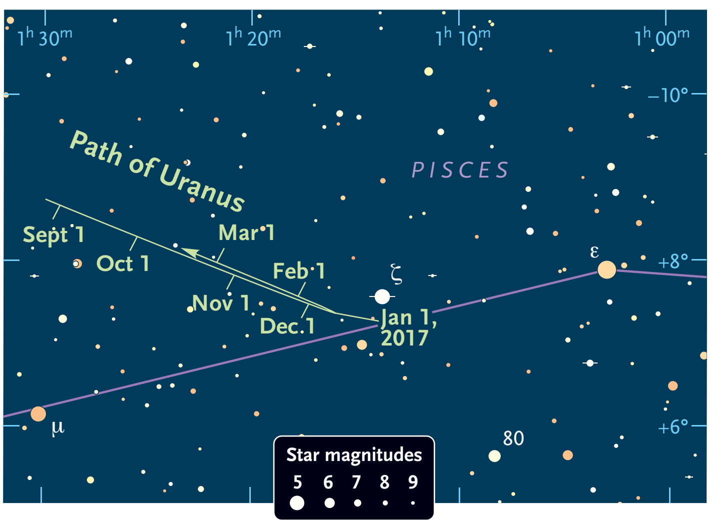


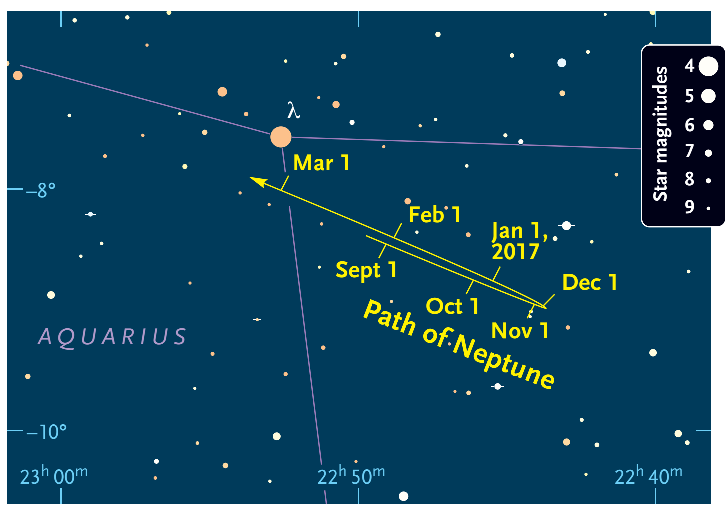
The chart above spans almost 60° under the Great Square of Pegasus. On the small blowups, interpolate between the first-of-the-month ticks to pinpoint each planet's position on your date. Uranus is the fifth-brightest object on its blowup chart.

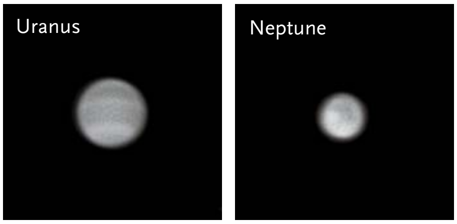
The two dim, gassy ice giants patrolling the outer solar system are coming up to greet late-night observers as the season changes. Neptune reaches opposition on September 2nd, Uranus on October 15th. They await you in Aquarius and Pisces, not far below the Great Square of Pegasus, as shown above. The Great Square's southern side is just inside the chart's top.

Uranus is easy to see in binoculars; it's magnitude 5.7 or 5.8 from now through January. Under a very dark sky, if you look carefully you can even follow it with the naked eye without too much trouble.

Which has always raised a question







Not often are Uranus and Neptune imaged well enough from the ground to show any markings. Marc Delcroix and François Colas used the 42-inch reflector at Pic du Midi Observatory in the French Pyrenees to take these infrared images on July 15, 2013.

for me. Worldwide, across thousands of years, didn't any shepherd or hunter or traveler, lying in a bedroll night after night, notice that a faint little zodiacal asterism he had been idly noticing was changing shape? What if he had showed others where to find the faint new wanderer, and the news spread?

The ancients knew of five "wandering stars," which with the Sun and Moon made seven "planets." Seven thus became a magic number full of esoteric meanings. Each of the "planets" governed, and named, a day of the week. What would the Greek math mystics, for instance, have made of an eighth? Eight is the first cubic number, symbolizing finality and completeness. Would they have kept the new little wanderer that completed the cosmic scheme a secret, only for the initiated? Would a hidden cult of the perfect eightness have passed down the centuries, with who knows what influence on religion and philosophy? Dan Brown ought to write a novel.

Neptune, by contrast, is quite beyond naked-eye ken at magnitude 7.8. It's about as difficult in 8×50 binoculars under moderate light pollution as Uranus is to the naked eye in the wilderness.

The charts here show where to find both. The large chart alone will be enough to identify Uranus, once you've checked the blowup to see where Uranus lies on its path for your date. It stays a few degrees from Zeta (ζ) Piscium, magnitude 5.2. Uranus is 3.7″ wide, enough to look like a definite little ball rather than a blurry star, in a 4-inch or larger scope at high power in good seeing. For inspiration, read Kevin Bailey's article on looking for detail on Uranus in last month's issue, page 52.

To find Neptune, you'll need to work from its blowup chart at the eyepiece. Lambda (λ) Aquarii nearby is magnitude 3.7. Neptune is 2.3″ or 2.4″ wide, barely enough to show a tiny ball in my 6-inch on fine nights. Neptune looks gray to me with a just hint of blue, while Uranus seems to have an overtone of aquamarine blue-green. Your impressions may vary.

Uranus and Neptune are often called twins. They're 4 Earths in diameter, have 14 and 17 Earth masses respectively, and are made of similar material. So, you might ask, how do they differ most?

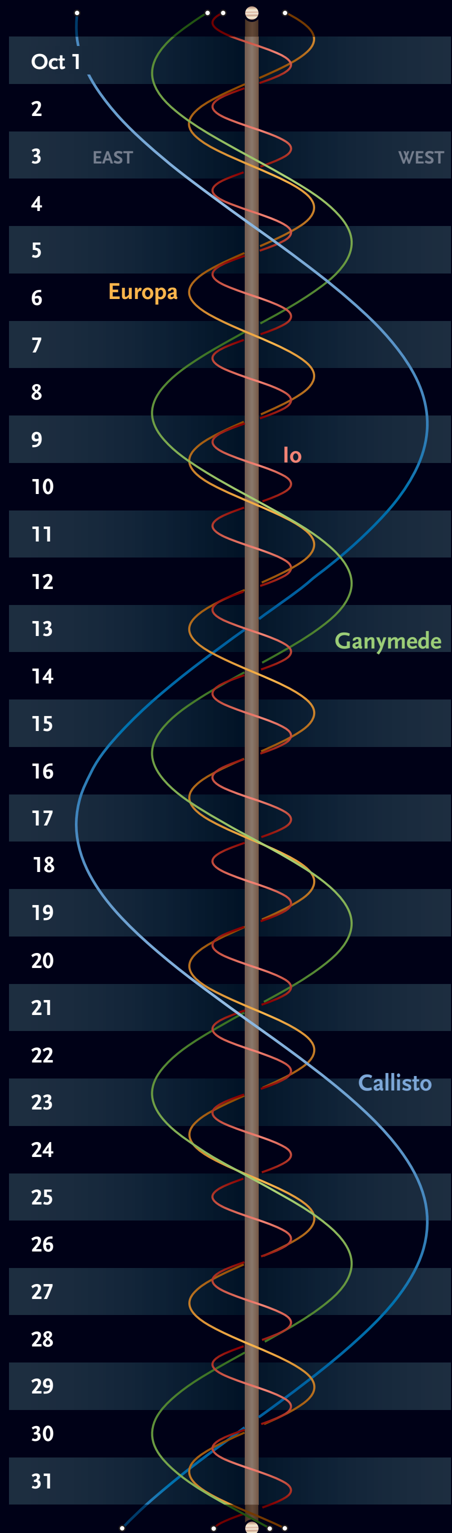
The answer may be what's going on inside them. Neptune radiates 2.6 times as much warmth as it receives from the distant Sun. A lot of heat is clearly emerging from its deep interior, as with Jupiter and Saturn. But Uranus radiates essentially no extra heat at all. It's dead inside, or very nearly so. No one knows why. ✦

Minima of Algol

Sept.	UT	Oct.	UT
1	4:51	2	17:45
4	1:39	5	14:34
6	22:28	8	11:23
9	19:16	11	8:11
12	16:05	14	5:00
15	12:54	17	1:49
18	9:42	19	22:38
21	6:31	22	19:26
24	3:19	25	16:15
27	0:08	28	13:04
29	20:57	31	9:53

These geocentric predictions are from the heliocentric elements Min. = JD 2452500.179 + 2.867335*E*, where *E* is any integer. For a naked-eye comparison-star chart and more information about Algol and its history, see SkyandTelescope.com/algol.

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.

Personal Observing Lists

Track down a group of lunar features that have special meaning for you.

In most Exploring the Moon columns I try to help observers understand the geologic and exploration history of various lunar features. Yet sometimes it's pleasant to observe the Moon for less scholarly reasons — but still with goals in mind.

This time I want to encourage you to create observing lists of features that have personally meaningful themes. Since the most common lunar features are craters, and since they're mostly named after philosophers, scientists, and explorers, you might try to observe all features named for a particular group of people.

For some ideas, the Moon Wiki website contains lists of craters (**https://is.gd/moon_wiki_lists**) named for mathematicians, astronauts, women, selenographers, Jesuit astronomers, mythological characters, and people from different countries. A history-loving British amateur might set out on a quest to see all craters named for astronomers royal, and someone fascinated by polar explorers might search out all craters named for those hardy adventurers.

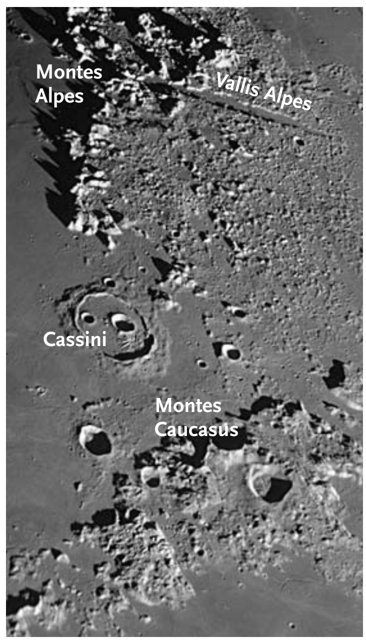
I have two observing lists that I casually pursue. One is based on my career as a lunar scientist, and the other is closely related but more personal.

As someone who has intensely studied the Moon and loves cartography, I observe craters named for those who've published lunar maps. Once again the Moon Wiki helps, for it contains a comprehensive list of nearly 400 maps of the Moon. Rather than looking at all of them, I pick and choose the ones of greatest importance. I start with Galileo and Harriot (the two earliest lunar mapmakers); skip to Langrenus, Hevelius, and Grimaldi (who created the first maps of decent quality); and catch my breath with Cassini, whose 1679 map is one of the most beautiful of all time — and whose crater is interesting too.

During the 1600s and well into the 1700s, many lunar maps were either poorly drawn (Blancanus) or derivative copies of earlier efforts (Doppelmayer). Although Tobias Mayer's crater is undistinguished, his 1748 map was the first one based on measured positions of features and the first to include a latitude-longitude grid. John Russell, a professional artist of the late 18th century, created another beautiful lunar map and a magnificent globe, so I stop by his crater from time to time to pay homage.

