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THE ESSENTIAL GUIDE TO ASTRONOMY

SKY & TELESCOPE

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SKY & TELESCOPE

February 2016 VOL. 131, NO. 2

On the cover:
Our galaxy's center is a crowded, exciting place, with a black hole, speedy stars and gas clouds, and many mysteries.

NASA / JPL-CALTECH / ESA / CXC / STSCI

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February 2016 Digital Extra

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- **Cirumpolar Galaxies**
  Find a complete list of all 35 galaxies in Steve Gottlieb's article on the celestial arctic.
- **Finding Your Way**
  Graduate from our central sky chart to more detailed star atlases and get familiar with your night sky.
- **Geoff Marcy: The Full Story**
  Read about the high-profile sexual harassment case that upset the field of astronomy.

Photo Gallery

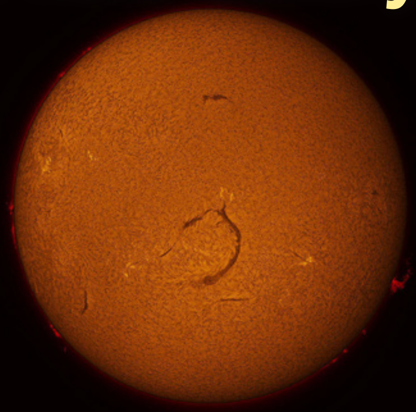

Image by Mike Borman

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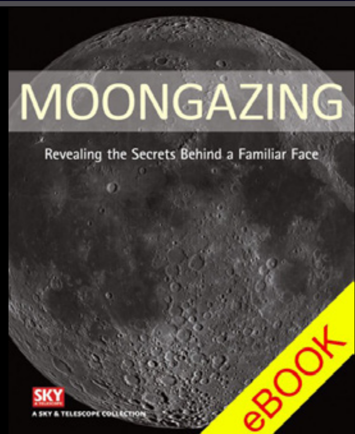

DIGITAL BACK ISSUES:

November, December, and January

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ONLINE PHOTO GALLERY

Jean-Claude Merlin used iTelescope to capture a black-and-white shot of the Horsehead Nebula from Siding Spring Observatory in Australia.

Peter Tyson
Spectrum

Hitch Your Wagon to the Galaxy

Astronomers have been reporting some amazing events over recent years in the heart of our Milky Way Galaxy.

In 2011, they detected an enigmatic object traveling nearly toward the supermassive black hole lying at our galaxy's hub, then watched as it later swung around the hole's far side intact. In early 2013, they picked up an X-ray burst that they soon determined came from a magnetar, a supremely exotic cosmic object. And twice in recent years, the black hole itself has released two of the brightest X-ray flares astronomers have ever observed anywhere. (See our cover story on page 16 for more details.)

These findings are especially remarkable considering the center of the Milky Way is 26,000 light-years away and obscured by intervening dust and gas. But with clever science and sophisticated instruments working in non-visible-light parts of the electromagnetic spectrum — radio, infrared, X-ray — astronomers have been able to "see" the Milky Way's center like never before.

The Milky Way as it might appear from afar

NASA / JPL-CALTECH

With all these discoveries and those elsewhere in our home galaxy, I've been wondering: should we humans be identifying ourselves first and foremost with our galaxy rather than with our solar system? We've gone from Ptolemy's geocentrism to Copernicus' heliocentrism and beyond. Perhaps galactocentrism is next.

We know the Milky Way is not the center of the universe any more than the Earth or Sun is. Indeed, the universe has no center: the Big Bang didn't happen somewhere but everywhere; it wasn't an expansion from a point in space but of space itself.

But we're not talking *center* as much as *centrism*. Consider it a thought experiment of a metaphysical rather than scientific kind. Has the time come when it might behoove us to hitch our wagon, philosophically speaking, to the galaxy as a whole rather than to our run-of-the-mill star and its motley collection of planets (much as we love them)?

Granted, it wouldn't be easy to make this shift. It would be like trying to think on geologic time scales — in epochs and periods rather than in years and centuries, say. Most of us can't do that without enormous and mostly failed effort.

But what if we succeeded, even in part? Where would it lead us? Over the centuries, our ever-deepening understanding of the universe has forced us to become progressively less provincial in our view of our place in it. Maybe galactocentrism of the kind I'm describing is a critical step on the path to a more enlightened cosmogony. ✦

Peter
Editor in Chief

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The Essential Guide to Astronomy

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Newsstand and Retail Distribution:
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The Analemma from Antarctica

Thanks to Earth's spin-axis tilt and the slight eccentricity of its orbit, the Sun does not return to the same spot in our sky at the same time every day but instead traces out a "figure eight" over an entire year. Photographing this looping circuit — called the *analemma* — has tempted amateurs ever since Dennis di Cicco's pioneering conquest nearly four decades ago (*S&T:* June 1979, p. 536).

Apparently no one has ever recorded the analemma from a polar region. But I had this chance in 2014, while working as a European Space Agency research doctor at the French-Italian polar station Concordia (75° south latitude). There I witnessed the Antarctic summer's midnight Sun, as well as the 3-month-long polar night. That's exactly what makes the Antarctic analemma so intriguing: owing to the extreme location, only one lobe of the usual 8-shaped figure is visible — and it also appears almost vertical in the sky.

I began in late 2013, making exposures at 4 p.m. local time every week from December 28th until the following March 23rd, and again from September 17th to December 13th. Attempts to use a DSLR or analog camera proved unfruitful due to the low temperatures. So I used my Canon PowerShot A4000 IS HD compact digital camera in its "Fireworks" mode. Other settings were a 5.0-mm focal length, f/9 focal ratio, ISO 100, and ½-second exposure. Strong winds affected the camera's steadiness, and that's why some exposures appear wobbly. I shot the background picture at 9:15 a.m. to avoid direct sunlight. Finally, all the exposures were compiled in a single photo with the help of fellow astronomer Tilemachos Athanasiadis.

Adrianos Golemis
Larisa, Greece

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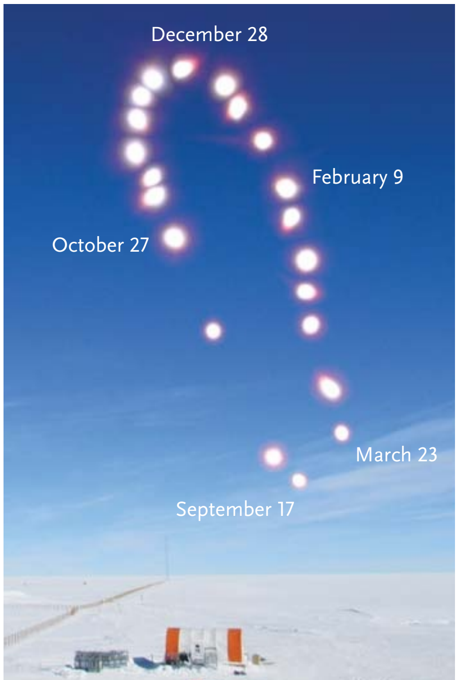


ADRIANOS GOLEMIS

A series of 21 exposures taken over 7 months from Concordia Station in Antarctica reveals half of the analemma. (There the Sun remains below the horizon from May to August.)

Information, Please!

I went out to get my Sunday paper on October 25th. Two bright "stars" appeared overhead; one was extremely bright, perhaps the brightest I've seen. I decided to find out which planets I was looking at, and your website provided the information immediately: Venus and Jupiter. Thank you — I will be visiting again.

Ed Hostettler
Billings, Montana

Saving America's Observatories

Trudy Bell's article on Lick Observatory (*S&T:* Aug. 2015, p. 24) evoked vivid and fond memories of my pre-grad-school days in the 1950s. While at Lick I was an observing assistant assigned to astronomer George Herbig, helping to complete a spectrographic survey of bright stars using the 36-inch Clark refractor. Computing the orbits of spectrographic binaries with a mechanical calculator was a rite of passage.

Friday night was visitors' night. Each week many dozens, if not a hundred, local residents made the hour-long drive up Mount Hamilton to see Saturn through the 36-inch and the Moon through Lick's 12-inch Clark refractor. Reservations were necessary to limit the crowd, but the tickets cost nothing. Completion of the Shane 120-inch reflector, then the world's second largest, ended those visitors' nights — presumably due to the disruption from car headlights on the mountain.

Yet public enthusiasm is the rooting soil of astronomical research. The decommissioned 12-inch should be restored to its small dome, and the original 1887 building and both Clark refractors should be designated a national monument. Funding in perpetuity should be contingent on at least one visitors' night per week.

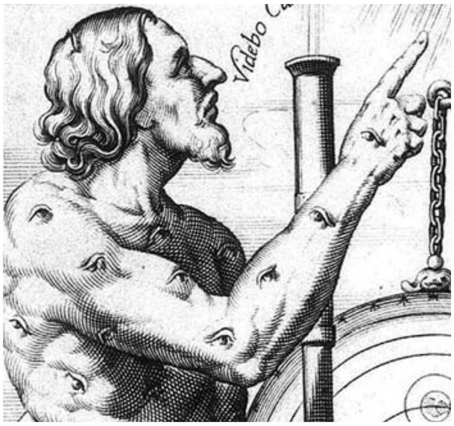
Robert Innes
Sebastopol, California

I have never seen the Moon or the stars through the eyepiece at a big observatory. But were I given the opportunity to look farther into the night sky than I had ever seen before, it would be an awe-inspiring moment. The sad reality is that many observatories face funding shortages because there are those who believe that looking up is a waste of time. However, in reality, it was through the study of astronomy that we have made so many scientific discoveries, including our very understanding of time, space, and our relationship to the cosmos.

Michael Aaron Gallagher
Syracuse, New York

Soon after I received the August issue, officials at Wichita State University announced that the school's Lake Afton Public Observatory would close on August 22nd. Those of us who volunteered at LAPO were very sad to see this happen. We love outreach education enough that we aren't really sure what, where, or how to go on. However, members of the Kansas Astronomical Observers are working on a proposal to maintain and operate the facility going forward.

James J. Fullerton
Wichita, Kansas



ALMAGESTUM NOVUM

The Eyes Have It

Concerning the identity of the man with many eyes depicted in Andrew Livingston's article on Riccioli (*S&T:* May 2015, p. 27, and Oct. 2015, p. 8), my best guess comes from having read Greek mythology as a kid: he's the 100-eyed giant Argus Panoptes. Perhaps Riccioli cast him as a stargazer due to his omniscience?

David Dickinson
Hudson, Florida

Andrew Livingston replies: *Or perhaps he's Helios Panoptes, the all-seeing Sun, since his telescope points significantly in that direction and he's a central character in the theories of both Tycho and Copernicus. Meanwhile, I owe Norman Hugh Redington an apology: Saint Catherine is indeed a patron saint of astronomy — at least in the Greek Orthodox Church.*

Messier's Missing Object(s)

In support of Michael A. Covington's article "The Case of the Missing M102" (*S&T:* Sept. 2015, p. 34), I used NGC 5866 for that object when submitting my observations for the Astronomical League's Messier Club Award in 2006. The site **messier.seds.org/m/ngc5866.html** convinced me that this galaxy corresponds to Messier's 102nd object. The proof is not without doubt, but, as Covington notes, replacing "0 Boötis" with "θ Boötis" puts M102 right where Messier described it.

Lloyd Lashbrook
Plano, Texas

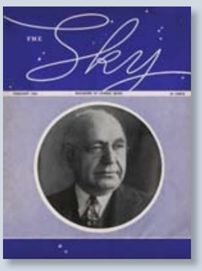
After reading "The Case of the Missing M102," I began to consider the possibility that NGC 581 is not M103. Instead, I believe that NGC 663 might be the object that Pierre Méchain, who contributed 28 objects to the Messier list, observed and recorded as "A cluster of stars between Epsilon and Delta of the leg of Cassiopeia." NGC 581 is about a third of the way between Delta and Epsilon and closer to Delta, whereas NGC 663 is almost at the midpoint, though slightly below the line between these two stars.