The 1800s included mapmakers who defined the classic period of lunar studies. Most renowned were Lohrmann (1824), Beer and Mädler (1834–37), Nasmyth and Carpenter (1874), Neison (1876), and Schmidt (1878). Near the turn of the century another spate of maps appeared by Fauth and Elger (both in 1895), along with


PARIS OBSERVATORY / DIGITAL MUSEUM OF PLANETARY MAPPING

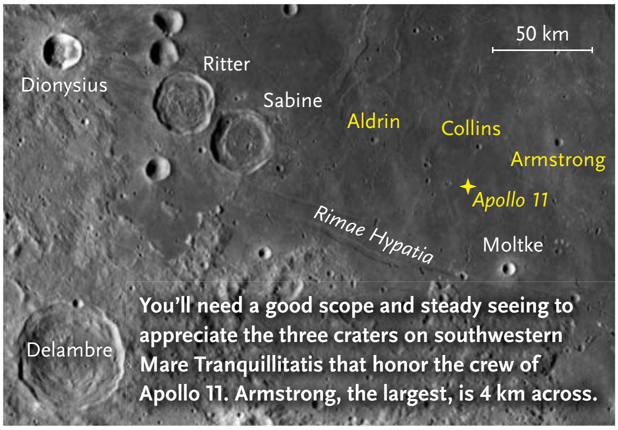


MICHAEL WIRTHS

Far left: **Among his many talents, Gian Domenico Cassini created a beautiful lunar map in 1679. One well-positioned crater (arrowed) would eventually be named in his honor.** ***Left:*** **You can spot 57-km-wide Cassini along the eastern shore of Mare Imbrium — most easily around times of first or last quarter. North is shown up.**

Contributing Editor ***Charles A. Wood*** *(www2.lpod.org) is coauthor of* 21st Century Atlas of the Moon.

Charles A. Wood



You'll need a good scope and steady seeing to appreciate the three craters on southwestern Mare Tranquillitatis that honor the crew of Apollo 11. Armstrong, the largest, is 4 km across.

NASA / LUNAR RECONNAISSANCE ORBITER

MAKING YOUR OWN

In case you're looking for ideas for an observing list, note that 31 lunar features are named for women, 11 for mythological figures, 8 for astronomers royal, and 7 for Australians. For something more challenging, about 300 features are named for mathematicians. Not all of these appear on the Moon's nearside, however.

the first photographic maps of the Moon by Loewy and Puiseux (1896 to 1910) and Pickering (1903). The modern British period of mappers included Goodacre (1931), Blagg and Müller (1935), and Wilkins and Moore (1955).

The period of professional mapping started with Kuiper (1960) and Alter (1964), but I have never observed the latter's crater since it's on the farside. As yet, none of the authors of the hundreds of maps published since 1964 have craters named for them. (As a member of that group, I'm actually glad — because you have to be dead for at least three years to be honored with a crater!)

My second, personal, observing list is much smaller and is comprised of people I have met during my scientific career. Because I was lucky to work in Gerard Kuiper's Lunar and Planetary Laboratory in the early 1960s, I met many of the leading lunar scientists of the time. At the head of this personal list are Kuiper and his archrival Harold Urey. Kuiper's small crater is in Mare Cognitum, a lava-covered expanse that he named in 1964 because it was the impact site for Ranger 7 (NASA's first successful lunar-imaging spacecraft). Urey's larger crater is squished near the eastern limb, and I have never knowingly observed it.

Another crater I have undoubtedly seen but not identified at the time is Harlan, a dark-floored crater on the nearside-facing shore of Mare Australe. It's named for Harlan Smith, whom I met only once at a conference, and it's one of a very few lunar craters given the first name of its honoree. My final scientist is George Van Biesbroeck, a famous Yerkes Observatory astronomer who retired to the Lunar Lab when I was there in the 1960s. His crater sits on the rim of Krieger, southeast of Aristarchus.

I met a number of other honorees when I worked at NASA's Johnson Space Center in the 1980s. Most were lunar scientists and colleagues who died too young. Their names are on farside craters and thus aren't on my observing list. One that *is* on it — just barely, because it only occasionally peeks into view near the south pole — is the crater named for iconic lunar scientist Gene Shoemaker.

Seven names on my "personal" list were the final crewmembers of the Space Shuttle *Challenger,* whom I helped train. Unfortunately, the craters for astronauts Dick Scobee, Mike Smith, Ron McNair, Ellison Onizuka, Judy Resnik, and Christa McAuliffe are out of sight on the farside. However, the Apollo 11 crew was honored with three nearside craters close to their landing site in southern Mare Tranquillitatis. I once served on a committee with Michael Collins, so his crater is the only one on my personal list named for an astronaut.

It might seem that I'm bragging about famous people I have known, all due to being born at a time that allowed me to be a bit player in lunar exploration. But ultimately these are simply examples, personal observing lists that are unique to me.

Yours will be unique as well, drawn from people or circumstances special to you. To get started, you'll need a detailed lunar map. I suggest *Sky & Telescope*'s Field Map of the Moon (**https://is.gd/lunar_field_map**) or the IAU's comprehensive Gazetteer of Planetary Nomenclature (**https://is.gd/lunar_gazetteer**). ✦

The Moon • October 2016

Phases

NEW MOON
October 1, 0:11 UT

FIRST QUARTER
October 9, 4:33 UT

FULL MOON
October 16, 4:23 UT

LAST QUARTER
October 22, 20:04 UT

NEW MOON
October 30, 17:38

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

Apogee 406,096 km	**October 4, 11ʰ UT** diameter: 29′ 26″
Perigee 357,861 km	**October 17, 0ʰ UT** diameter: 33′ 23″

Favorable Librations

Demonax (crater)	October 5
Byrd (crater)	October 16
Peary (crater)	October 19

The Celestial Swan

October's familiar skies contain a wealth of fresh sights.

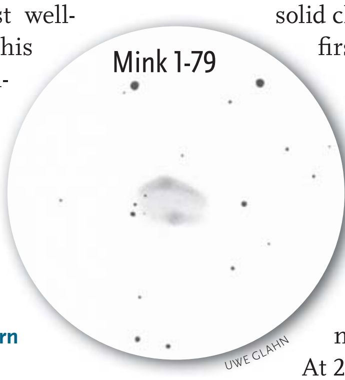
Oh Nature! all-sufficient! over all!
Enrich me with the knowledge of thy works!
Snatch me to heaven; thy rolling wonders there,
World beyond world, in infinite extent,
Profusely scatter'd o'er the void immense.

— James Thomson, *Autumn*, 1730

High in the evening sky, we now behold the starry splendor of Cygnus, the Swan, whose outstretched wings evoke such grace that we can easily envision him gliding above the silvery stream of the Milky Way. Many deep-sky wonders call Cygnus home, including more than a few you may never have seen.

But let's begin with one of the most well-known denizens of Cygnus, **Messier 39**. This splashy open cluster is visible with any optical aid. I recently perused M39 with 18×50 image-stabilized binoculars and was greeted by 24 mixed bright and faint stars in a noteworthy, triangular group. The cluster is a simple star-hop from the arrowhead of stars behind the swan's tail (Deneb) along a line of similarly bright stars.

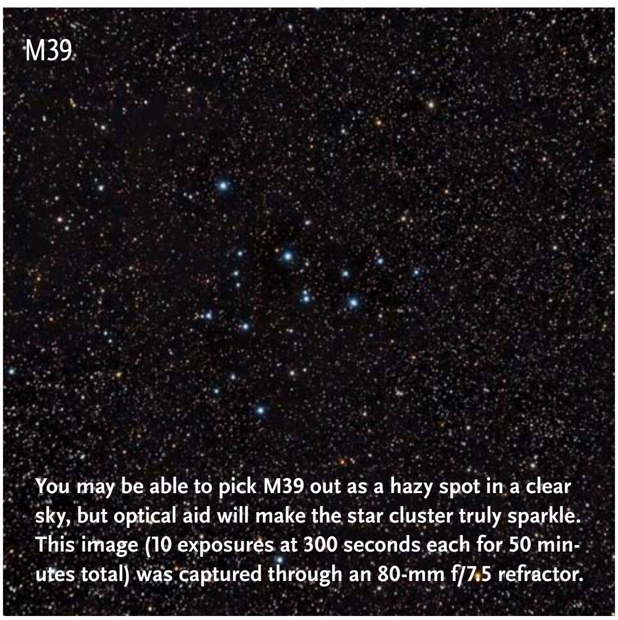
In a dark sky, M39 is visible as a hazy spot to the unaided eye, and Aristotle is sometimes put forth as the cluster's discoverer. This attribution stems from a mistake by Peter Doig, who in 1925 wrote that John Ellard Gore had made this claim. Gore did write a series of papers about the Messier objects, published in *The Observatory* in 1902, but it was M41's discovery that Gore ascribed to Aristotle. Charles Messier holds the only solid claim for the discovery of M39, which he first logged on October 24, 1764.



Studying Minkowski 1-79 through his 27-inch f/4.2 reflector at 586× without a filter, amateur astronomer Uwe Glahn noted that the planetary nebula appeared highly elongated east-west with a brighter center. He also spotted two tiny patches of haze on the northern and southern edges of the nebula.

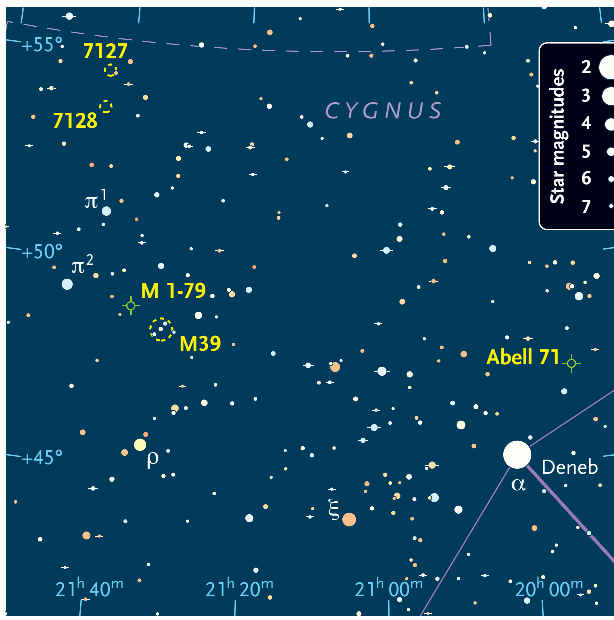
UWE GLAHN

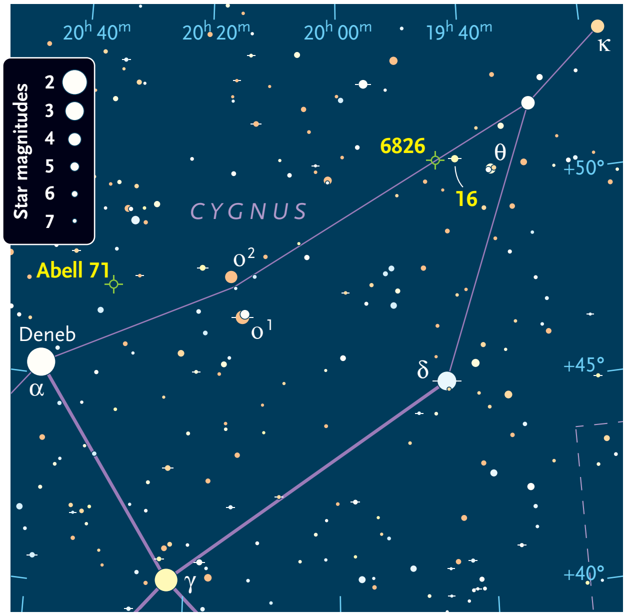
Sitting 1° east-northeast of M39, **Minkowski 1-79** is a nice planetary nebula for medium-size scopes. My 10-inch reflector at 115× shows a faint, east-west oval less than 1′ long. There are 12th- to 13th-magnitude stars positioned about 1′ north and northwest, and another close to its western end. An O III filter makes the nebula stand out much better. At 213× a faint star appears at the planetary's



You may be able to pick M39 out as a hazy spot in a clear sky, but optical aid will make the star cluster truly sparkle. This image (10 exposures at 300 seconds each for 50 minutes total) was captured through an 80-mm f/7.5 refractor.

CRAIG & TAMMY TEMPLE





Cygnus Sights

Object	Type	Mag(v)	Size/Sep	RA	Dec.
M39	Open cluster	4.6	31′	21^h 31.9^m	+48° 26′
Mink 1-79	Planetary nebula	13.2	46″ × 24″	21^h 37.0^m	+48° 56′
NGC 7128	Open cluster	9.7	4.0′	21^h 44.0^m	+53° 43′
NGC 7127	Open cluster	—	6.0′	21^h 43.9^m	+54° 36′
Abell 71	Planetary nebula	14.0	2.6′	20^h 32.4^m	+47° 21′
NGC 6826	Planetary nebula	8.8	32″ × 25″	19^h 44.8^m	+50° 32′
16 Cygni	Double star	6.0, 6.2	42″	19^h 41.8^m	+50° 32′

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.

eastern end, nearly making a rhombus with the other three stars. At the higher magnification, I prefer a narrowband filter when viewing the nebula.