Moreover, NGC 663 gives the appearance, especially in binoculars, of a round, comet-like object. I can see it in my 10×50 binoculars as a diffuse glow, and it's easier to spot than NGC 581. John Herschel describes it as "Bright cluster, pretty large; round and rich, with stars 10 and 11 mag." But NGC 581 is not round. So in my opinion it fits neither Méchain's position nor Herschel's description of M103.

Tom Reiland
Pittsburgh, Pennsylvania

75, 50 & 25 Years Ago

Roger W. Sinnott



February 1941

What's Your Sign? "The public interest in astrology has grown rapidly during the past decade. This increasing popular appeal is in no small measure due to the general misapprehension that exists in the minds of many about the standing of astrology as a 'science.' . . . There is hardly an astronomer who has not been approached on more than one occasion with a request for the preparation of a horoscope. . . .

"Hollywood appears to be a veritable astrologers' paradise, and in a quieter way Wall Street has proved a fertile field for astrological activity. Thus it is quite apparent that the influence of astrology is by no means limited to persons with salaries in lower income brackets. . . ."

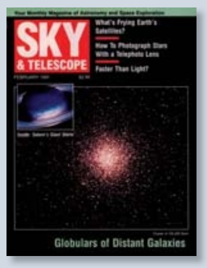
Along with this report, "Scientists Denounce Astrology," editors Charles and Helen Federer railed against astrology in an accompanying editorial. Yet, as recently as 2005, a Gallup poll found that fully 25% of Americans believe in "astrology, or that the position of the stars and planets can affect people's lives."

February 1966

Martian Water "Last summer, when the Mariner 4 photographs of Mars were first studied, it was quickly realized that the planet has about as many craters, area for area, as the moon. This fact led [many] to speculate that the Martian surface is about as old as the moon's — two to five billion years. . . .

"Three later investigations [indicate] the Martian surface may be much younger. . . . E. Anders (University of Chicago) and J. R. Arnold [have] deduced statistically that Mars should experience about 25 times as many asteroid impacts, area for area, as the moon. [They] conclude the surface of Mars is only a sixth as old as the moon's. . . . 'In any event, the crater density on Mars no longer precludes the possibility that liquid water and a denser atmosphere were present on Mars during the first 3.5 billion years of its history.'"

*How surprised they'd be at NASA's finding, announced last September, that liquid water exists on Mars now (*S&T: *Jan. 2016, p. 14).*



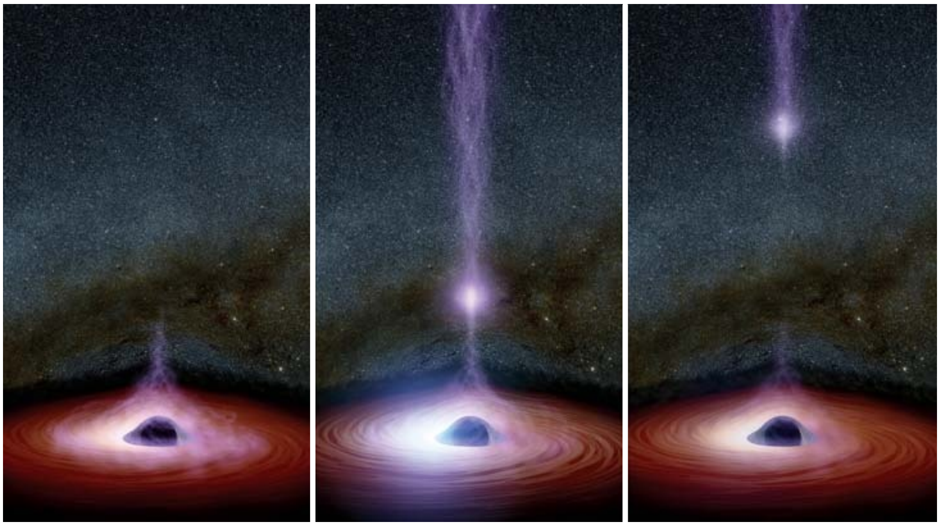
February 1991

Sundown, Exactly "When does the last gleam of sunlight disappear? . . . To find out, Bradley E. Schaefer (NASA-Goddard Space Flight Center) and William Liller (Isaac Newton Institute, Santiago, Chile) collected 144 measurements of the low Sun. They adjusted each one to establish what the actual refraction would have been on the horizon for an observer at sea level [and find the spread to be] 0°.64 at the 95-percent confidence level. This variance is much larger than has been previously assumed by nearly all the world's astronomers. . . .

"[This u]npredictable refraction casts doubt on some claims by archaeoastronomers that ancient stone walls and monuments are aligned with the rising and setting directions of specific celestial objects. This is so because, in general, objects approach the horizon obliquely. [Examples include] the claims by the late Alexander Thom that British megalithic sites were accurate lunar observatories. . . ."

To get astronomy news as it breaks, visit skypub.com/newsblog.

BLACK HOLES | How Flares Happen



NASA / JPL-CALTECH

This series of artist's illustrations shows what might happen when a supermassive black hole flares. The purplish glow around the black hole represents the corona, a haze of energetic particles that generate X-ray light. During a flare, the corona contracts *(left)*, then launches *(middle and right)*, beaming X-rays at observers in the direction of its motion.

Astronomers regularly watch black holes flare, but they're not actually sure *why* flares happen. New X-ray observations now suggest that the brilliant surges occur when a black hole's atmosphere contracts and launches away from it.

This atmosphere, called the corona, is a haze of high-energy electrons that hovers over the black hole and its accretion disk. Photons from the disk collide with the electrons and receive a mighty energy boost, becoming the X-rays we observe.

Dan Wilkins (Saint Mary's University, Canada) and colleagues used the Swift and NuSTAR space telescopes to watch how X-ray emission changed during a month-long flare from the active supermassive black hole in the galaxy Markarian 335, which lies roughly 300 million light-years away in the constellation Pegasus. They noticed that, even though the corona was bright and compact during the flare, the disk reflected fewer than half of the X-rays expected. The corona was still producing X-rays, yet most of them weren't hitting the disk.

The team thinks that, before a flare, the corona is spread out across the disk's surface. Then it gathers itself together into a vertical, jetlike structure, like a cat preparing to spring. This compact haze then launches off the disk at relativistic speeds. When an object moves that fast, it beams more of its radiation in the direction it's moving — which, in this case, is away from the disk. This effect is called *relativistic beaming*. Also, with the corona now farther from the black hole, more of the photons can escape the hole's gravity and reach us. These effects produce the apparent flare.

The flare ends when the jetlike corona collapses back to the disk. However, astronomers don't know why the corona launches in the first place. The study appears in the December 21st *Monthly Notices of the Royal Astronomical Society*.

■ **CAMILLE M. CARLISLE**

STELLAR | Magnetic Fields Weaken Stars' Inner Sloshing

Astronomers have found an indirect way to discern the strength of magnetic fields within red giant stars.

Stars are roiling balls of plasma, and as they roil, their flickers and pulsations reveal clues to what's going on inside. Jim Fuller (Caltech) and colleagues used these changes to study a few dozen red giant stars that had been monitored for years by the Kepler spacecraft.

Red giants have finished fusing their core hydrogen into helium. They often exhibit half-and-half behavior: first one hemisphere brightens, then it dims as the other lights up. This half-on, half-off pattern can be chalked up to sound waves sloshing through the star's interior. But the fluctuations seen in these few dozen red giants are weaker than those in hundreds of others that Kepler observed during the same time period.

To explain this weird behavior, Fuller and colleagues propose that a super-strong inner magnetic field is weakening the brightness variations. In a red giant star, a large convective envelope of plasma surrounds a radiative core where fusion happens. Sound waves churn the outer envelope, interacting with ocean wave–like motions called *gravity waves* within the star's hot, dense plasma core. Sound waves can "talk" to the gravity waves, donating energy to the core. But in the presence of a strong magnetic field, the gravity waves can't "reply" — they're trapped in the core. So the sound waves' energy bleeds into the gravity waves, which themselves gradually dissipate. The lost energy has little effect on the giant star other than the slight weakening of the hemisphere brightness variations.

To explain the observations, a field of at least 100,000 gauss (10 teslas) must be lurking in these stars' cores. That's 100,000 times stronger than the Sun's polar magnetic field and 30 times greater even than sunspots, the strongest magnetic concentrations found on the Sun. The team published the results in the October 23rd *Science*.

■ **MONICA YOUNG**

PLUTO | Cryogenic Volcanoes Found on Dwarf Planet?

Results from New Horizons' July 14, 2015, flyby of Pluto and its moons continue to trickle back to Earth, and in November at the American Astronomical Society's Division for Planetary Sciences annual meeting, mission scientists recapped details from the first 20% received.

The spacecraft's images have already shown that Pluto has an unexpectedly dynamic geology, with towering ice mountains, fresh plains of nitrogen ice that have slowly oozed like glaciers, and a deeply fractured crust. Now you can add "giant ice volcanoes" to that list.

According to Oliver White (NASA Ames Research Center), the spacecraft imaged two broad, tall mountains that are perhaps 150 km (90 miles) across and topped with depressions at their summits. They're dead ringers for the kind of broad shield volcanoes found on Earth (think "Mauna Kea") and other inner planets — and very unlike anything ever seen on dozens of icy moons in the outer solar system. "Whatever they are, they're definitely weird," admits White, "and 'volcanoes' is the least weird explanation at the moment."

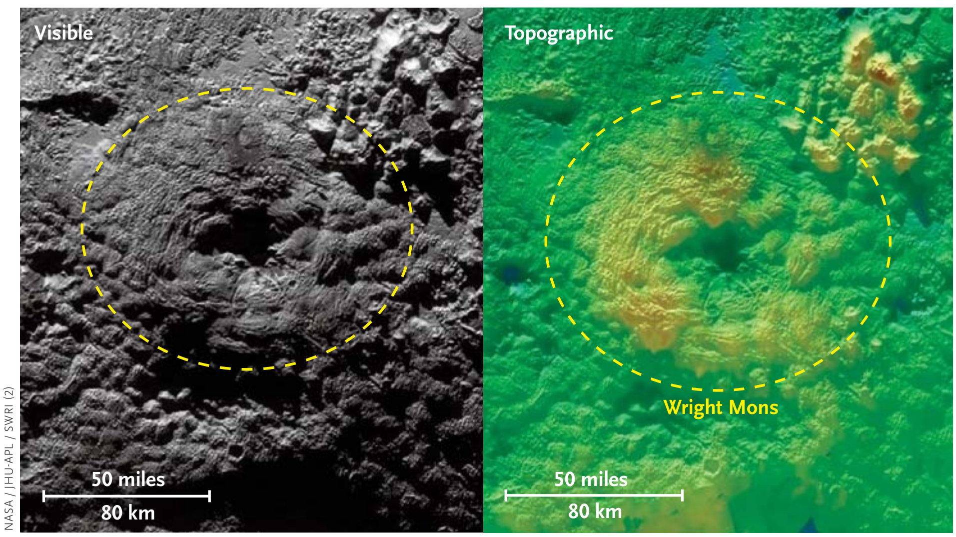
The two mounds aren't immediately obvious in any given image, but they show up in the 3D topographic maps created by viewing the surface from multiple angles (see below). The taller one, informally named Piccard Mons, is 5 km high (16,000 feet); Wright Mons is 3 km high.

The "lava" in this case was not molten rock — Pluto's interior is far too cold for that. Instead, it would have been a slushy mixture of water mixed with ammonia and other normally icy compounds that became liquefied deep down and gushed out onto the surface.

If these really are cryovolcanoes, their summit depressions formed when the source feeding them shut down and the peaks collapsed. Strange, hummocky textures on their flanks might represent individual flows, though no one has yet offered details on their composition or origin.

Add "Piccard" and "Wright" to the growing evidence that Pluto's interior remained warm — and likely still *is* warm — for more than 4 billion years. Ordinarily, objects of this size should have frozen solid long ago. The interior heat isn't from tidal stretching and squeezing incited by another body, as occurs on Io thanks to Jupiter: Pluto and its big moon Charon are locked in a spin-orbit coupling that rules out tidal torquing. The only other plausible heat source would be the long-term decay of radioactive isotopes in the rocky core, which occupies most of Pluto's mass and about 70% of its diameter.

■ **J. KELLY BEATTY**



The informally named feature Wright Mons (center feature) is about 160 km (100 miles) wide and 3 km (10,000 feet) high. Its summit depression is 56 km across, and its sides exhibit a distinctive hummocky texture. Its shape matches that of shield volcanoes on Earth.

BRIEFS from the DIVISION for PLANETARY SCIENCES

■ **J. KELLY BEATTY**

Cracks on Phobos. The enigmatic grooves on Mars's larger satellite were long thought to be a consequence of the formation of Stickney, a 9-km-wide crater that's a third of Phobos's length. But a new analysis by Terry Hurford (NASA Goddard) and others shows that many of the cracks align well with predicted tidal stresses induced by Mars. Phobos is slowly spiraling toward the Red Planet, and tidal forces can produce more than enough stress to fracture the surface. Although no new fractures have appeared in the decades since spacecraft first imaged Phobos at close range, some grooves are younger than others — as would occur if the process that creates them is ongoing.

Defining Planets Redux? Many astronomers have issues with the divisive, Pluto-demoting definition for a planet adopted by the International Astronomical Union in 2006. Strictly, it doesn't apply to exoplanets, nor does it define the upper mass limit for planethood. In a treatise to appear in *Astronomical Journal*, dynamicist Jean-Luc Margot (University of California, Los Angeles) suggests a relatively simple "planet test" that depends only on the candidate's mass, orbital period, and the mass of its host star. The upshot is that a body massive enough to clear its orbit of smaller interlopers within the star's lifetime is a planet. (Pluto would still fall short.)

Chance Collision? Astronomers have recorded what looks like the aftermath of an impact on the main-belt asteroid 493 Griseldis. Images taken in March 2015 show a faint fan of dust coming from the asteroid, but the plume is absent from images taken the following spring and in 2010 and 2012. The feature's orientation is inconsistent with a cometary tail, and at the time Griseldis was far from the perihelion of its 5½-year orbit. So David Tholen (University of Hawaii) and colleagues think they have evidence of a substantial impact on the 46-km-wide asteroid's surface.

STELLAR | Dusty Mystery Around AU Microscopii

Astronomers have discovered inexplicable ripples racing outward in a dusty disk around the star AU Microscopii. Gaps, clumps, or warped features in such disks can signal the presence of forming planets. As part of an effort to look for these telltale planetary signs, Anthony Boccaletti (Paris Observatory) and his colleagues imaged AU Mic with Sphere, an advanced adaptive optics and coronagraph instrument at the Very Large Telescope in Chile.

But what they found was something utterly unexpected: wave-like arches on one side of the disk. Data gathered by the Hubble Space Telescope in 2010 and 2011 show the features, too. Between the four years spanned by the Hubble and VLT observations, the arching waves had moved at a breakneck pace through the disk, moving away from the central star at 4 to 10 kilometers per second (between 9,000 and 22,000 mph).

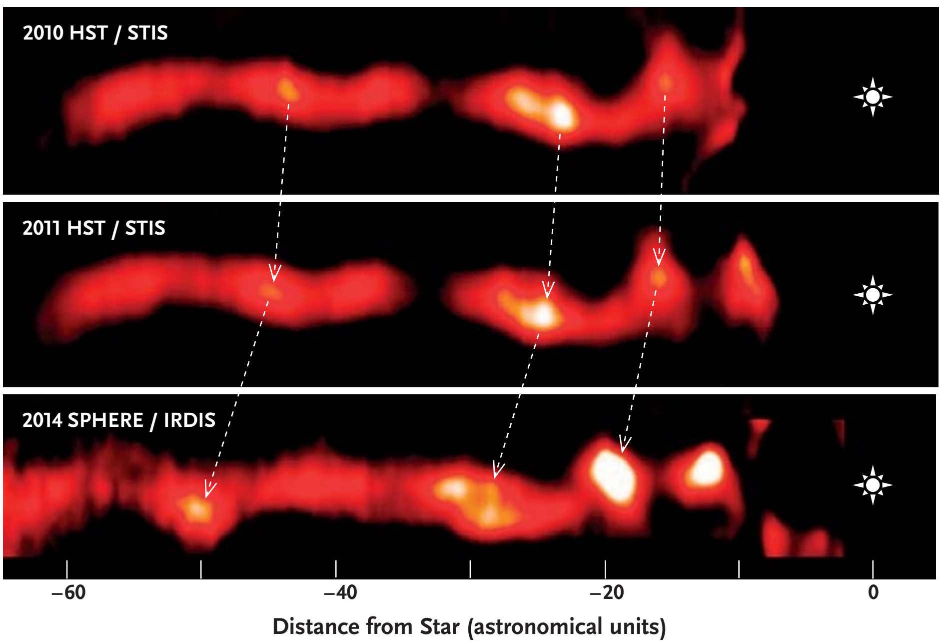
Near-infrared images reveal at least five bright smears within the rippling disk, spaced 10 to 60 astronomical units from the star. They're probably dense clouds of dust. At least three are moving so fast through the outer disk (where, oddly, the waves move faster) that they could easily slip beyond the star's gravitational pull.

"This is a fascinating result," says Richard Nelson (Queen Mary University of London), who was not involved in the study. "But interpreting the observations is a real puzzle."

As the team reports in the October 8th *Nature*, such high speeds rule out any classic scenarios caused by orbiting planets. A warp carved in the disk by a nearby planet, for example, would move at comparatively lethargic speeds. Besides, Boccaletti's team searched carefully for a planet, with no luck. "If there was a planet in there and it was larger than six Jupiter masses, we'd be able to find it," says coauthor Dean Hines (Space Telescope Science Institute). "If there's something in there stirring up the pot, which there almost certainly is, it's going to be smaller than that."

The most promising scenario requires a violent interaction. Young stars like AU Mic can be wildly active, emitting giant flares that can wreak havoc on a surrounding planetary disk. A flare that hits a forming planet could easily strip material away and carry it outward at rapid speeds. Nelson, however, doubts whether even these speeds would be fast enough to match those found within the observed disk.

■ **SHANNON HALL**



NASA / ESA / ESO / A. BOCCALETTI (PARIS OBSERVATORY)

Warps and bright features have traveled surprisingly fast through part of the disk around the young star AU Microscopii. These images track the disk's changes over four years.

IN BRIEF

Closest Star-shredding Black Hole. The observed last hurrah of a star wrenched apart by a supermassive black hole matches astronomers' predictions. In the October 22nd *Nature*, Jon Miller (University of Michigan) and colleagues report the details of ASASSN-14li, the closest yet seen of these *tidal disruption events* (*S&T:* June 2013, p. 16). The event's light has a redshift of 0.02, so the photons traveled only about 290 million years to reach us. At this range, the astronomers can see spectroscopic signs of some sort of wind or filamentary debris moving toward us, but not fast enough to escape the black hole. It could be gas stuck along the (now disrupted) star's elliptical orbit, swinging out the farthest it can get from the hole. That would match computer simulations, which predict both that leftover gas will take a while to circularize its orbit and that flows should be filamentary — even while gas much closer to the black hole quickly forms a disk that drains material in to the event horizon.

■ **CAMILLE M. CARLISLE**

Exoplanet Leader Resigns in Sexual Harassment Scandal. A University of California, Berkeley, investigation found that exoplanet pioneer Geoffrey Marcy sexually pressured and harassed female students and researchers under his supervision for at least a decade. The report remained secret for several months, until *BuzzFeed* broke the story on October 9th. Subsequent revelations confirmed that Marcy's inappropriate conduct spanned decades and was, as one former colleague put it, "one of the biggest 'open secrets'" in professional astronomy, with women passing warnings to one another at meetings and within his department. Unfortunately, repeated attempts to report and stop Marcy's behavior led nowhere. It's unclear whether this high-profile case will spur changes in protecting young astronomers from prestigious colleagues. Full story: http://is.gd/marcycrisis.

■ **ALAN MACROBERT**

STELLAR | White Dwarf Eats Rock, Another Star Might Have Destroyed Comet

Strange dips in the light from two stars observed by the Kepler space telescope reveal what might be disintegrating bodies.

The first star is a white dwarf designated 1145+017. White dwarfs generally have hydrogen and helium atmospheres, with the heavier elements (such as carbon and silicon) sunk far below. But roughly a third have atmospheres mysteriously tainted by these heavy elements. Debris disks also encircle a few. So astronomers suspect that these white dwarfs are covered in the crumbs of munched planets.

As Andrew Vanderburg (Harvard-Smithsonian Center for Astrophysics) and colleagues report in the October 22nd *Nature*, they've now found around 1145+017 at least one potential disintegrating planetesimal — or maybe even six or more, all about the size of the asteroid Ceres or smaller. The object revealed itself by passing repeatedly between us and the white dwarf, creating a weird transit pattern in the white dwarf's light. When first observed with Kepler in 2014, the star's light dipped only a bit but stayed low for about an hour. But when observed nearly a year later with multiple ground-based telescopes, the star's brightness dropped by a whopping 40% for 5 minutes. The transits also weren't symmetric.

The object orbits the white dwarf closely in about 4½ hours and trails a comet-like tail. Spectroscopic measurements reveal heavy elements in the white dwarf's atmosphere, too, and the star has a dusty debris disk, further adding to evidence that the "pollution" comes from a torn-up world.

The signal from the star KIC 8462852 is a far more curious case. Citizen scientists with the Planet Hunters program first spotted a dip of 0.5% that lasted for an incredible 4 days. Subsequent dips proved ragged and irregular, sometimes shallow but sometimes blocking up to 20% of the star's light, with unpredictable timing.

Tabetha Boyajian (Yale) and colleagues delved deeply into the mystery in an analysis published October 17th in *Monthly Notices of the Royal Astronomical Society*, but without finding an answer. The signals aren't from the 12th-magnitude, yellow *F* star itself — no hint of giant starspots, throbbing pulsations, or other quirks. Nor are there signs of debris clouds from smashed-up asteroids or planets. A large, random assortment of cometary debris spread out along a single orbit might work, though a shattered-comet model has trouble producing some of the starlight dips' quirks. The American Association of Variable Star Observers has issued an alert requesting more observations of this star.

In the spirit of fun, the team is contemplating one more hypothesis, not mentioned in the paper: a partially completed "Dyson sphere," a hypothetical mega-structure constructed around a star by an advanced alien civilization to capture the energy the star radiates. Boyajian has now teamed up with exoplanet specialist Jason Wright (Penn State) and SETI researcher Andrew Siemion (University of California, Berkeley) to conduct a radio search for transmissions that might be leaking out from the aliens' construction site. An independent SETI search has turned up nothing yet.