Next we'll visit two unassuming star clusters that loll beneath the Cygnus-Cepheus border. The more conspicuous one is **NGC 7128**, which floats 2.5° north of Pi^1 (π^1) Cygni. My 130-mm refractor at 37× reveals one 9.6-magnitude star, two faint stars, and a few extremely faint sparkles decorating a diminutive patch of haze. A magnification of 63× shows eight stars outlining a 1.6′ × 1.1′ oval, 117× yields a dozen stars in a 2.6′ group, and 164× discloses 16 stars in a 3′ group. Through the

Observers sometimes disagree on the position, size, and age of open cluster NGC 7127. Some catalogs include the (possibly physically related) group that sits to the northwest of the main group as part of the cluster's body.

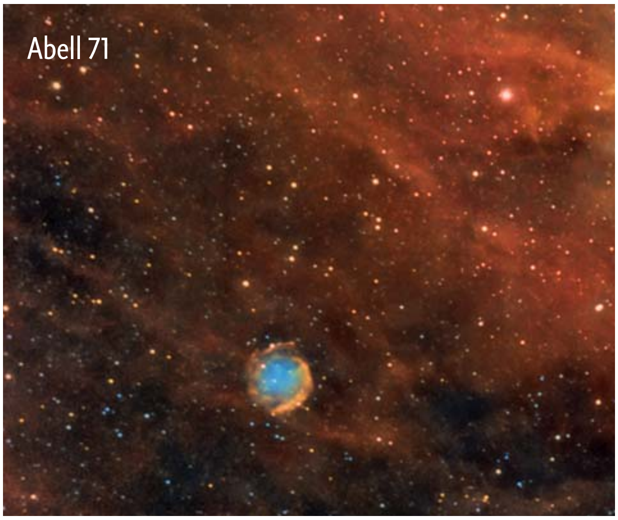
POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

10-inch scope at 213×, NGC 7128 is a 3.2′, triangular group of 20 stars, the brightest an orange gem affixed to its southeastern point.

The second cluster is **NGC 7127**. It hovers 53′ due north of NGC 7128, which shares the field of view through the 130-mm scope at 37×. NGC 7127 displays a misty knot encompassing one moderately faint and four dim stars. A detached asterism of five stars sits close northwest, and a golden, 7.0-magnitude star rests 8.5′ west-southwest. At 117× NGC 7127 has a 3½′ concentration of 10 stars, and there are two outliers northeast. The northwestern group becomes a boxy collection of 10 stars whose longest dimension is about 4′.

NGC 7127 is a problematic cluster. Its given age, distance, apparent size, and position differ significantly from source to source. Some include part of the northwestern group. The size and position in our table come from *Star Clusters* (Brent A. Archinal and Steven J. Hynes, 2003). John Herschel discovered this star group in 1829 and later described it as "A small, poor, but neatly defined cluster of stars 10th to 12th magnitude; with appendages northwest at some distance."

The remarkable but painfully faint planetary nebula **Abell 71** is an excellent target for amateur astronomers who like a real challenge. It's not difficult to locate Abell 71, but actually seeing its phantom presence in such a starry field is another matter. The nebula lies 2.6° northwest of Deneb and only 14′ northwest of the golden, 7.8-magnitude star HD 196090 (SAO 49786). Seen through my 15-inch reflector, this star sits at the tip of a 27′-long, tapered arrowhead of fairly prominent stars that points toward Abell 71. At 216× the nebula makes a grudging appearance that's hard-won through patient study. A 12.7-magnitude star perches just beyond its south-southwestern edge and a similarly bright star sits



Left: **The physical structure of Abell 71 becomes more apparent thanks to astrophotography. J. P. Metsävainio imaged the planetary nebula with a series of filtered exposures and mapped the emission of the ionized elements to different colors: the vibrant blue center shows the interior oxygen emission.** ***Right:*** **Niels Christensen stacked a series of raw frames captured through a 16-inch ACF Schmidt-Cassegrain. The halo around NGC 6826 represents hydrogen and oxygen data passed through H-alpha and O III filters.**

within the southwestern edge. Stars about one magnitude dimmer rest slightly west of the nebula's center and at its northeastern edge. Very faint stars occupy the southeastern quadrant and the northern and northwestern edges. Those last two are the southernmost of a little bunch of stars that crowns the nebula. The nebula itself is roundish, not quite as dim in the sector that runs east-southeast clockwise to north-northeast, and very difficult to detect. I estimate a diameter of somewhere around 2¼′. After seeing Abell 71 in the 15-inch scope, I tried to observe it a number of times in the 10-inch. With considerable effort or imagination, I'm honestly not sure which, I occasionally thought I could glimpse the "brighter" sector. What do you think?

It's noised about on the internet that Abell 71 is not truly a planetary nebula, but rather an H II region (an emission nebula whose hydrogen is ionized by the radiation of massive stars). This idea stems from a single paper that was published in 1991 (Paris Pişmiş et al., *Publications of the Astronomical Society of the Pacific*). As of this writing, at least 30 papers that include Abell 71 have been published in the ensuing years, all of them treating Abell 71 as a planetary nebula.

A telling testament to the nature of Abell 71 are composite images that use filters to capture its various emission lines and combine them in a color-coded image. For example, the magnificent image by Finnish astrophotographer Jukka-Pekka Metsävainio clearly shows the interior oxygen emission (blue) indicative of a planetary nebula. Lowell Observatory's Brian Skiff writes that images combining hydrogen-alpha and other emission lines in a complete imaging survey along the galactic plane would be a significant asset to professional astronomers. Interested parties may contact Skiff at **bas@lowell.edu**.

Since we've attempted one exceptionally difficult planetary nebula, let's close with one that's quite a showpiece. **NGC 6826** rests 28′ east of **16 Cygni**, a wide, pretty double composed of two 6th-magnitude yellow stars. In my 105-mm refractor at 47×, the planetary is a tiny, blue-grey disk. At 127× its slightly oval form is about 25″ across and brighter around the nebula's central star. Under some observing conditions, the outer oval seems to dim when you look directly at the central star but brightens again if you direct your gaze a little to one side. This accounts for NGC 6826's popular nickname — the Blinking Planetary.

NGC 6826 is gorgeous in my 15-inch reflector. At 133× the nebula shines a beautiful colonial blue punctuated with a bright central star. At 247× the planetary looks oval, tipped a bit east of southeast. There is a bright, diffuse halo surrounding a very bright interior that has dark patches close to the central star. The entire structure seems to be embedded in a large, round, exceedingly faint, outer halo. As judged by the distance between field stars, it's roughly 2′ across. An O III filter can help make this ethereal glow detectable. At 345× the oval, inner halo spans about ½′. I didn't notice the somewhat brighter patches within the oval's ends that have been logged by other observers. Can you spot them? ✦

 Rod Mollise

Video Astronomy:

The Atik Infinity

Atik brings video observing fully into the digital age.

Atik Infinity
U.S. price: $995
Available from dealers worldwide.

ALL PHOTOS BY THE AUTHOR

HOW DO YOU do video observing? It used to be an easy question to answer. You attached an analog video camera to your telescope, and a 15- to 30-second exposure was long enough to capture countless faint objects, while short enough to give the illusion you were observing them in real time. Advanced cameras often included a neat function that stacked each new exposure into the previous one, resulting in a deeper, more detailed image.

These analog cameras showed plenty of objects but came with a lot of caveats. The images they produced were noisy. Using the camera was difficult, too; you needed a dedicated video monitor out at the telescope, or a special adapter to convert the analog signal to a digital format to display them on a laptop computer. Finally, the small size of the cameras' sensors meant they only covered narrow fields of view.

Fortunately, today there's an easier way to observe with video that preserves the immediacy and produces higher-resolution images. Enter the Atik Infinity from the United Kingdom. This multi-purpose CCD camera promises to make video observing easy and fun while reducing the amount of equipment needed at the telescope.

The Atik Infinity is a dedicated video astronomy camera designed to reveal targets through your telescope that are often fainter than you can see with your eye.

A Compact Package

The Atik Infinity is a beautifully finished "box" with red anodizing and a black nosepiece. With the exception of its lack of controls or an LCD screen, the Infinity looks more like a point-and-shoot digital camera than a video camera. The unit has just three ports: a type-B female USB connector, an RJ-12 autoguiding port, and a connector for the 12-volt DC power supply. It's rectangular in shape and thin, measuring 113 mm by 70 mm high and

The camera includes a T-to-1¼-inch nosepiece, a 3-meter (9.8-foot) USB 2.0 cable, a 1.8-m DC power cable, a quick start booklet, and a disk with the camera drivers and control software.

WHAT WE LIKE:
Lightweight, solid construction
Low-noise, high-sensitivity sensor
WHAT WE DON'T LIKE:
Generic "quick start" booklet
Loose power cable

25 mm thick. The camera's nosepiece features T-threads that can be used with standard adapters and accepts most T- to 1¼-inch adapters. The camera is available with either color or monochrome CCD sensors, though I requested a color camera for this review.

In addition to its digital nature, a big attraction of the Atik Infinity is its relatively large CCD chip. It's a 16-bit, ⅔-inch Sony ICX825 with a 1,392 × 1,040 pixel array, which promises much wider fields of view than analog video cameras, particularly when it's used with focal lengths of 1,000 mm or less. The sensor's mid-sized 6.45-micron-square pixels, combined with its high quantum efficiency, should allow it to rival and even surpass the sensitivity of its analog predecessors.

The Infinity's compact body is possibly due to its bare-bones design; there's no Peltier unit or fan to cool the CCD chip. Normally, a CCD detector require electronic cooling to reduce thermal noise, which appears as many bright pixels in the images it produces. The manufacturer claims the inherent low-noise characteristics of the camera's Sony EXview HAD CCD II sensor eliminates the need for cooling that keeps thermal noise at bay. According to Atik's literature, dark frames are not required to remove warm pixels generated by heat. I was skeptical. My DSLRs do fine without cooling, but they require dark frames to be subtracted from images to remove the many false stars of thermal noise.

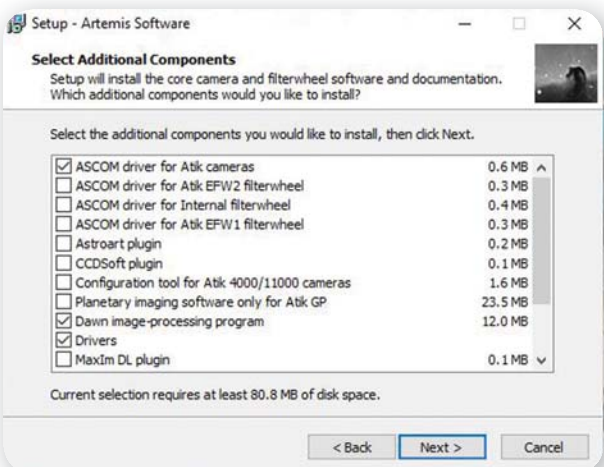
Included with the camera is a 3-meter (9.8-foot) USB cable, a 1.8-m, 12-volt power cable equipped with a "cigarette lighter"-style plug, a 1¼-inch screw-on adapter, a brief quick-start guide, and a DVD containing the camera

Left: **The Infinity's ⅔-inch format Sony ICX825 EXview HAD CCD II detector boasts high quantum efficiency, meaning you'll record faint objects with fairly short exposures.** ***Right:*** **Three ports on the bottom of the Infinity are a B-type USB 2.0, an RJ-12 port that allows the camera to be used as an autoguider, and a DC power input. The red LED is activated only when the camera is connected to your telescope mount.**

drivers and software needed to operate the camera, as well as a PDF manual. Currently, the Infinity's software is only available for PCs running Windows Vista, 7, 8, or 10.

I was impressed with the build quality of the Infinity, but was less impressed with its software installer and quick-start guide. Both are generic and don't address the Infinity specifically; they're applicable to all Atik cameras. Likewise, the DVD contains software for the entire range of Atik products. Inserting it yielded an install window with a long list of programs and utilities that could be installed. It was obvious I needed to load "*Infinity*," but did I also need ASCOM drivers? What were the "plug-ins" the app was offering to install?

The quick-start guide helped some by cautioning me to be sure "drivers" (not ASCOM drivers) was checked in the window. Otherwise, it instructed me to select any optional software I need. But what did I need? With the help of the Atik website, I finally figured out I only



Included with the Infinity is an install disk with the camera drivers and software necessary to operate the camera. It also includes many other drivers and plug-ins for third-party software, as well as drivers for many other Atik products.

needed to install the *Infinity* application in addition to the camera drivers.

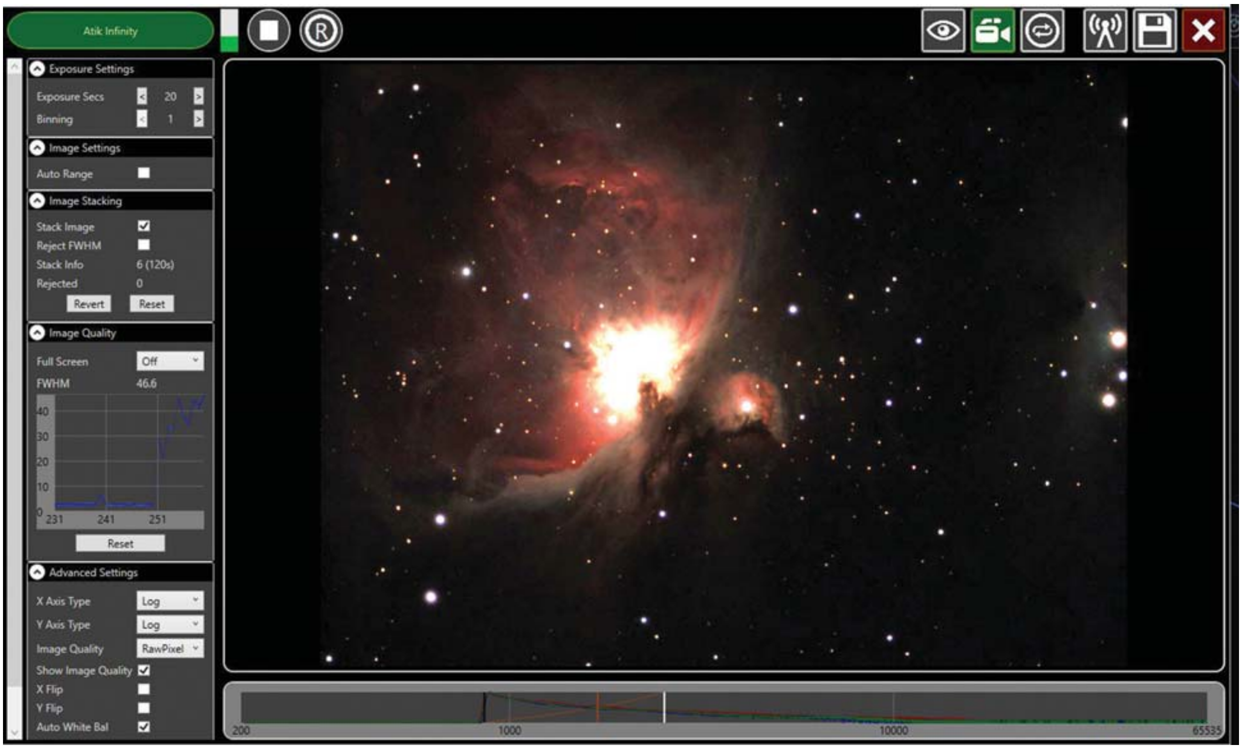
Once I got past the installation, I thought I'd have a look at the *Infinity* program indoors. But it wasn't clear how I was supposed to do that, since the installer didn't place an icon for the program on my desktop. A little digging around on the hard drive turned up a directory named "ArtemisCCD," which I recalled from the quick-start guide. Inside that directory was a sub-directory called "Infinity," and in it was the software application of the same name.

When I launched the program, I became a lot happier. The software doesn't have an overwhelming number of features, but that's in keeping with the nature of video astronomy as a simpler way to take images. There are no menus to navigate to set up the camera; just connect the power, plug in the USB cable, and run the program.

From there it's a matter of learning a few buttons, controls, and indicators. Exposures are limited to a maximum of 120 seconds, but for the dimmest objects, you can select a binning mode, a process combining the sensor's pixels into groups of 2×2, 4×4, or 8×8. The result is considerably more sensitivity but at the expense of resolution. Also, due to the way the Infinity produces color images, binned exposures appear in black and white.

One of the software's most important features is "Image Stacking." When stacking is enabled, the program automatically aligns and combines incoming images into a single, smoother-looking frame. While stacking doesn't add details not present in the individual sub-frames, it makes everything clearer by reducing the noise in the image, which made a big difference in what I was able to achieve with the Infinity.

The remaining controls that will get the most use concern the histogram at the bottom of the screen. The program also permits users to select automatic histogram settings — high, medium, low — to set image brightness and contrast, but manual adjustment of the



Once installed, the *Infinity* program was easy to master. The software has only a few controls, which makes operating the camera easy and relatively intuitive. The image of M42 is mirror-reversed due to the author using a star diagonal.

black, white, and gray sliders along the bottom of the screen usually yielded better results. Unlike with some imaging programs, these settings don't just affect the displayed image; they're saved with the picture, so before clicking "save," be sure the image looks good onscreen.

After just a little use, I grew to appreciate the *Infinity* program — with one exception. It's not a true Windows application. Not only does it lack standard Windows menus, it can't be minimized. Clicking the program's top bar will downsize it, but you can't completely minimize the program. That was slightly annoying when I wanted to access other running software, like the planetarium program I use to control my telescope mount.

In the Field

Preliminaries done, I was ready to hit the backyard. My back-forty is hardly perfect, with a zenith limiting magnitude of about 5.0 on a good night, but it's sufficient to allow video cameras to pull in amazingly dim targets with my 5- and 8-inch telescopes. Since my 5-inch f/7 refractor was already set up on its Go To equatorial mount, I thought I'd try the Infinity with it first.

While the chip of the Infinity is larger than those of my analog cameras, calculations showed I would still need a focal reducer to allow the camera to frame larger targets. Unfortunately, all I had for the refractor was an inexpensive 0.5× reducer. I decided to use it, and if I couldn't bring the scope to focus, or if I had other problems, I'd use a shorter focal length telescope the following night.

Once I had the mount Go To aligned, I inserted the camera and reducer into the scope's focuser via the Infinity's 1¼-inch nosepiece and almost immediately ran into a problem. When I'd plugged the power supply into the camera experimentally in the house, I'd noted the connection felt loose. The same was true of the cigarette lighter cord. In the backyard the power connector wasn't just loose, it fell out the moment I moved the telescope.

The solution was simple. I mounted the Infinity upside down in the focuser with the power and other connectors facing up. That didn't cause any operational problems, but was a little annoying. Atik needs to provide a more secure connector, perhaps one with a threaded collar.

Power restored, I sent the telescope to a bright star and focused. I tried the Infinity's finder mode first but soon switched to normal video. Exposures in video mode were smoother and sharper looking, and I found it easier to focus by eye than in finder mode. One-second shots

Low surface brightness galaxies such as M33 were easy targets using the Infinity and the author's 80-mm refractor. This image was the result of stacking twelve 30-second exposures at f/6 combined automatically in the *Infinity* program.

Images taken with the Infinity and the author's 80-mm refractor were extremely noise-free, with only a handful of hot pixels visible when using the camera on warm summer nights. Hot pixels appear as red, green, and blue dots, and appear in clusters in these images because they combine multiple exposures. The better your tracking is, the less these will detract from your view.

The camera's power cable port was very loose, often allowing the cable to fall out when slewing the telescope. A simple fix was to mount the Infinity upside down in the focuser.

allowed me to get Aldebaran as small as possible, and bumping up the exposure to 2 seconds showed plenty of dimmer stars. By watching those dimmer stars and observing the Full Width Half Minimum readout in the program, I was able to achieve good focus.

I wasn't going to go easy on the Infinity. My first target would be a challenging one. The Flaming Star Nebula in Auriga, IC 405, has bedeviled me over the years. I'm not sure I've ever been convinced I've seen it visually, even in large telescopes. I'd never tried my analog cameras on it, because it's just too large for their small chips to properly frame. Frankly, I didn't expect it to show up on my monitor on this night given the state of my backyard sky, which wasn't close to its magnitude-5.0 best.

Surprise! There it was in a 45-second exposure. Carefully adjusting the histogram showed impressive detail and multiple loops of nebulosity. In addition to my surprise and pleasure at turning up such a dim target with ease, I was happy to see how noise-free the picture looked. If there was thermal noise present, it wasn't obvious.

One issue I ran into using the Infinity on my refractors when attaching the camera at prime focus was limited focus travel. The Infinity's chip is close to the front of the camera, only 13 mm back, so I couldn't reach focus unless I had my star diagonal in place, or an extension tube. If your telescope doesn't have a lot of back-focus range, be prepared for this problem.

The second evening's first subject was Messier 33, the Pinwheel Galaxy. Once on target with my 80-mm refractor, I was relieved to see the 1°-wide object just fit in the field. Since it was getting low in the west, I didn't expect my image of the galaxy to look good, and, indeed, the 30-second exposure looked grainy and washed out.

Before moving on, however, I thought I'd try the program's automatic image-stacking feature. Not only did it work, it made all the difference in the world. By the time 4 or 5 frames had accumulated, the galaxy was looking smooth and pretty. I was seeing plenty of spiral detail and was able to pick out multiple pinkish H II regions, nebulae in the big galaxy.

Later, my first look at Orion's dim Horsehead Nebula allayed any remaining concerns about the Infinity's sensitivity. A single 40-second exposure was enough to show the dark Horsehead, B33, and the dim red emission nebula, IC 434, that forms its background. After five 40-second frames had accumulated, I wasn't just seeing the Horsehead, I was detecting fine details!

So it went for the remainder of the evening, dim object after dim object falling to the Infinity and eliciting plenty of oohs and aahs from my fellow observers. Despite a few annoyances at the start, I was quite impressed with the camera. The Atik Infinity has me ready to put my much-loved analog cameras on the shelf. ✦

Contributing Editor ***Rod Mollise*** *can often be found observing at many of the summer star parties held throughout the southern United States.*

New Product Showcase

▼**UHC FILTERS** Farpoint Astro introduces a new Ultimate High Contrast Narrowband filter (starting at $109.95 for the 1¼-inch version). The filter passes 3 emission line wavelengths while simultaneously blocking most light pollution and other unwanted signals with a very steep drop-off in the transmission curve. The result is high-contrast views of nebulae, including M42, M8, and other nebulae. The Farpoint Astro UHC is available in 1¼ and 2-inch threaded cells. See the manufacturer's website for additional specifications.

Farpoint Astro
11358 Amalgam Way, Suite A1,
Gold River, CA 95670, 877-623-4021
farpointastro.com

▶ **PORTABLE MAK** Levenhuk unveils the SkyMatic 127 GT MAK ($769.95). This compact 5-inch f/11.8 Maksutov-Cassegrain telescope features a generous aperture to provide satisfying views of solar system targets as well as many deep-sky objects. The telescope rides on a sturdy single-arm Go To mount powered by 8 AA batteries. Its SynScan hand controller includes an extensive database of more than 42,000 objects, including all the Messier, NGC, and IC object catalogs and is quickly aligned by aiming at two bright stars. The telescope includes a 90° star prism, a 6×30 finderscope, and both 10- and 26-mm 1¼-inch eyepieces.

Levenhuk USA
924-D East 124th Ave., Tampa, FL 33612
813-468-3001; levenhuk.com

◀ **COOLED DSLR** PrimaLuce Lab announces the Cooled Canon 700Da Astrophotography Camera ($1,950). This modified DSLR features a fully integrated Peltier cooling system capable of operating at 30°C below ambient temperature to greatly reduce thermal noise in your images. The camera is built around the popular Canon 700D with its APS-format 18-megapixel CMOS array and also includes an articulated LCD viewing screen that allows you convenient viewing from virtually any angle. A modified infrared-blocking filter extends the camera's hydrogen-alpha sensitivity, and an internal anti-dewing system eliminates fogging issues on the sensor.

PrimaLuce Lab
Available in the U.S. at Woodland Hills Camera & Telescope
5348 Topanga Canyon Blvd., Woodland Hills, CA 91364
888-427-8766; telescopes.net

George Willis RITCHEY'S Great Adventure

The world's giant telescopes today owe their optical design to a star-crossed, obsessive genius.