■ **CAMILLE M. CARLISLE & J. KELLY BEATTY**

IN BRIEF

Small Galaxies Helped Light Universe. Hubble observations confirm that much of the ultraviolet light that broke up the early universe's hydrogen atoms came from the smallest galaxies. This breakup, called the *era of reionization*, occurred within the universe's first billion years. Astronomers think that almost all of the ultraviolet radiation responsible came from star-forming galaxies, and simulations suggest that dwarf galaxies in particular might have contributed 30% of the ultraviolet energy needed. As part of the Frontier Fields project (*S&T:* Jan. 2015, p. 20), Hakim Atek (Federal Polytechnic School of Lausanne, Switzerland) and colleagues went hunting for early, faint galaxies using the gravitational magnifying power of three massive galaxy clusters. They detected 252 galaxies from about 650 to 950 million years after the Big Bang and confirmed that such systems contributed about 20% to 60% of the needed ultraviolet photons. All told, there was enough radiation to totally reionize the universe by about 750 million years after the Big Bang, the team reports in an upcoming *Astrophysical Journal*.

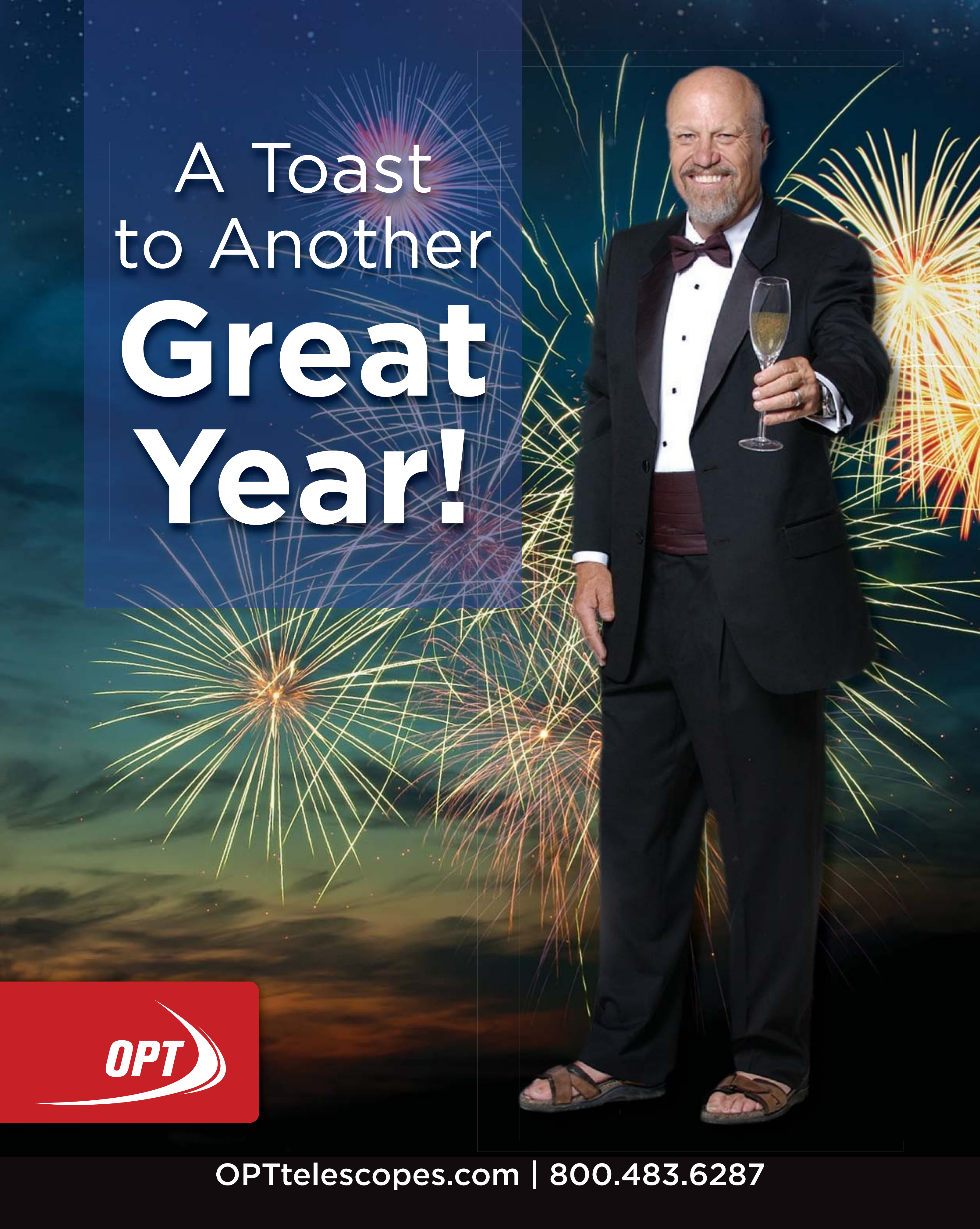
■ **CAMILLE M. CARLISLE**

Planets Hiding Around HL Tauri? A bull's-eye disk of dust and gas surrounds the young star HL Tauri, with ringlike gaps 15, 30, and 70 astronomical units from the star. Such gaps normally signal forming planets. But Leonardo Testi (European Southern Observatory, Germany) and colleagues found nothing when they used the Large Binocular Telescope in Arizona to look at the farthest-out gap (the others were blocked by the telescope's coronagraph) — even though they should have been able to detect the infrared glow from the expected super-Jupiter, they report in the October 20th *Astrophysical Journal Letters*. Yet in the October 11th *Monthly Notices of the Royal Astronomical Society*, Giovanni Dipierro (University of Milan, Italy) and colleagues found that planets with a few tenths of Jupiter's mass could also create the gaps — but only if they clear away the dust and *not* the gas. Astronomers will need to devise an observing technique to unambiguously detect that gas in order to confirm the theory.

■ **MONICA YOUNG**

Giant Scope Reopens Eye. McDonald Observatory's Hobby-Eberly Telescope (HET) has completed its upgrade, begun in 2009 (*S&T:* Jan. 2015, p. 60). The facility now sports new mechanics, software, and a complex optical system that increases its effective aperture from 9.2 to 10 meters; in effective area, HET is tied with the Southern African Large Telescope for third place in the world's largest optical telescopes. At the end of 2016, the instrument will begin a three-year observing project to document the universe's expansion rate over cosmic time. ✦

■ **CAMILLE M. CARLISLE**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Into the Heart


DARYL HAGGARD & GEOFFREY C. BOWER

WHEN ASTRONOMERS TUNED IN TO WATCH OUR GALAXY'S SUPERMASSIVE BLACK HOLE FEED, THEY FOUND MORE (AND LESS) THAN THEY EXPECTED.

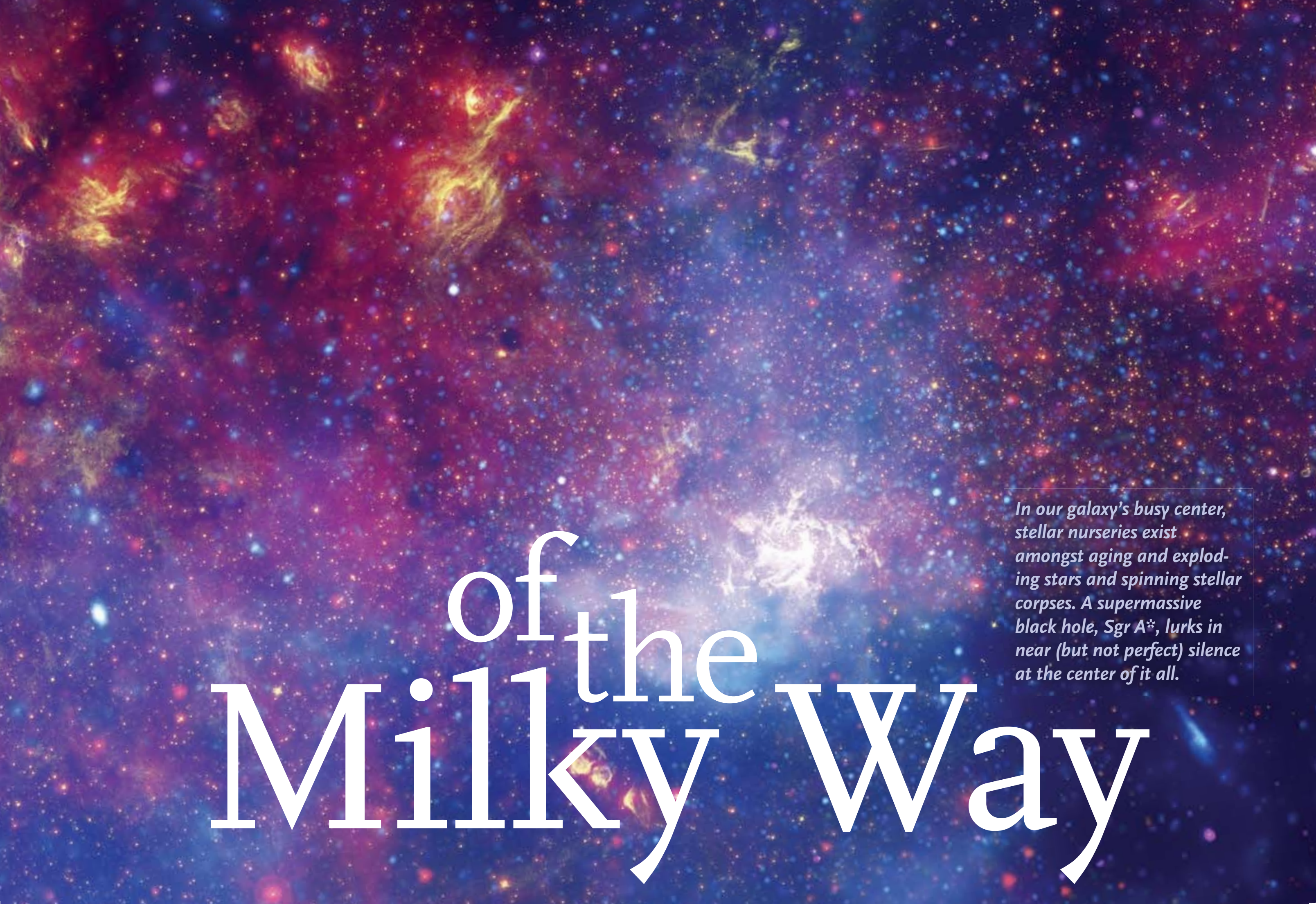
THE MILKY WAY GALAXY'S nucleus is full of surprises. Scientists began to uncover exotic phenomena there more than 40 years ago, when they discovered the supermassive black hole, Sagittarius A* (Sgr A*, pronounced "saj A-star"), lurking at its core. Over the last several years, galactic-center happenings have been particularly spectacular and unpredictable. In 2012, observers reported a small, dusty object nicknamed G2 plummeting toward the black hole. All eyes (and telescopes!) turned to watch this little daredevil's destruction.

Across the globe, astronomers followed G2's fall, monitoring it across the electromagnetic spectrum for many months, hoping to discern the object's structure and fate. And then, before our telescopic eyes, something completely unexpected appeared. In early 2013, several months before G2's closest approach to Sgr A*, astronomers caught a bright X-ray outburst. But it didn't come from the black hole. The combined X-ray powers of the Swift, NUSTAR, and Chandra observatories quickly revealed that this newcomer was a *magnetar*, a young, highly magnetic neutron star — the first of its kind to be seen in the galactic center. Rapid radio follow-up conclusively placed this object at the distance of the galactic center, very likely in orbit around the black hole (though at a larger distance than G2).

After all this action, Sgr A* would not be outdone. Later, in September 2013 and again in October 2014, Sgr A* shot off two of the brightest X-ray flares we've ever observed. Rich data from the G2- and magnetar-monitoring campaigns offered an unprecedented multiwavelength view of these bright flares. These observations may hold the keys to understanding the environment around our nearest supermassive black hole.

The G2 Encounter

In 2012, a team of scientists led by Stefan Gillessen (Max Planck Institute for Extraterrestrial Physics, Germany) reported the discovery of G2, a faint infrared blob on a



of the Milky Way

In our galaxy's busy center, stellar nurseries exist amongst aging and exploding stars and spinning stellar corpses. A supermassive black hole, Sgr A, lurks in near (but not perfect) silence at the center of it all.*

NASA / JPL-CALTECH / ESA / CXC / STSCI

nearly suicidal slingshot orbit around Sgr A* (*S&T:* June 2013, p. 23). Already, astronomers could see that its path would take it within a couple hundred astronomical units (a.u., the distance between Earth and the Sun) of the black hole and deep into a hot, gas-filled environment.

Controversy ensued: was G2 a gas cloud, a gas-shrouded exoplanet, a star, or something altogether new?

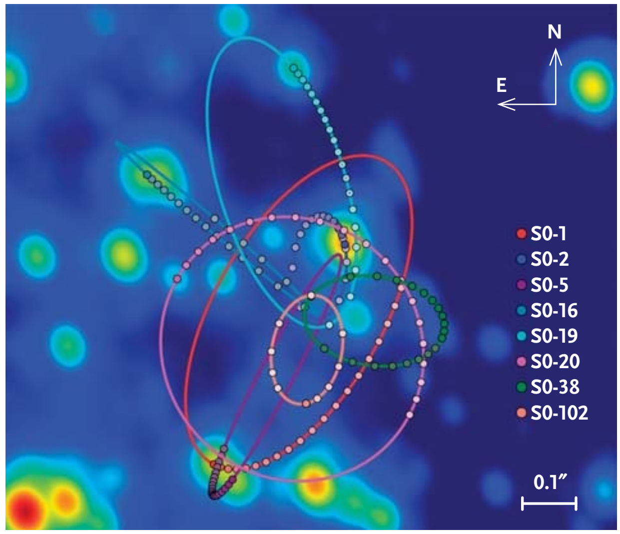
Normally, Sgr A* is a notoriously quiet black hole, accreting only about a thousandth of an Earth mass every year. Early models for G2 estimated about 3 Earths' worth of mass in gas, assuming a simple spherical geometry. If a substantial fraction of this gas fell onto the black hole over the course of a few years, Sgr A* would morph into something akin to an active galactic nucleus (AGN), similar to those we observe in galaxies in the far reaches of the universe. To witness this transition would be spectacular.

But G2 might not be wholly gas. Other interpretations yield equally compelling possibilities. G2 could be a gas-shrouded exoplanet torn from its parent star during a close encounter in one of Sgr A*'s stellar disks, tossed into a plunging, *Interstellar*-style orbit around the black hole.

What is Sgr A*?

At a distance of 26,000 light-years, Sgr A* is our nearest supermassive black hole. Thanks to observations that monitor stars' orbits around this unseen dark object, we know its mass to excellent accuracy: between 3.8 and 4.8 million times the mass of the Sun.

Sgr A* feeds on winds blown out from massive stars in its vicinity. But for reasons we still don't understand, Sgr A* is an inefficient gas-guzzler. It swallows only a small fraction of an Earth mass per year (somewhere between 0.06 and 6 times the Moon's mass per year, as estimated from radio polarization measurements), blowing the rest back out into the galaxy. Its low-calorie diet leads to the surprising conclusion that the largest black hole in our galaxy is not a roaring lion but a cosmic pussycat, emitting about one-billionth of its maximum theoretical radiation.



UCLA GALACTIC CENTER GROUP / W.M. KECK OBSERVATORY LASER TEAM

CENTRAL STARS For about two decades, astronomers have used adaptive optics to monitor stars' orbital motions around the 4.3 million-solar-mass black hole sitting at the center of our galaxy. Dots mark stars' average annual positions.

Or perhaps it's a much more massive object: a star. If half the Sun's mass were buried inside G2's dusty, cool envelope, it could bind a puffy atmosphere and prevent it from being stripped as G2 passed near Sgr A*. But why the puffy shroud to begin with? One team, led by Andrea Ghez (University of California, Los Angeles), suggested that G2 could be the product of a stellar merger. Perhaps two low-mass stars slammed into each other, robbed the stars of their angular momentum, and sent the merger product plunging toward Sgr A*. This collision would disrupt the outer layers of the two progenitor stars and, until they had a chance to settle, leave a merged star with an extended, cold, dusty veil.

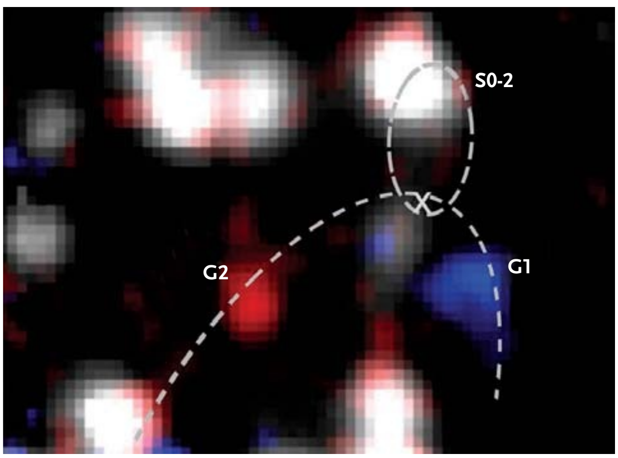
From the infrared images taken in 2012, as well as archival images of G2 dating back to 2004, observers soon concluded that the object's strongest interaction with Sgr A* would occur in the spring of 2014. Astronomers lined up to watch the encounter.

But despite continued infrared detections, radio, submillimeter, and X-ray observatories have come up dry so far. G2 didn't create the shock fronts we expected as it blasted through the hot gas around Sgr A*, nor has it yet bumped up Sgr A*'s accretion rate or created a jet.

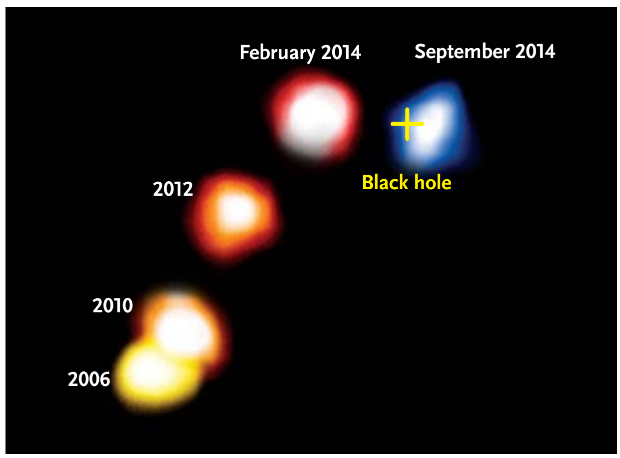
The lack of radio waves from a shock front means G2 is smaller than originally thought. Many think the size limits inferred from radio observations strengthen the stellar interpretation. The object could still be fairly big within those limits, similar in size to some of the largest known stars, so-called hypergiants, whose diameters can reach up to roughly 20 a.u.

But the cloud idea isn't ruled out yet. It's just that if the object were a cloud, some force would need to act on it to limit its size. A strong magnetic field could deform the cloud, stellar winds might confine it, or we might be seeing the gaseous veil surrounding a merged star. The case remains wide open.

At the moment, observers are watching G2 as it re-emerges from behind Sgr A*. Ghez's team, using infrared images from the Keck telescopes, has seen the object reappear intact, which they say supports the star scenario. However, spectroscopic data collected from Gillessen's team suggest that the gas tail was significantly disrupted during the close encounter, evidence of tidal streams shorn from a cloud. Hope remains that we could still see an increase in accretion onto Sgr A* on long time scales, perhaps spread over several years.



O. PFUHL ET AL. / ASTROPHYSICAL JOURNAL 2015



ESO / A. ECKART

WATCHING G2 *Left:* An archival image from 2006 reveals G2 (red), the dusty body discovered traversing the galaxy's center in 2011. (A similar object named G1 is shown in blue.) Even with adaptive optics, the Very Large Telescope (VLT) in Chile sees stars as blobs of near-infrared light (white/gray). Dashed lines show the orbits of G2 and a close-in star named S0-2, which zips around Sgr A* every 16 years. *Right:* In this composite VLT image, colors indicate G2's velocity: the object receded from us as it approached the black hole (yellow, orange, and red), now it's rounding the bend and coming back (blue). Both images are about 0.1 light-year across.

Can a Magnetar Probe General Relativity?

The discovery of a magnetar in the galactic center has opened up an opportunity for studying stellar evolution in the galaxy's frenetic downtown, understanding black holes, and perhaps even testing Einstein's theory of general relativity. In fact, astronomers have long sought to discover a pulsar in orbit around Sgr A*, which could provide an unprecedented measurement of the black hole's mass and spin, as well as test for deviations from our current theory of gravity.

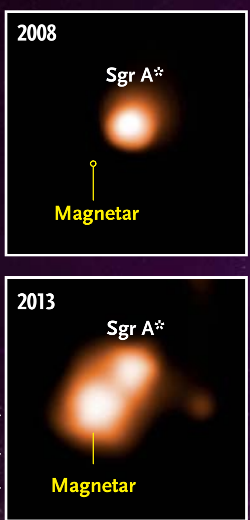
The power to make these exquisite measurements comes from the stability of these massive and energetically spinning objects. Pulsars are arguably the best-known clocks in the universe: a pulsar's period and its change over time are often measured to 10 significant digits, sufficient to track changes in the arrival time of individual pulses with accuracies better than 1 microsecond. So a pulsar orbiting a black hole is a relativist's dream — its pulses would trace the black hole's complex spacetime structure, and subtle but predictable changes in the pulses' arrival time would reveal the black hole's mass and spin.

The magnetar in the galactic center is unfortunately too far away and too jittery to perform these kinds of measurements. At its distance, it will take at least 700 years to orbit Sgr A*. And due to instabilities arising from its strong magnetic field, a magnetar makes a poor clock — more like an old spring-wound wristwatch than a precision atomic timepiece.

Nevertheless, we plan to continue watching the magnetar over the coming years. With luck, it will remain bright enough to reveal whether its motion describes an orbit around Sgr A*.

Ordinary pulsars may not be found in orbit around Sgr A* (see page 21). Fortunately, this is not the end of our quest to use pulsars to probe fundamental physics around Sgr A*. Millisecond pulsars, which spin so fast they're close to breaking apart, are old neutron stars that have "spun up" by interacting with a companion star.

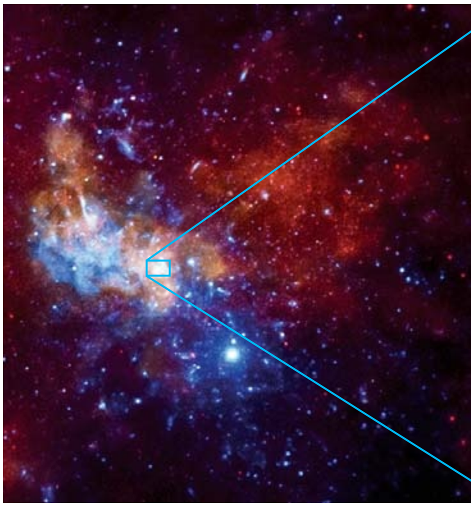
Current radio telescopes would miss any millisecond pulsars in the galactic center due to radio scattering. But a new generation of radio telescopes, including MeerKAT in South Africa and the Square Kilometer Array in South Africa and Australia, will have the sensitivity to detect these fast-spinning pulsars in Sgr A*'s vicinity and, if successful, help us test general relativity.