Ted Rafferty

George Ritchey was an unlikely man to build astronomy's path out of the 19th century into the modern era. Born in 1864 in the small town of Tuppers Plains, Ohio, he learned the trade of cabinetmaker. He was employed as a woodshop teacher when, in 1891 at age 27, he crossed paths with a young and ambitious astronomer: George Ellery Hale, scion of a Chicago manufacturing family.Ritchey already had an interest in astronomy and a perfectionist's eye for mechanics. Hale was on a crusade to build a new astronomy for the 20th century. He would eventually hire Ritchey as the chief optician and designer for telescopes larger than the world had ever seen. The irascible Ritchey's ultimate falling out with the driven, idiosyncratic Hale echoed through American astronomy's institutional politics for decades after both were dead. And Ritchey never lived to see the triumph of perhaps his greatest invention.

The first functional reflecting telescope was made by Isaac Newton in 1668, but reflectors were very slow to develop. Refractors had the jump on them technologically, and reflectors got stuck with a reputation as being second rate. Reinforcing this reputation in the 19th century was the poor performance of a 48-inch reflector built by Grubb & Sons of Dublin in 1868 and installed at Melbourne Observatory in Australia. In 1904 Ritchey wrote: "I consider the failure of the great Melbourne reflector to have been one of the greatest calamities in the history of instrumental astronomy, for by destroying confidence in the usefulness of great reflecting telescopes it has hindered the development of this type of instrument, so wonderfully efficient in photographic and spectroscopic work, by nearly a third of a century."

UNIVERSITY OF CHICAGO PHOTOGRAPHIC ARCHIVE (2)

Between 1896 and 1935, Ritchey built only five telescopes (not including a number of specialized solar telescopes he made for Hale, who began as a solar astronomer). All five were very large. The first three — 24, 60, and 100 inches in aperture — were quickly hailed as milestones in the development of astronomy. The 100-inch in particular opened new vistas for cosmic research that left the refractor forever behind. But Ritchey's last two reflectors were considered failures, and the value of their novel design, used nearly universally today, went unrecognized until a decade after Ritchey's death.

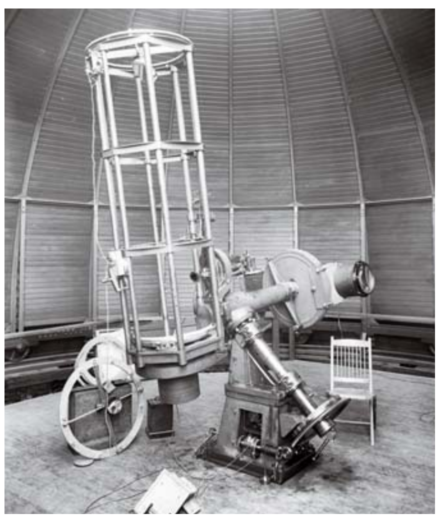
Viewed from a distance, the history of astronomy, and of science in general, can look like one long, steady construction of a great edifice, with each new brick being laid naturally and logically on top of the ones before. Look closer and the construction process is messy and chaotic, organic and evolutionary — full of dead ends long forgotten (until, perhaps, they revive) and instances of three steps forward, two steps back. So here is the tale of George Ritchey's five telescopes.

1. The Yerkes 24-inch Reflector

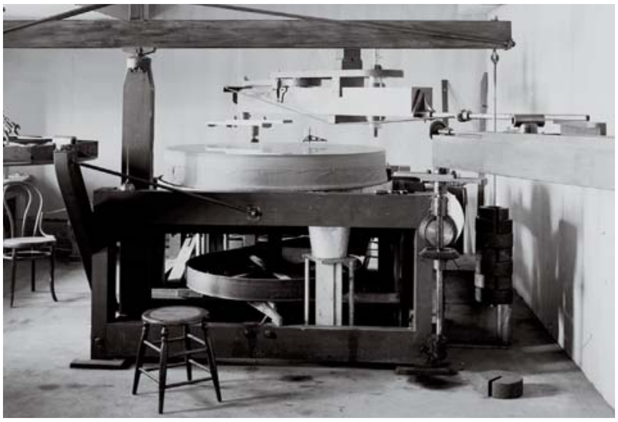
George Ellery Hale, Ritchey's junior by four years, was already a highly accomplished astronomer by his mid-twenties — single-minded, ceaselessly energetic, even frenetic, though prone to spells of depression. His passion to build a really large reflector was such that in 1896, he talked his father into ordering a 60-inch diameter mirror blank from the Saint Gobain glassworks in France, as well as several smaller blanks. One of the latter was 23.5 inches in diameter and 2.6 inches thick. Saint Gobain's main product was wine bottles; all the disks were made from "wine bottle" glass.

Hale asked Ritchey to grind and figure the 24-inch. To do so Ritchey used a grinding machine that he built himself and operated at his Chicago home. He gave the mirror a paraboloid figure (required for a Newtonian reflector) with a focal length of 93 inches, making it an f/4.0. He didn't have the funds to build the rest of a telescope around it, so he sold it to the new Yerkes Observatory for $200. At the time Hale was working for Yerkes's parent institution, the University of Chicago, and he had talked his father into paying Ritchey a salary. Soon after Yerkes bought the mirror, it hired Ritchey onto its staff, and there he finished the rest of the telescope.

Ritchey designed an innovative arrangement for the 24-inch scope (pictured below). It could be used in two configurations: as a standard short-focus Newtonian and as a long-focus Cassegrain. For the latter, the flat Newtonian secondary mirror could be replaced with a five-inch hyperboloid convex mirror that reflected starlight back down the tube to a flat diagonal, which sent it to a focus on the side of the tube's back end. (The primary mirror



BOUND FOR GLORY In an 1898 photo of Yerkes Observatory staff, George Ritchey is enlarged at right. George Ellery Hale is indicated to the left. The two men — intense, tenacious, and eventually bitter enemies — together built the instruments that opened modern research astronomy. ***At left:*** Ritchey's first large telescope was this 24-inch reflector. The Newtonian diagonal mirror in the top of the tube could be swapped out for the convex, hyperboloid secondary mirror mounted in the ring displayed on the floor.



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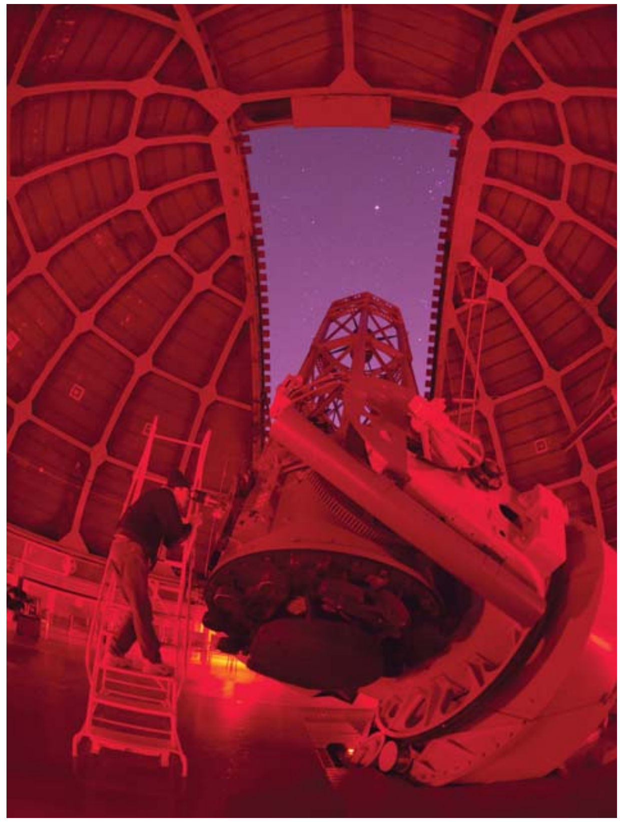


BRYAN SNOW

MIRROR MUSCLE *Above:* Ritchey designed the grinding machine for shaping the Mount Wilson 60-inch mirror. The sluice at right brought water and abrasive. The iron grinding tool hangs at far left. *Right:* The author views Jupiter at the f/16 Cassegrain focus of the 60-inch, now rebuilt around the original optics and used for amateur and public viewing. From 1908 to 1919 it was the largest telescope in the world. *Facing page:* Sunlight streams into the dome of the Mount Wilson 100-inch, completed in 1919. Hale wanted it to be a larger version of the 60-inch; Ritchey wanted to make it the world's first Ritchey-Chrétien. Hale won. It was the world's largest telescope until the 200-inch Hale Telescope began operations on Palomar Mountain in 1949.

did not have a hole in its middle, as most Cassegrains do now.) The Cassegrain configuration had an effective focal length of 456 inches (f/19.4), providing a very large image scale.

But this was just Ritchey's warm-up.

2. The Mount Wilson 60-inch

In 1897 Ritchey moved to the recently completed Yerkes Observatory in Williams Bay, Wisconsin. Here he had a grinding machine built for Hale's great 60-inch disk, for which Hale's father had paid $2,000 (about $54,000 in today's dollars). Progress on grinding the 60-inch was slowed by Ritchey's involvement in other projects, such as the Snow solar telescope that Hale was building with $10,000 he had drummed up from a donor. Hale was in no hurry to have the 60-inch optics completed, because he didn't want the telescope erected at Yerkes. He had a better site in mind.

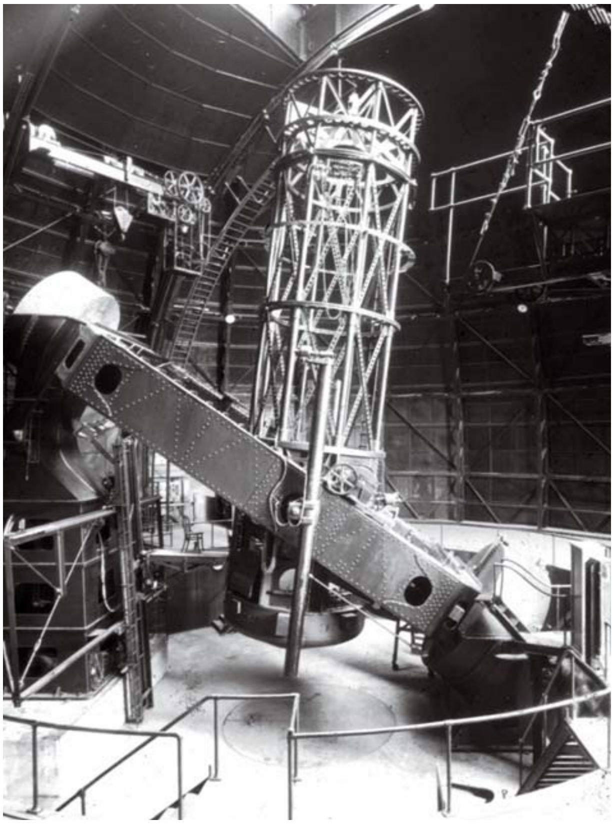
In April 1905, Hale moved the unfinished 60-inch mirror from Yerkes to Pasadena, California, near Los Angeles and below the 5,700-foot peak of Mount Wilson. Here Ritchey completed the grinding, figuring, and polishing. He also designed the mount and dome for the telescope, supervised the widening of the road to Mount Wilson's summit, and ordered the special trucks that would haul the giant telescope parts up the mountain. He finished the 60-inch mirror in August 1907, and in December the complete 60-inch telescope began operations. At its Newtonian focus it had a focal length of 25 feet (f/5). Three different hyperboloid secondary mirrors gave effective focal lengths of 80 feet (f/16), 100 feet (f/20), and 150 feet (f/30). It was the largest working telescope in the world.

3. The Mount Wilson 100-inch

While the 60-inch was still in the grinding stage, the ever-more-ambitious Hale persuaded John D. Hooker, who had made a fortune in iron and oil, to pay for a mirror blank for a 100-inch reflector to surpass even the 60-inch. The Saint Gobain company again poured the disk using wine-bottle glass. Whereas the 60-inch blank was 7.5 inches thick and weighed 1,950 pounds, the 100-inch disk would be 12 inches thick and weigh 9,500 pounds.

The first attempt, in 1907, failed when the disk cracked during the cooling process. A second attempt later that year made it through cooling, but it had layers of bubbles due to Saint Gobain being unable to pour the molten glass in a single pour (it required three). The disk was shipped to Pasadena, but both Ritchey and Hale rejected it. Ritchey went to France in early 1908 and stayed for several months in an effort to improve the glass-pouring procedures. Three more attempts all failed.