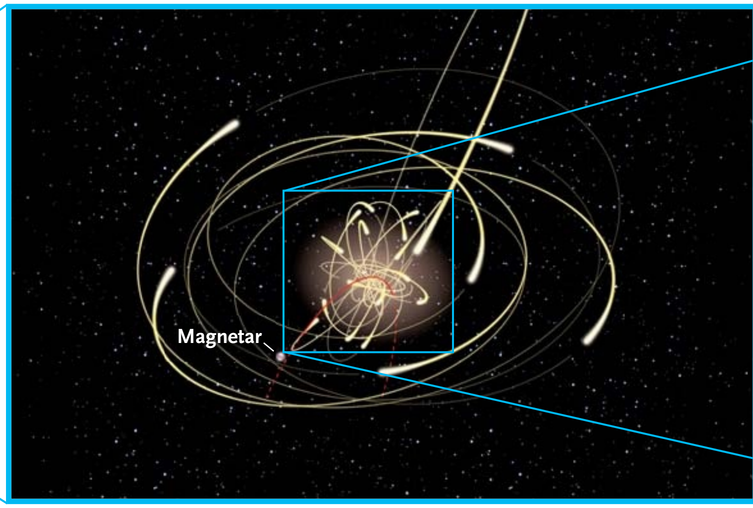
NASA / CXC / INAF / F. COTI ZELATI ET AL., MNRAS, 449, 2685, 2015

MAGNETAR A neutron star with extraordinarily powerful magnetic fields, SGR 1745-2900 lies as close as 0.3 light-year to Sgr A*. Chandra captured the magnetar's X-ray outburst in 2013 (*above*). An artist's conception (*right*) shows how an outburst might happen: a rupture in the neutron star's solid crust, accompanied by a rearrangement of the magnetic field, could release tremendous amounts of energy.

ART: NASA GSFC / S. WIESSINGER



INTO THE HEART This image from the Chandra space telescope captures X-rays from the busy galactic center in a view 50 light-years across. Red, green, and blue indicate low, medium, and high-energy X-rays, respectively.



STELLAR DISK + MAGNETAR Drawing from near-infrared data gathered by the Keck telescopes, this frame shows stellar orbits in the galactic center. Stars farther out tend to orbit clockwise in a disk, while the closer-in cluster contains stars on more chaotic orbits. The X-ray-emitting magnetar is a projected 0.3 light-year from the center. G2's current orbit follows the red track.

Due to the different nature of their data, the two teams might be looking at different sides of the same coin: even if the black hole yanked some gas off G2, there may yet be a star lurking within the gaseous envelope.

What of Sgr A* itself? Did the black hole notice all this action in its domain? In the midst of the G2 observing frenzy, Sgr A* offered up some surprises of its own.

Inflows, Outflows, and Flares

X-ray observations confirm that Sgr A* feeds off stellar winds. But most of that mass never makes it all the way to the gaping maw. Daniel Wang (University of Massachusetts, Amherst) led a team that studied X-ray emission around Sgr A*. The researchers reported that less than 1% of the material flowing toward the black hole successfully makes the journey inside — the other 99% blows back out into the surrounding environment.

In the process, our delicately snacking black hole belches X-ray flares: mild bursts occur roughly once a day, and bright spikes appear every 10 days or so. Thanks to G2 monitoring in 2013 and 2014, one of us (Haggard) led a team that discovered two of the most impressive X-ray flares ever seen. Over the course of a couple of hours, each released several hundred times the X-rays normally seen from this region.

Simultaneous multiwavelength observations (when they exist) generally show infrared and radio-wave spikes accompanying X-ray flares. But the inverse isn't true — a typical day sees four times as many infrared flares as X-ray flares. So it's not clear how emissions at different wavelengths relate to each other.

Because of these uncertainties, we still don't understand the flares' origin. A reordering of magnetic fields could create flares in a way similar to those seen from our Sun. Or the black hole's extreme gravity might shred the occasional asteroid that comes in a little too close.

The X-rays brighten and fade within a couple of hours. If they arise in the accretion disk, then their source must lie just outside the black hole's event horizon, the point of no return for material and light entering the black hole. Since that puts the escaping X-rays within an a.u. from the black hole, in the thick of whatever gaseous flow feeds Sgr A*, the flares are unlikely to be connected to G2's closest approach at roughly 150 a.u.

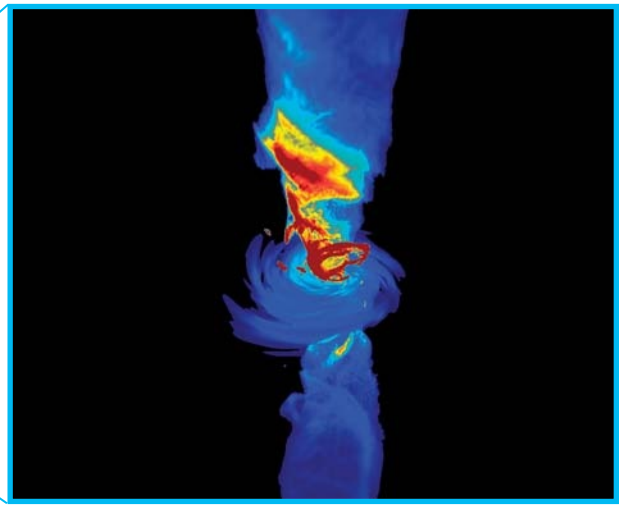
Nevertheless, a recent study of 150 Chandra and XMM-Newton observations spanning 15 years, led by Gabriele Ponti (Max Planck Institute for Extraterrestrial Physics, Germany), shows that bright flares became more frequent about six months after G2 made its closest approach to the black hole. Coincidence? Maybe — other black holes show similar flare clustering.

Continued multiwavelength monitoring of Sgr A* is our best hope of pinpointing the source of the flares.

Discovery of an Exotic Pulsar

The same monitoring that followed G2's approach and captured two brilliant flares led to another surprise on April 24, 2013. As G2 approached Sgr A*, daily monitoring of the black hole with the Swift satellite jolted scientists with the announcement of a bright X-ray outburst. Observers around the world rushed to their telescopes to capture a more complete picture of the anticipated disruption of the G2 cloud.

But the picture quickly became much more complex. The X-ray outburst lasted for hours, then days — much longer than the typical 1- or 2-hour duration of an X-ray



S&T: G. DINDERMAN, SOURCES: X-RAY: NASA / CXC / UMASS / D. WANG ET AL.; STARS: NCSA / UCLA / KECK; BLACK HOLE: M. MOSCIBRODZKA ET AL., A&A, 570, A7, 2014, REPRODUCED WITH PERMISSION © ESO

CLOSING IN ON G2 This frame, a few tenths of a light-year on a side, zooms in on the central cluster of stars, suffused by the gentle glow of hot, X-ray-emitting gas that's on its way toward the black hole. G2's observed orbit followed the red solid line; the dashed line extrapolates a bit beyond observations.

SUPERMASSIVE BLACK HOLE This frame from a recent simulation shows 1-millimeter radio emission from around Sgr A* as it accretes from a small gas flow and spews a jet. The view spans 6 astronomical units, a distance slightly larger than Jupiter's orbit around the Sun.

flare from Sgr A*. Radio telescopes in the United States and Japan, on the other hand, didn't see the expected jump in radio emission, which typically follows Sgr A*'s bright X-ray flares. This was clearly not an ordinary enhancement of activity around the black hole.

Two days after the initial outburst, NASA's NUSTAR X-ray telescope discovered that the emission was not steady but in fact pulsed every 3.76 seconds. Radio telescopes in Australia, the United States, and Germany confirmed radio pulsations with the same period shortly after that. Within five days of the initial outburst, the sharp eyes of the Chandra X-ray Observatory demonstrated that the pulsed emission arose not from Sgr A* but from a compact object only 3 arcseconds, or 0.3 light-year, away from the black hole.

This rapid response of space- and ground-based telescopes across the electromagnetic spectrum provided unambiguous evidence that this outburst came from an exotic compact object known as a *magnetar*.

When massive stars with less than 25 solar masses burn through all their nuclear fuel, they explode in a supernova, leaving behind a crushed object composed almost entirely of neutrons. This remnant packs one to two times the mass of the Sun into a sphere comparable in size to a small asteroid, only 10 kilometers (6 miles) in diameter. Moreover, the neutron star is born spinning as fast as 600 revolutions per second. If the jet of radiation spewed out of its magnetic poles sweeps across our line of sight, we call it a pulsar due to the jet's lighthouse effect.

Pulsars are exotic enough in their own right, but magnetars are stranger still. Possessing magnetic fields 100 times stronger than that of a typical pulsar, they're rare: astronomers have discovered thousands of pulsars in the galaxy, but only 30 or so magnetars. Where their strong fields come from isn't known, but the magnetic energy appears to drive magnetars' characteristic X-ray flashes. Dramatic rearrangement of the fields at the star's surface leads to explosive heating, creating a thermal hot spot that cools slowly over time.

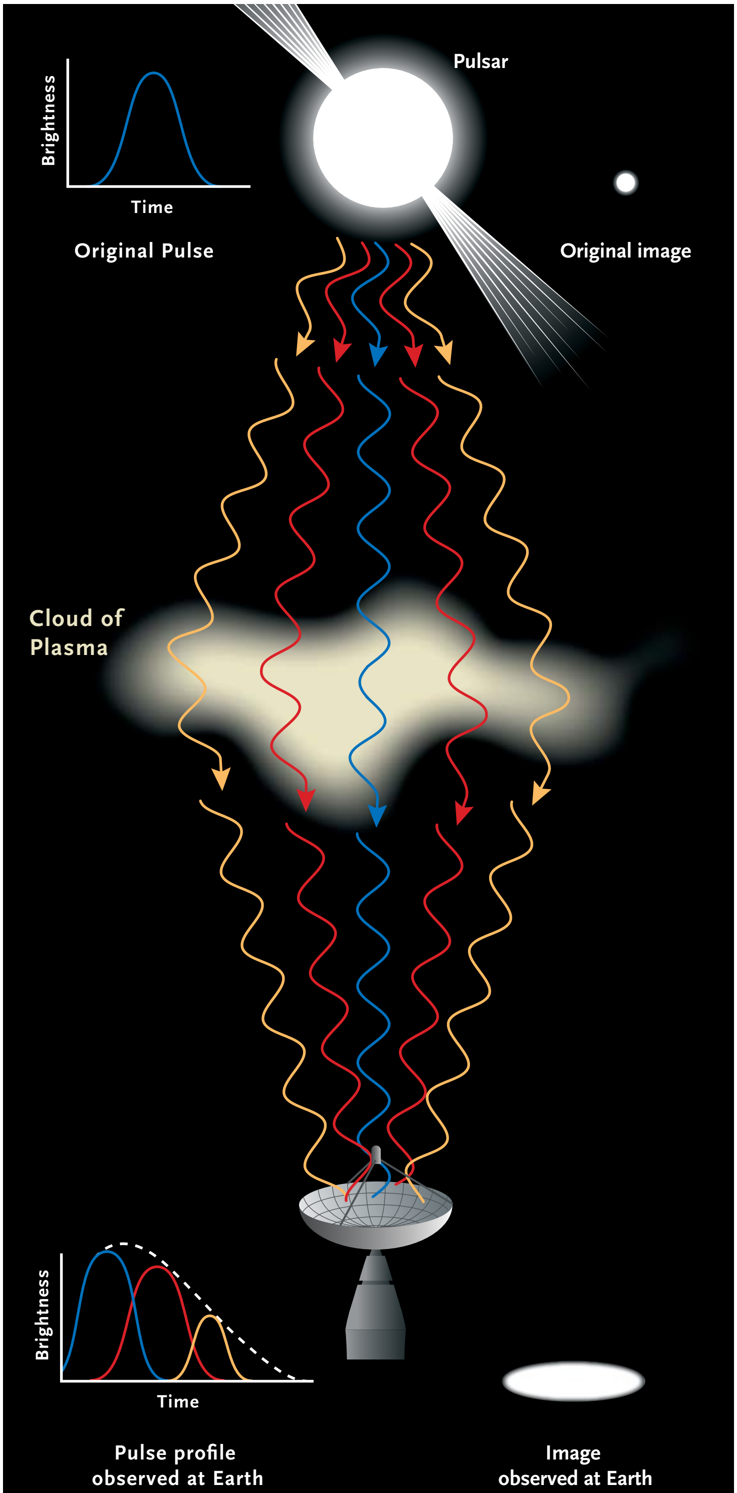
The galactic center magnetar is still cooling off two years after its initial outburst, its X-rays steadily declining in intensity. Mysteriously, its radio emission, which radiates from charged particles racing around the pulsar's strong magnetic field, has remained steady.

The Missing Pulsar Problem

The galactic center is full of young, massive stars of exactly the type that one would expect to go through a

Sgr A* and Friends

Galactic Nucleus	Black Hole Mass (in solar masses)	Accretion Rate (solar masses per year)
Sgr A* (quiet nucleus)	3.8 – 4.8 million	10^{-7} – 10^{-9}
M87 (active but low-luminosity nucleus)	3 – 6 billion	< 0.001
3C 273 (quasar, very active nucleus)	0.9 – 2.4 billion	4 – 10



PLASMA-SMEARED PULSE When a spinning neutron star emits an earthward pulse, some radio waves travel directly to us. But most of its photons encounter free electrons floating in clouds of plasma, which force radio waves on detours. By the time scattered photons converge on an earthbound detector, the pulsar's point-like image has smeared out. Moreover, the longer paths of scattered photons delay their arrival times, smudging the pulse profile in time as well.

S&T: GREGG DINDERMAN; SOURCE: G. BOWER

supernova phase and result in a neutron star or black hole. Some of these stars have been used to study the gravitational field of Sgr A* as they orbit the black hole. Theorists have suggested that there might be thousands of pulsars close to Sgr A*, leading to numerous searches at radio wavelengths.

But none of these searches has uncovered a pulsar any closer to the center than about 80 light-years, a distance too far away for them to be gravitationally bound to Sgr A*. This absence of radio pulsars has proved puzzling and made the magnetar's discovery all the more surprising.

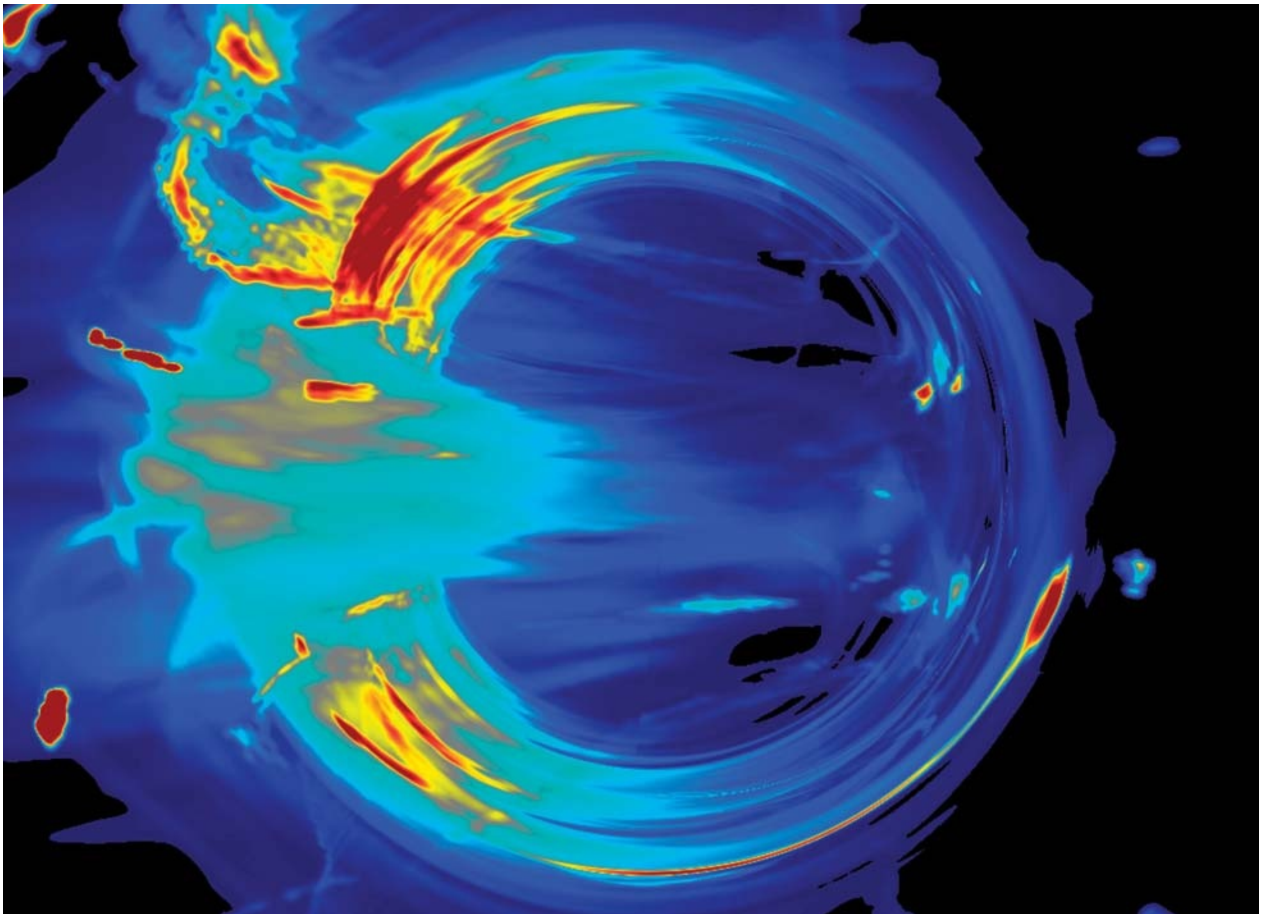
For the past two decades, the leading explanation has been not the absence of pulsars but the cloaking of their signal. Dust obscures the galactic center at visible wavelengths even as radio waves pass right through. But plasma, ionized gas between Earth and the galactic center, scatters radio waves and blurs images of radio sources such as Sgr A* (see box at left). The blurring has the effect of smearing individual pulses of radiation. If that smearing in time is longer than the pulse period of a particular pulsar, then the pulsar will cease to appear as a pulsed source and we won't detect it in our searches.

The smearing effect is strongest at long radio wavelengths and diminishes rapidly at shorter wavelengths. But perversely, typical pulsars become fainter at shorter wavelengths, making them much harder to detect.

One of us (Bower) used the Very Long Baseline Array, a transcontinental network of radio telescopes, to measure the effects of scattering on the radio waves coming from Sgr A* and the magnetar. We have long known that Sgr A* is one of the most heavily scattered objects in the galaxy, and new observations show that the magnetar suffers exactly the same fate, leading to a blurred image of the magnetar. This isn't surprising because the two objects are so close together.

But the second measurement, measuring how much the magnetar's individual pulses smeared in time, was quite surprising. Current understanding suggested that pulses might smear by as much as 100 seconds at a wavelength of 30 cm, much longer than the typical pulsar period. But our observations showed that the magnetar's pulses are smudged by only 1 second at 30 cm, and even less at shorter wavelengths. If the "missing" pulsars are in the galactic center and behind the same amount of material, previous surveys should have easily seen through the fog of interstellar plasma to find them.

So why have past searches failed? And why was the first pulsar discovered in the galactic center a rare magnetar? Perhaps these facts tell us that the extreme conditions in the galactic center, such as strong magnetic fields and dense gas, drive the formation of stars and neutron stars that are more highly magnetized than their ordinary cousins throughout the Milky Way. Some have suggested far more exotic ideas: neutron stars might accrete dark matter, which should be prevalent



in the galactic center, then implode into black holes. Or more prosaically, perhaps the scattering effects of the interstellar medium are more complex and time-variable than our current models can account for.

HUNGRY BLACK HOLE **This simulated radio image, about 1 a.u. across, gives an edge-on view of gas flowing around and into the black hole. The black hole's gravity bends radiation from this flow into an apparent ring-like structure. Simulations like this guide expectations for the Event Horizon Telescope.**

What's Up Next?

The galactic center is often described as the kitchen sink of the galaxy: a medley of anything and everything in the cosmos. And it's clear that the banquet isn't over yet. A new suite of observatories, combined with recent happenings in the galactic center, promise new discoveries and deeper understanding.

Among the most promising new tools available to astronomers is the project known as the Event Horizon Telescope (EHT, *S&T:* Feb. 2012, p. 20). This network will bring together an array of powerful radio telescopes in California, Hawai'i, Arizona, Mexico, Chile, Spain, France, Greenland, and Antarctica to image Sgr A* at millimeter wavelengths with an angular resolution comparable to the black hole's event horizon.

EHT images will reveal the inward accretion flow as well as the outflow (if there is one) on an unprecedented scale, potentially showing material that circles the black hole on the innermost stable orbit with a period of 20 minutes or less. When combined with X-ray studies of flares, we will be able to trace the flow of gas from the outer edge of the accretion flow all the way to the edge of the event horizon.

Even more importantly, the EHT will explore the structure of spacetime on those same scales, imaging the strong gravitational lensing effects that lead to a "shadow" and ring of emission around the black hole. Short of the discovery of a pulsar in close orbit around Sgr A*, these observations will provide the most compelling test of general relativity and our best view ever of the supermassive black hole at the heart of the Milky Way. ✦

__Daryl Haggard__ is an assistant professor at McGill University, where she studies the interplay between supermassive black holes and their host galaxies. __Geoffrey C. Bower__ is an astronomer at the Academia Sinica Institute of Astronomy and Astrophysics, where he investigates transient radio sources, black holes, and instruments and techniques for radio astronomy.

The Astrolabe:

Astronomy's First Hot App

Loaded with features, an ancient analog computer replicates the sky's workings.

Bruce Watson

THE TIME MUSEUM

ASTRONOMICAL JEWEL This German astrolabe, made in Nuremberg in 1532, has an ornate brass rete that supports 27 points. The points form a star map; each is labeled with the name of a star. Near the bottom, for instance, are *Procion, Oculus Tauri* (Eye of Taurus), and *Pes Sin(ister) Orionis* (left foot of Orion). An astrolabe's sky is mirror-imaged right for left. The star-map grillwork, including the ecliptic circle, turns above a plate marked with, among other things, a fine grid of altitudes and azimuths above the user's horizon.

On a cold November evening, I consult my astronomy app to see if the night sky will be worth the chill. Star by star, this little wonder spreads the constellations before me. At 9:00 p.m., I see, Altair will be 18° high in the west, on its way to becoming the first Summer Triangle star to set. The Big Dipper will skirt the northern horizon, while Betelgeuse will be 10° up in the east. Sirius won't rise until 10:12, but Cassiopeia is already high overhead. Hanging my app on my belt, I grab a coat.