Back in Pasadena, Hale reexamined the mirror blank that he had, and he became convinced that it would do; the bubbles were below the level where the reflective surface would be. Ritchey disagreed; Hale overruled him. Ritchey started grinding the gigantic disk on November 10, 1910.



UNIVERSITY OF CHICAGO PHOTOGRAPHIC ARCHIVE

Ritchey's relationship with Hale, often stormy, worsened as work on the 100-inch mirror proceeded. Ritchey wanted to shape the telescope's mirrors to his own new and better optical design; Hale thought an untested design was too risky. Ritchey went over Hale's head and appealed to Hooker, the financial patron; Hale was enraged. In the end the 100-inch, like the 60-inch, was ground to an f/5 parabola, with different hyperboloid secondary mirrors providing longer effective focal lengths.

Hale limited Ritchey's involvement in the design of the telescope's mount. He allowed Ritchey to use the 60-inch to take photographic plates at night, but gave him less and less telescope time. Other astronomers on the staff didn't much like having Ritchey around; a strong-willed cabinetmaker in a group of astronomers wasn't a good mix. Plus, Ritchey was getting wide praise for his astronomical photographs; no one else had the patience or stamina to visually guide exposures for four hours or more. In October 1919, shortly after Ritchey completed the optics for the 100-inch, Hale fired him.

The previous month, Ritchey wrote (to the engineer and inventor Elihu Thompson) that Hale "has reached a place where scientific work and honors are not enough; he must have vast power also; power to dictate the welfare, the making or unmaking, the positions even, of scientific men both in the observatory and outside of it — as far as his influences can possibly reach."

Not a good enemy to have for one's future career.

4. The First Ritchey-Chrétien Telescope

Henri Chrétien, a member of Nice Observatory in France, had come to Mount Wilson as a visiting astronomer in 1910 and worked with Ritchey on deep-sky photography. They were acutely familiar with a problem of short-focus reflectors: the optical aberration known as coma, which turns stars located away from the center of the field into comet shapes rather than sharply focused points. While working with the different hyperboloid secondary mirrors for the 60-inch in its Cassegrain configurations, Ritchey noticed that coma was less than when the 60-inch was used in its Newtonian configuration. Ritchey had Chrétien investigate this optical effect mathematically.

Chrétien found a mathematical sweet spot. If the primary mirror was a specific concave *hyperboloid* instead of the standard paraboloid, and the secondary mirror was a specific convex hyperboloid, coma would disappear. Thus was born the Ritchey-Chrétien optical design, the one Ritchey had wanted to implement for the 100-inch.

Following the ugly break with Hale in 1919, Ritchey was unable to find work building telescopes in the United States. In 1924 the Paris Observatory offered him a job in France, to build an equatorially mounted reflector along the lines of the very successful Mount Wilson 60-inch. But by now Ritchey had much grander plans. Based on an idea he'd had in 1919, he proposed building a fixed, vertically aimed telescope with three or four interchangeable 200- to 240-inch primary mirrors and a pair of similarly large flat mirrors that would track the sky to send starlight down the telescope tube. Ritchey also suggested that the mirrors shouldn't be single disks of glass, but made of thinner disks glued together. The French were taken aback by Ritchey's suggestion of a vertical telescope and its huge cost, and rejected it.

Ritchey then turned back to the possibilities of the Ritchey-Chrétien optical design. He decided the best way to prove its worth was to finish the mirrors for a 20-inch Ritchey-Chrétien that he had started at Mount Wilson but never completed. He figured the primary to a very deep f/2.5 hyperboloid — no small feat, but Ritchey was a perfectionist with great patience. With its convex hyperbolic secondary, the system had a focal ratio of f/6.25.

Not until a decade after Ritchey's death would astronomers finally grasp the wide-field power of the Ritchey-Chrétien optical design.

Ritchey lacked the funds to mount these optics. But he talked Paris Observatory into a contract to make a 20-inch Ritchey-Chrétien telescope — and decided to grind a new set of mirrors for it instead of the ones he had already completed.

This second 20-inch Ritchey-Chrétien, which he finished in 1927, had a focal ratio of f/6.8. Its primary sported an innovation: a hole in the middle to let the light beam go out the back, skipping the third reflection to the side.

Ritchey had the money to complete this second set of optics and a telescope tube for them, but not enough for an equatorial mount. Chrétien managed to borrow a mount from another observatory, and in 1930 the world's first Ritchey-Chrétien telescope opened its eye on the sky from a roll-off-roof building near Paris (below).

The results from the telescope were not what Ritchey had hoped. The photographic plates had to be made concave to match the focal plane; he had to grind and polish each plate to the correct shape and coat it with photographic emulsion himself. The mount proved poorly suited for taking long exposures, and Ritchey, now 66 years old, wasn't as skilled at the exacting task of eyeball-guiding a big telescope through long exposures as he had been at Yerkes and Mount Wilson.

Ritchey left Paris to return to the United States in 1930. He had the nearly unusable 20-inch shipped to Miami, hoping to use it to raise interest in a possibly larger Ritchey-Chrétien telescope for that city. This project too fell through, and the 20-inch was sent back to Paris without ever being set up in Florida.

5. The Naval Observatory 40-inch

Ritchey now turned elsewhere. The U.S. Naval Observatory in Washington, DC, was looking to upgrade its aging capabilities. In 1931, he won a contract from USNO superintendent J. F. Hellweg to build a 40-inch reflector on the Ritchey-Chrétien design for $76,000 ($1.2 million today). Hellweg gave him office and work space in the main building on the observatory grounds in Washington, and let him hire his own people for the project. Hellweg assigned the young W. Malcolm Browne to work with Ritchey full-time, so that someone at the USNO would be familiar with the telescope's details. Ritchey ordered a 40-inch glass disk, again from Saint Gobain.

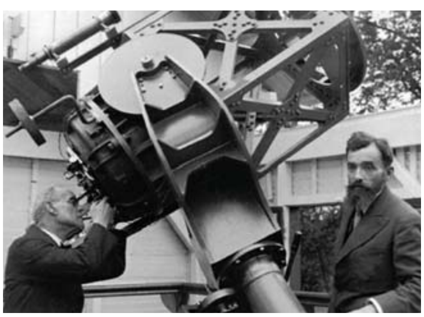
Unlike the Yerkes 24-inch and the Mount Wilson 60- and 100-inch mirrors, the USNO 40-inch blank had a hole in its middle to put the focal plane behind the mirror. When the disk arrived from France, the hole was too small. Ritchey decided that he could enlarge it in Washington instead of having a new disk poured in France, but he decided this would best be done after he finished the mirror's rough grinding. In mid-1932, when Ritchey attempted to have the hole enlarged, the disk cracked.

Ritchey ordered a second disk from France, this time with the right size hole.

In April 1934 Ritchey declared the 40-inch finished. With its 16-inch secondary mirror it had a focal ratio of f/6.8. He started taking test photographs with it. None of the photos came close to Superintendent Hellweg's overinflated expectations for the 40-inch; he had been boasting to the world that it would outperform the Mount Wilson 100-inch, due to secret innovations. Many astronomers, both in the USNO and elsewhere, concluded that the telescope was an outright failure. Ritchey's temporary appointment expired that October, and he was let go. Browne was put in charge of the telescope.

A problem with the flotation support for the primary mirror developed in early 1935. This could only be fixed by removing the mirror, and Ritchey was asked to assist in the operation. On May 4, 1935, while the 500-pound glass was being lifted from the telescope, one side of the hoist support failed. The mirror fell a few feet to the floor, landed on its edge, and started to tip over. Browne acted quickest. He grabbed it and tried to hold it up, but the weight was too great. It fell face down on the dome's metal floor, crushing three of Browne's left fingers. Miraculously, when the mirror was righted, the astrono-

INVENTORS ***Below:*** **Ritchey (left) and Henri Chrétien with the first Ritchey-Chrétien telescope, at the site outside Paris where in 1930 it saw first light.** ***Right:*** **The U.S. Naval Observatory's 40-inch Ritchey-Chrétien telescope in 1934, shortly before Ritchey and his crew dropped the mirror. At right is Ritchey; at left is USNO superintendent Captain J. F. Hellweg.**



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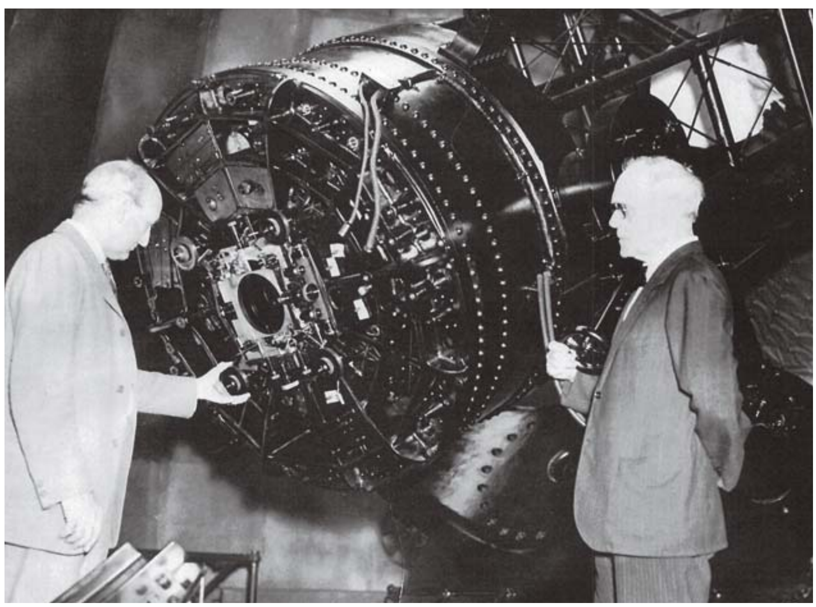

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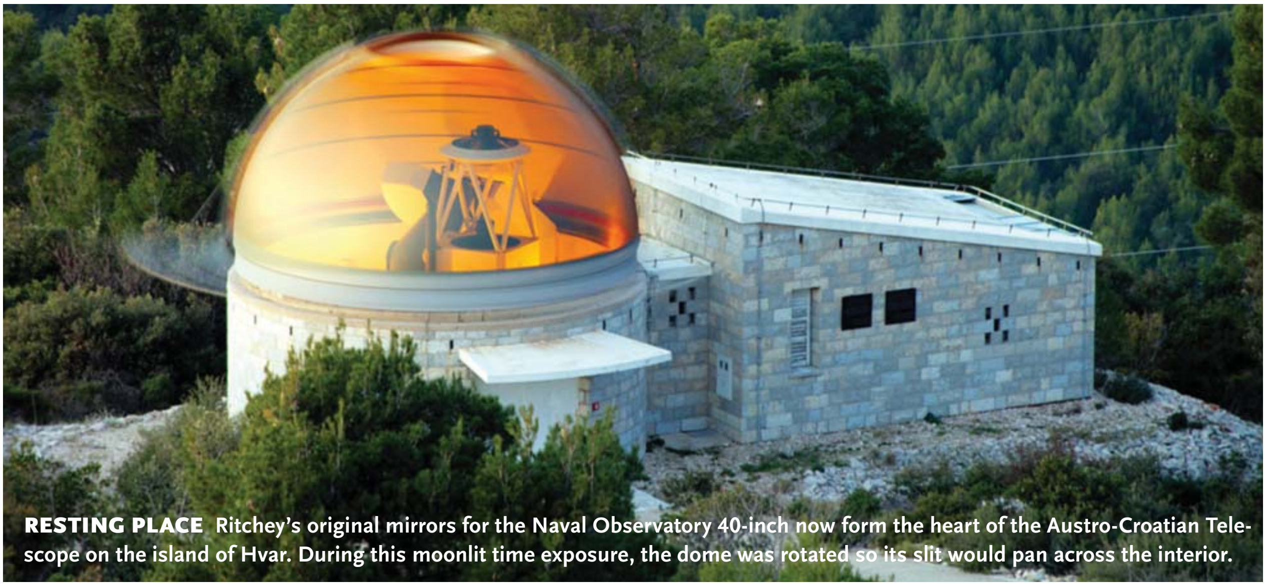


RESTING PLACE Ritchey's original mirrors for the Naval Observatory 40-inch now form the heart of the Austro-Croatian Telescope on the island of Hvar. During this moonlit time exposure, the dome was rotated so its slit would pan across the interior.

HVAR OBSERVATORY

mers found only slight damage around the very edges of the front surface. As a result of the mishap, Hellweg banned Ritchey from the USNO grounds.

Aftermath

In 1936 Ritchey left Washington and moved back to his ranch in Azusa, California. Biographer Stefan Hughes describes him at this point as "a broken man. He had been sacked three times for daring to go 'outside the box' when it came to telescope design and for his inability to follow the 'management line.' He was the archetypal nightmare team member for any project manager." He died in Azusa on November 4, 1945, at age 80. He never lived to see the triumph that the Ritchey-Chrétien optical design would become.

In September 1955, the USNO moved the 40-inch to Flagstaff, Arizona. On a dark desert peak at 7,457 feet, rather than in humid, light-polluted, sea-level Washington, the 40-inch finally showed its potential. And at last the advantage of its Ritchey-Chrétien optics, affording a wide field free of coma, became apparent to the astronomical world.

Today, nearly all great telescopes use the Ritchey-Chrétien design. Among them are the Keck 10-meter twins, the 8-meter Gemini North and South telescopes, and the Hubble. The 6.5-meter James Webb Space Telescope, scheduled for launch in October 2018, uses it too.

The R-C design, as it's now called, has also spread downward in size to amateur use. High-end amateur astrophotographers treasure it for its excellent wide fields, and R-Cs with apertures of 8 to 14 inches command premium prices.

And where are Ritchey's own telescopes today?

The Yerkes 24-inch reflector remained in use at Yerkes into the early 1960s and was donated to the Smithsonian in 1966. It is currently a museum piece at the Chabot Space and Science Center in Oakland, California.

The 60-inch and 100-inch telescopes still operate at Mount Wilson. They are no longer used for professional research, but can be rented by amateur groups for special projects and public viewing (as told in last month's issue, page 22).

The world's first Ritchey-Chrétien telescope, the 20-inch that Ritchey built in France, was installed at the Pic-du-Midi Observatory in the French Pyrenees after Ritchey sent it back from Florida in 1931. Later its secondary mirror was damaged, and the two mirrors were sent to Paris. Their current location is unknown.

The USNO 40-inch reflector is still in research use at Flagstaff, but in 1970 the original wine-glass optics that Ritchey fashioned were replaced with ultra-low expansion silica optics, again on the Ritchey-Chrétien design.

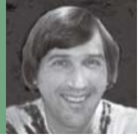
"These telescopes will reveal such mysteries and such riches of the Universe as it has not entered the heart of man to conceive."

In 1998 the old mirrors were installed in the Austro-Croatian Telescope on Croatia's island of Hvar in the Adriatic Sea, where they continue in use today.

In 1929, Ritchey wrote of his passion for building large telescopes: "This is the Great Adventure. These telescopes will reveal such mysteries and such riches of the Universe as it has not entered the heart of man to conceive." Little did he realize that his own role in the Great Adventure would extend long beyond his death, to telescopes of sizes inconceivable during his era, and into space itself. ✦

***Ted Rafferty** is a retired astronomer who worked for the U.S. Naval Observatory for 32 years.*

Jerry Oltion
Astronomer's Workbench



Weijenberg's Propdob Nano

An 8-inch triumph of miniaturization and packaging.

I CAN TELL there's going to be one serious hazard in writing this monthly column: I want to build everything I write about. That's especially true this month. The moment I saw Dutch ATM Roel Weijenberg's 8-inch travel scope, I knew I'd found my next project.

Seriously! Who can resist the lure of a scope that breaks down into a package so small you could lose it under a couch, is light enough (11 pounds!) to carry on a camping trip, yet provides enough aperture to see the spiral arms of M51? This is a must-make project.

Roel was a contender in Gary Seronik's travel scope challenge (*S&T:* Apr., Aug., and Sep. 2009 issues), but for his upcoming trip to the U.S. to witness the 2017 eclipse he wanted something even smaller. He chose an 8″ f/4 mirror made by fellow ATMer Jean Pierre Grootaerd and designed the scope around that. Why 8″ f/4? Roel says, "For me personally an aperture of 8 inches is 'the biggest small telescope' or 'the smallest big telescope' — a size that's very versatile at resolution, light gathering, and portability." Roel also wanted the scope to be solid, not just for stability in observing but also to withstand baggage handlers if he packed it inside a suitcase. And he wanted it sized to use without a chair, which would be more difficult to carry than the telescope.

ROEL WEIJENBERG (2)

Roel calls this scope the "Propdob Nano" because it's tightly compressed for transport. "Prop" roughly translates to "wad" or "half-pint" in Dutch.

Everything packs neatly inside the box.

The rest, as the old saying goes, was just engineering. All the parts would fit into a hard case, so Roel used the top and bottom of the case as the ground board and rocker box, Sumerian Optics style. The eight three-piece aluminum trusses fit inside the box, along with the mirror box, altitude bearings, secondary ring, red-dot finder, helical focuser, four eyepieces, Barlow, light shield, secondary heater, shroud, solar filter, red flashlight, and collimator. Yes, all that goes inside a case 10.55″ long, 9.25″ wide, and 3.94″ high.

When the case is opened out, the trusses clamp to the corners of the mirror box, and the clamps provide enough wood to bolt the altitude bearings to. The effective diameter of the altitude bearings is a respectable 11.5″, which provides a smooth motion and puts the center of gravity close enough to the center of rotation to require just a little tension of a bungee to balance.

The secondary ring is made of 15 mm plywood and holds a three-vane spider. The 2″ helical focuser is made out of the inner working of an old camera objective lens — very lightweight and very low profile. A red-dot finder and a foldable 14″ light shield keep the weight of the upper tube assembly just below 1 pound.

The primary mirror is collimated from behind with nylon screws in what has to be the simplest system I've ever seen. When asked if there was a push-pull spring system securing the mirror, Roel replied, "No springs, just bolts and gravity."

During transport the mirror is "collimated" upwards firmly against a felt-covered protective plate, which itself is tightly packed against the rest of the telescope parts. So no sliding or rattling inside the box! There are also strategically placed drill holes, openings, and slots to make every part fit nicely tucked in place and to prevent things from sliding around and damaging the mirrors during transport.

So how does something this light perform in the wild? Roel reports: "It's surprisingly rigid. I expected it to be a bit more shaky than my larger scope, but it turned out to be the opposite. Vibrations are damped almost instantly, so higher magnifications are no problem at all. And the portability is amazing. Driving to a remote observing site on an old moped (yes, I did that) with a complete 8″ telescope in a small backpack is something special. And when hiking in the mountains it is even possible to boldly go where no 8″ has gone before. I really can't wait to just walk into the desert next year on my U.S. road trip, knowing that everything for a great night of observing is inside that little box."

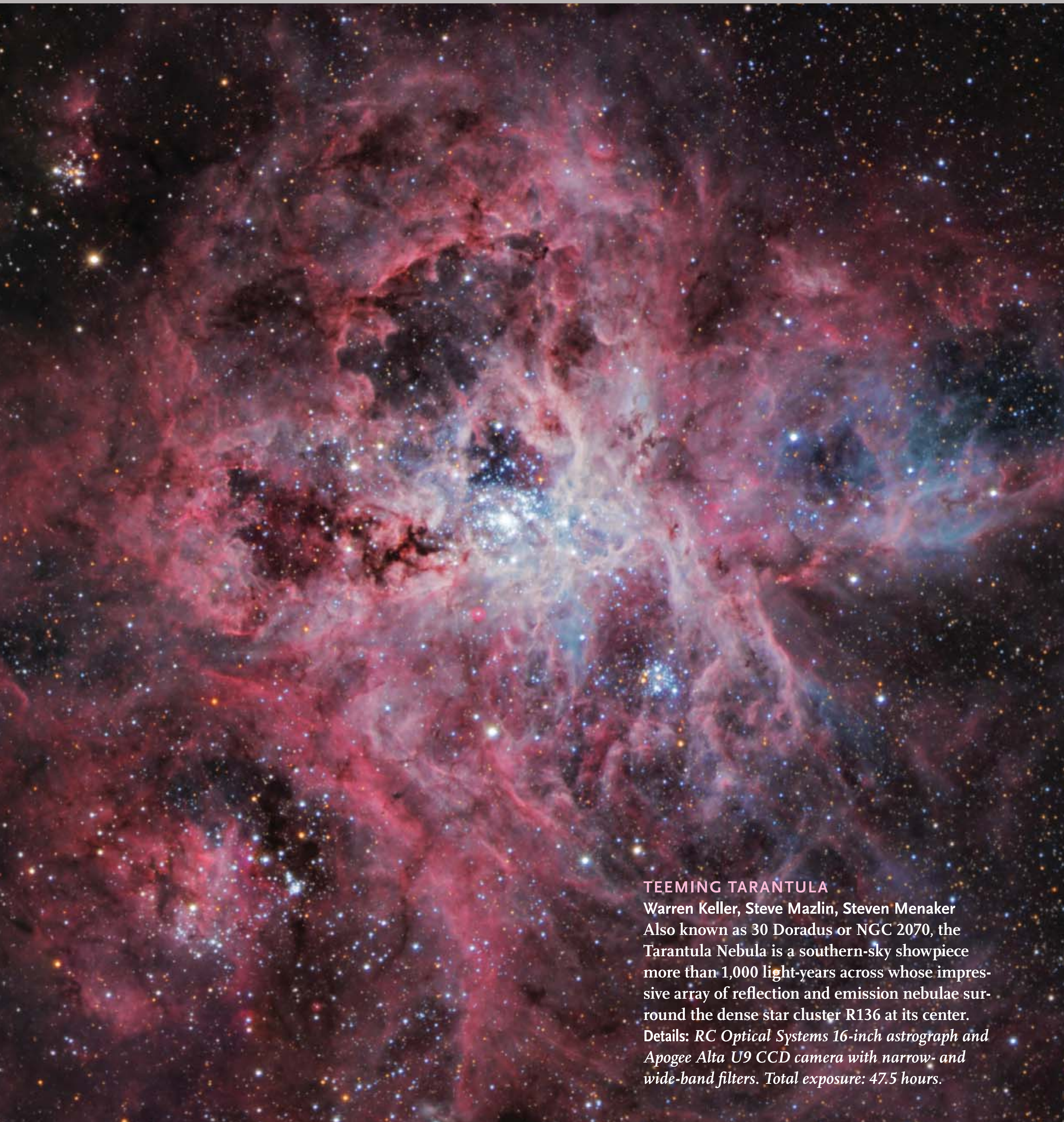
And I can't wait to build one of my own. See more about this and Roel's many other amazing telescopes, including a video of Roel assembling a 10″ Propdob, at **roelblog.nl**. ✦

Jerry Oltion has packed a 20″ scope in a VW Beetle, but he looks forward to packing his new 8″ Propdob Nano by hand.

ROEL WEIJENBERG

The packed scope is amazingly portable.

Do you have a telescope or observing accessory that *S&T* readers would enjoy knowing about? Get featured in Astronomer's Workbench by e-mailing Jerry Oltion at j.oltion@sff.net.



TEEMING TARANTULA

Warren Keller, Steve Mazlin, Steven Menaker

Also known as 30 Doradus or NGC 2070, the Tarantula Nebula is a southern-sky showpiece more than 1,000 light-years across whose impressive array of reflection and emission nebulae surround the dense star cluster R136 at its center.

Details: *RC Optical Systems 16-inch astrograph and Apogee Alta U9 CCD camera with narrow- and wide-band filters. Total exposure: 47.5 hours.*

◂ **SCORPION'S BUTTERFLY**

Dan Crowson

Messier 6, the Butterfly Cluster, is a big, bright collection of young stars that flits near the tail of Scorpius and flirts with naked-eye visibility on very dark nights. The dominant orange star is BM Scorpii. **Details:** *Astro-Tech AT90EDT apochromatic refractor, SBIG ST-8300M CCD camera, and LRGB filters. Total exposure: 4 hours.*

▾ **FULL MOON AT NIGHTFALL**

Amir Shahcheraghian

Dal Khani Forest in northern Iran was the setting for this dramatic moonrise on April 21, 2016, with Earth's shadow (fringed by its pink-hued Belt of Venus) welling up from the eastern horizon. **Details:** *Canon EOS 6D modified DSLR camera at ISO 500 and 28-to-75-mm zoom lens used at 68 mm. Exposure: 1/640 second.*

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◂ **A COMET'S TAIL CUTS LOOSE**

Gerald Rhemann

Comet PanSTARRS (C/2013 X1) displayed lovely gas and dust tails on June 14th. But two days later *(lower panel)* solar-wind turbulence caused the gas tail to break free in a magnetic *disconnection event*.

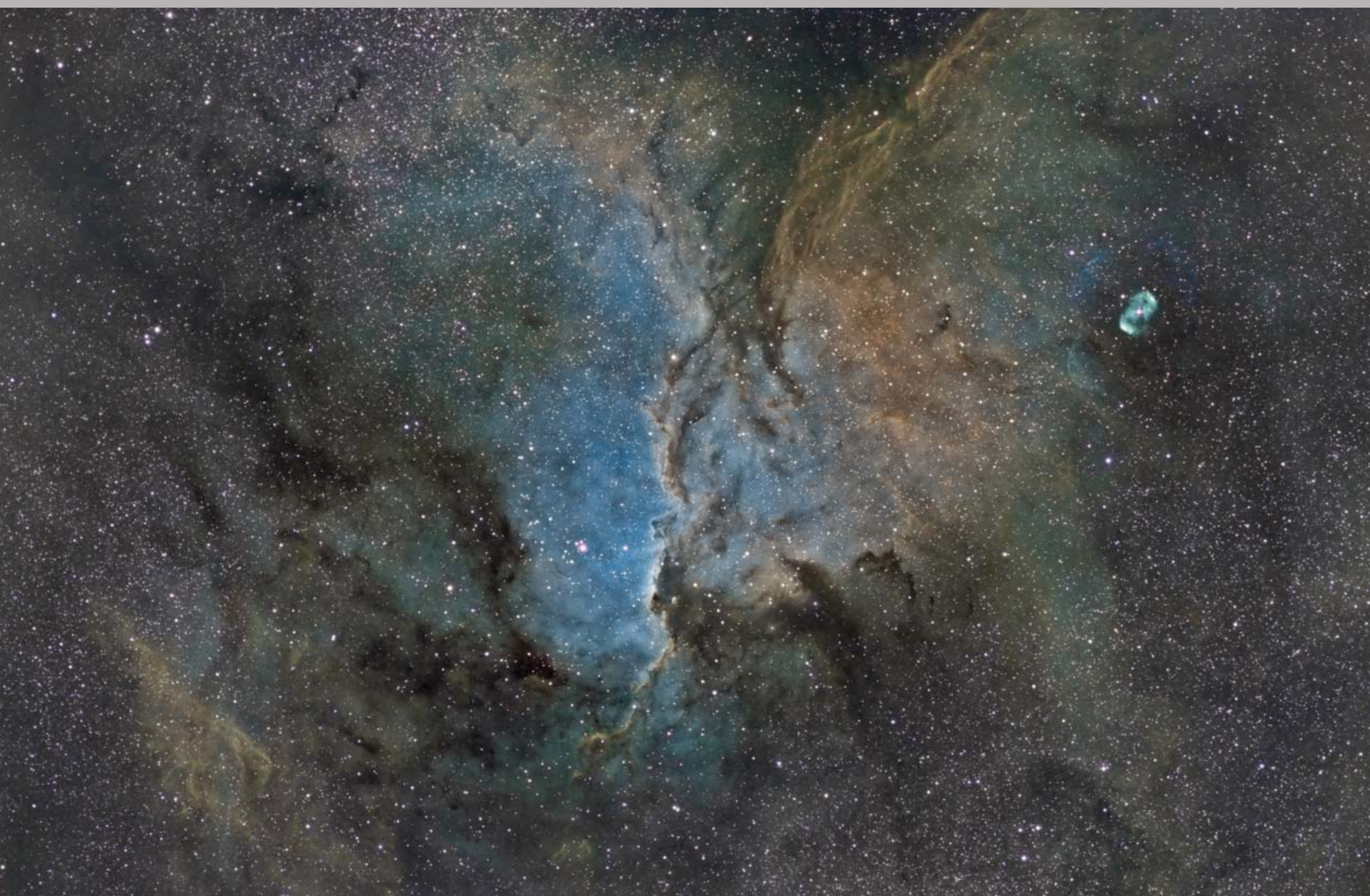
Details: *ASA 12N astrograph and FLI ProLine 16200 CCD camera with LRGB filters. Total exposure: 33.4 and 40 minutes, respectively.*

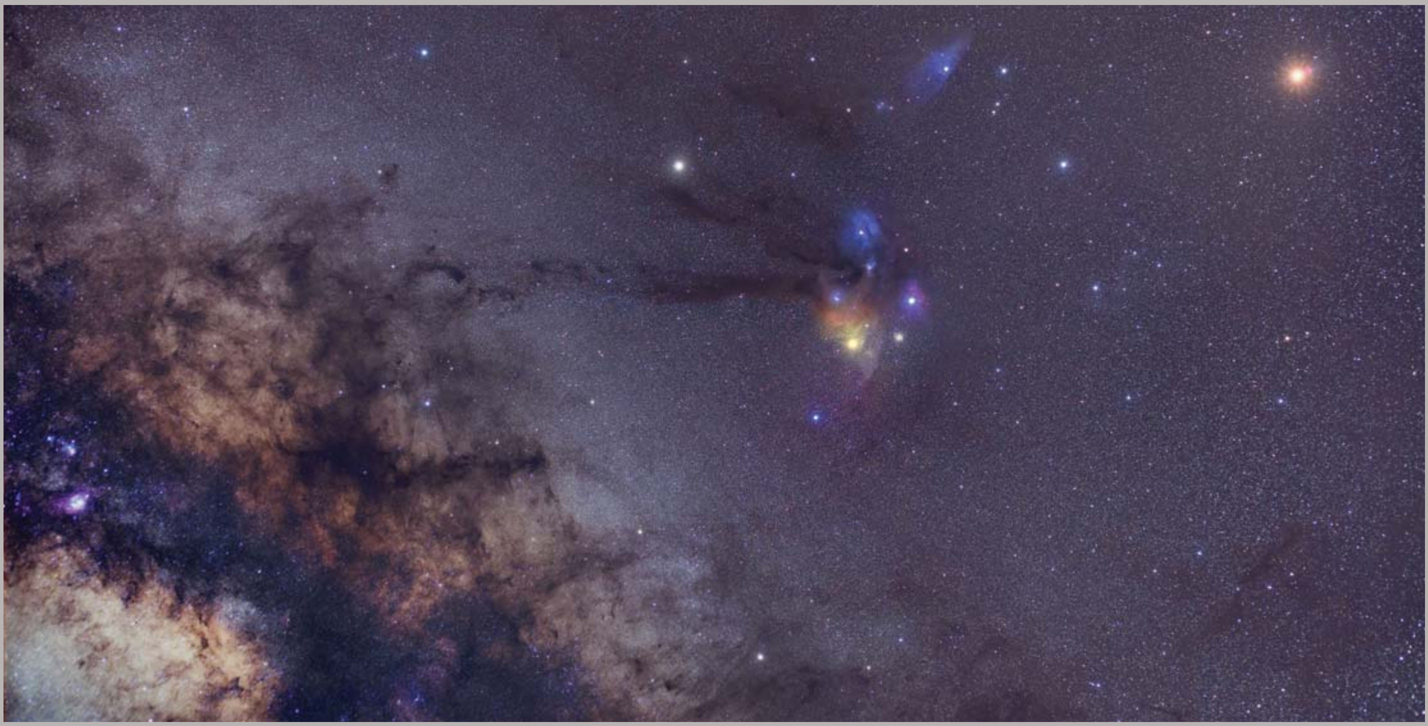
▾ **DUELING DRAGONS**

Shawn Nielsen

Some observers call NGC 6188's collection of emission and reflection nebulae the Fighting Dragons of Ara. At right is NGC 6164, a striking, symmetric cloud of emission that mimics a planetary nebula.

Details: *Takahashi FSQ-106ED astrograph and SBIG STL-11000M CCD camera with hydrogen-alpha, sulfur-II, and oxygen-III filters. Total exposure: 3 hours.*





▲ **WANDERING INTRUDERS**

John Vermette

In June 2016, the rich star clouds of Sagittarius, Scorpius, and Ophiuchus hosted visitors Saturn (above center) and dazzling Mars (upper right). Near center is the Rho Ophiuchi cloud complex. **Details** *Canon EOS 6D DSLR camera at ISO 1600 and 50-mm lens. Total exposure: 2.9 hours.*

▶ **A RIOT OF COLOR**

Matt Dahl

The yellowish reflection nebula IC 4606 near 1st-magnitude Antares complements the bluish clouds around Rho Ophiuchi and pink-tinged Sharpless 9. Wreaths of dark nebulae and globular cluster Messier 4 complete the scene. **Details:** *Canon EOS 6D modified DSLR camera at ISO 1600 and 300-mm lens. Total exposure: 61 minutes.* ✦

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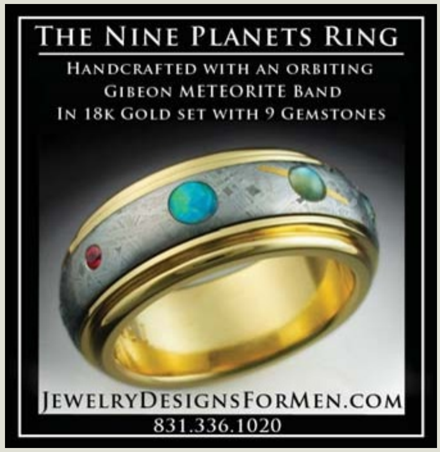

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Mark Mathosian

The Moon Does That to You

Twilight observations draw a range of memorable reactions from strangers.

ISABELLE CARDINAL

The late Sir Patrick Moore, perhaps the world's most famous amateur astronomer, liked to say, "Once a Moon man, always a Moon man." Those are my sentiments exactly and why I receive great pleasure showing people our planet's satellite through my telescope.

My wife and I once owned a condominium in Boca Raton, Florida and did the annual snowbird routine to avoid cold weather. I always brought along a telescope — my 90-mm f/13.8 Maksutov-Cassegrain — as Florida skies are commonly clear at that time of year. I routinely set up the scope and invited passersby to observe the Moon. I relied on trusted 26- and 32-mm oculars, knowing both provided sharp images of our neighboring orb.

Typically, I would set up my telescope before dawn or sunset on the walk running along Ocean Boulevard in front of our building. People strolled, jogged, or cycled on that path all day, but early risers in particular enjoyed extra benefits. They could often view the Moon and then watch a beautiful sunrise over the Atlantic Ocean. When people came close to me, I eagerly announced, "Want to see the Moon?" Some immediately said yes, others kept going, and a few needed a little encouragement: "Have you ever observed the Moon through a telescope? It's amazing. Come have a peek."

One pre-dawn morning a lovely crescent shone boldly in a nearly cloudless sky. Various people accepted my offer. I showed them how to float their eye over the ocular and politely warned them not to touch the scope as it might jiggle our target from view. There was a brief silence as they found the sweet spot in the eyepiece, followed by gasps of "Ooh," "Beautiful," and "You made my day!"

When they lifted their heads I gave them a few seconds to absorb the experience and then said, "Have another look!"

When they did so, a sense of accomplishment swept through me. I knew I had impacted their lives in a special way, and they would likely never again take the Moon for granted. Nor would they forget their pre-dawn outing when brilliant Luna looked almost touchable. They would tell everyone how they saw the bright, ashen sphere through a telescope and what a stunning sight it was. A crescent or gibbous Moon displaying cavernous craters, majestic mountains, and deep, shadowy valleys is always mesmerizing.

After the initial exhilaration wore off the questions began. "What is that dark, smooth area?" "How tall are the mountains?" "Can you see the American flag?" And the query that always made me chuckle: "How much does a telescope like this cost?" A Canadian man made one of the funniest comments. After thanking me he started walking up the path then suddenly stopped, glanced over his shoulder, and exclaimed in all seriousness, "You should charge for that."

Occasionally, a view of the Moon elicits a deeply personal response. One evening a woman peered through the eyepiece, and when she lifted her head she was crying. "What's wrong?" I asked, a bit confused. In a low voice she explained that her daughter had recently died, and when she observed the Moon she felt the two of them were communicating on a spiritual level. Through teary eyes she blessed me. That left me speechless. I simply nodded my head and thought to myself, "The Moon does that to you." ✦

***Mark Mathosian**, a freelance writer, lives with his wife, Kathy, in North Carolina, where they love seeing their grandchildren.*

New
smaller
model