My device has neither screen nor software. But since antiquity, this ingenious tool has accurately modeled the movements of the Sun and stars. Before there were good clocks, its main use was to tell the time. Now that we always know the time, it can work backward to tell where the Sun and stars are, or will be. It's the forebear of the ship's sextant and the modern skygazer's handy planisphere. Users once relied on it to tell the astrological house of the Sun, the 28 lunar stations, when to perform the Islamic prayers, and the "unequal hours" that divided the changing days and nights into perfect twelfths, different for each day (standard practice before clocks, then continued for astrology and magic). It also solved everyday trigonometry problems, measured heights and aided surveyors, and performed other functions depending on the design. It was feature-packed. "All the conclusions that can be found, or might possibly be found in so noble an instrument as an Astrolabe, be unknown

perfectly to any mortal man in this region," marveled Geoffrey Chaucer in 1391. Kind of like my phone.

Astrolabes are now found in museums rather than observatories or travelers' packs. Reposing in glass cases, their golden wheels within wheels conjure up images of bearded men in tunics charting horoscopes. Before the telescope, the astrolabe was the icon of astronomy: the proud possession of kings and princes, doctors, geographers, would-be wizards with an astrological bent, and of course astronomers themselves.

If I wanted to understand how skywatchers in ancient Greece, Arabia, Persia, or Renaissance Europe sensed the celestial clockwork, I would have to learn the astrolabe. But where could I get one?

It turns out you can buy a modern brass astrolabe on eBay or Amazon for about $200. A plastic model goes for $75. A craftsman in Germany will forge a stunning brass replica for a mere $1,100. And the true antiques? An immaculate astrolabe crafted in 1505–6 for the Ottoman Sultan Bayezid II recently sold at Sotheby's for $1.56 million. It's no wonder that fakes abound (*S&T:* May 1982, p. 465).

I chose a $29 plastic-laminated model, custom printed on card stock for my home latitude and longitude, from James E. Morrison of Rehoboth Beach, Delaware, who does business as Janus. It's shown at right.

While waiting for it to arrive in the mail, I learned how this ingenious device put Sun, night, and time into the palm of a hand.

Ancient Knowledge

No one is sure who invented the astrolabe. A likely candidate is the Greek astronomer Hipparchus, who worked on the Isle of Rhodes around 150 BC, but it evolved in complexity and usefulness over many centuries. The word *astrolabe* is from the Greek for "star taker." Most varieties have the same basics: a sighting device, a movable star map in the form of a metal network including a finely scaled zodiac ring; a flat, stereographic projection of the sky's altazimuth coordinate grid from horizon to zenith; and a finely divided circular scale of hours around the outside.

Astrolabes reached their maturity during the Golden Age of Islam, 700–1200 AD. After steering Arab sailors to Spain, they entranced travelers who brought them to northern Europe around 1000 AD. Marco Polo saw many in China during his travels in the late 1200s. They democratized astronomy. Well-established royal astronomers used big, wooden or bronze armillary spheres to track the Sun, planets, and stars more precisely, but the astrolabe let any well-off amateur do it with a brass disc hung on his belt.

Ancient astrolabes relied on knowledge of the zodiac, but the version I bought from Janus (he sells two) was his modernized one that leaves astrology behind. Instead of Roman numerals, the 24 hours around its rim are ordinary numbers. And instead of degrees within houses of the zodiac, the ecliptic circle is marked with calendar months and days. But otherwise, my laminated model matches the classics.

S&T: SEAN WALKER (2)

CELESTIAL SIGHT Like a telescope today, an astrolabe in ancient and medieval times marked you as an astronomer. It too required special knowledge and a good eye. This is the modern astrolabe described in the text.

D. GORDON E. ROBERTSON / WIKIMEDIA COMMONS

TAKING THE SUN The 17th-century explorer Samuel de Champlain, founder of New France and Quebec City, uses a simplified mariner's astrolabe. This statue, sculpted in 1915, stands at Nepean Point in Ottawa, Canada. The explorer looks slightly clueless here; perhaps no one told the sculptor that the alidade should be aligned with the sighter's eye.

The base, known as the *mater* or mother, encloses a disk, the *tympan* or *climate*, with fine, off-center grid lines. The circles of this grid, known by their Arabic term *almucantars,* are altitude lines above your local horizon. The arcs cutting across them from horizon to the zenith mark azimuths, or compass directions (nowadays measured in degrees counting clockwise from north). Traditionally, a fine astrolabe came with a set of interchangeable tympans for use at different latitudes. On mine, the mater and tympan are a single layer printed for my own latitude exactly.

The heart of an astrolabe is its star map or *rete,* from the Latin for net. The classical rete was a rotating metal filigree, including the circle of the ecliptic, with labeled metal points representing the positions of bright stars: Rigel, Sirius, Capella, Vega. . . . My rete is clear plastic with stars printed on it.

Turn the rete and stars rise and set, crossing the horizon-edge of the tympan's nested circles. The ecliptic circle among the stars travels with them. The ecliptic is the Sun's annual path around the sky, so when your date marked on this circle rises and sets, so does the Sun.

Finally, an astrolabe usually has two rotating rulers, one on each side. The ruler on the back is the *alidade,* a sighting device. It sometimes had little uprights with holes or sight notches for precision. The ruler on the front is just called the *rule,* used for matching a reading on one part of the face to an index on another part — in particular the outer circle of hours.

Once I learned its parts and history, I was eager to take my astrolabe outside. But the arcs and wheels hardly explained themselves. Luckily, Janus's instruction book was easier than I expected.

SEBASO / WIKIMEDIA COMMONS

WORKS IN REVERSE! The famous astronomical clock on Prague's Old Town Hall, installed in 1410, is an astrolabe driven by clockwork to show the position of the Sun and Moon. It also tells the time in three systems: modern hours (roman numerals), hours from sunset (outer gold numbers), and the ancient unequal hours (black numbers). Here, the Sun is approaching the horizon of sunset (*occasus*) and the Sun's subterranean domain in twilight (*crepusculum*). In the upper corners, Death rings his bell every hour and Pride, Greed, and Lust shake their heads in reply, "No, not yet."

Under the Stars

To check the night's parade of the heavens, I first wheeled the rete so that my date on the edge of the ecliptic circle touched the west side of the horizon arc: sunset! Using the rule to point from there to the rim told me the sunset time.

Or rather, it told me sunset's *local apparent solar time* (sundial time). That's what everyone used in the centuries before accurate clocks and fast communication. Since I want modern clock time instead (which runs with uniform speed and applies across an entire time zone), adjustments are needed. Custom-printed on the back is my permanent correction in minutes for the longitude of my home. Thanks, Janus! Also on the back is a graphical scale for finding the Equation of Time correction for any date, using the alidade as a rule. The Equation of Time adjusts for the fact that Sun time runs as much as 16 minutes fast or slow around the year, due to the tilt of Earth's axis and the ellipticity of its orbit. Thanks again.

And when daylight-saving time is in effect, I need to add an hour. For astronomers who want to track the Sun and stars, rather than catch a train or arrive on time for a meeting, modern time is complicated!

The astrolabe, I learned, also reads past and future. Aligning different dates on the ecliptic to the horizon, I could read the time of sunrise or sunset for any day of the year. Or I could pick a star — Arcturus, say — and spinning to other dates and times, see where it would stand above or below the horizon. By the time I stepped out on that chilly November night I was a 21st-century Hipparchus, ready to take the stars.

To check the time, I spotted Aldebaran and held the astrolabe aloft by its two-ring chain, letting gravity align the vertical. On the back side, I carefully nudged the alidade to point exactly at Aldebaran. I then read, where the alidade crossed the protractor scale on the outermost rim, that Aldebaran was 41° above the horizon. I turned over my astrolabe, found Aldebaran on the clear plastic rete, and positioned the star at 41° in the east on the grid of almucantar circles.

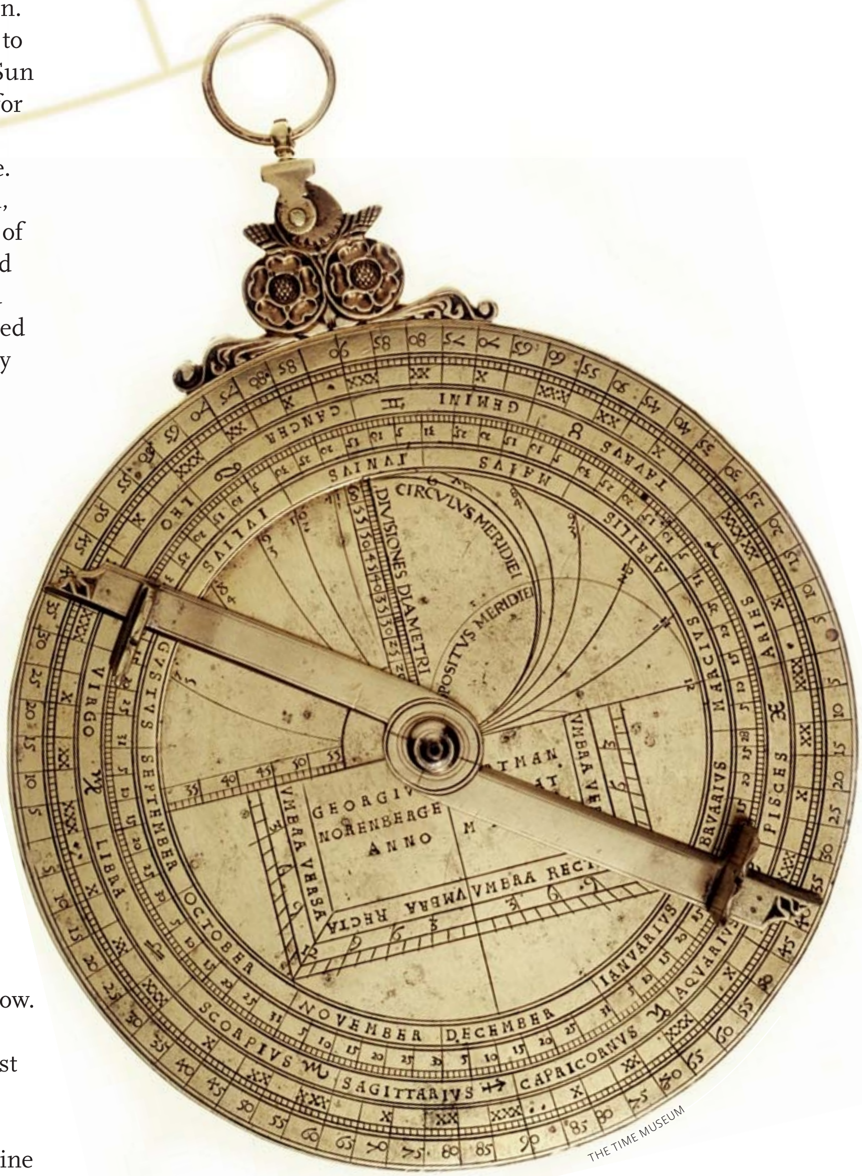
Holding the rete in place, I found my date (November 15th) on its ecliptic circle and aligned the rule to that date. Where the edge of the rule met the outer rim, I read the time: a hair short of 9:55. Call it 9:54. Apply my longitude correction, read the Equation of Time correction for November 15th from the scale on the back, and I had 9:31 p.m. Eastern Standard Time.

I checked my phone. My astrolabe was a minute slow. Not bad for a paper-and-plastic replica of a timepiece older than Ptolemy. Maybe I was a bit lucky on my first try, but to check and improve my accuracy I can take several star-sightings and average them.

It seems like a lot of work to get the time, but imagine if it was the only way you could. Or if you wanted to know when the Sun would rise on the date of an impending battle, or how the stars were arrayed at the time of your patron's birth. Early sailors used the astrolabe for navigation, especially after a streamlined mariner's version made it easy to "shoot the Sun" and the pole star. The sextant (recently reintroduced in the U.S. Navy as a backup in case of cyberattack) is merely a further refinement.

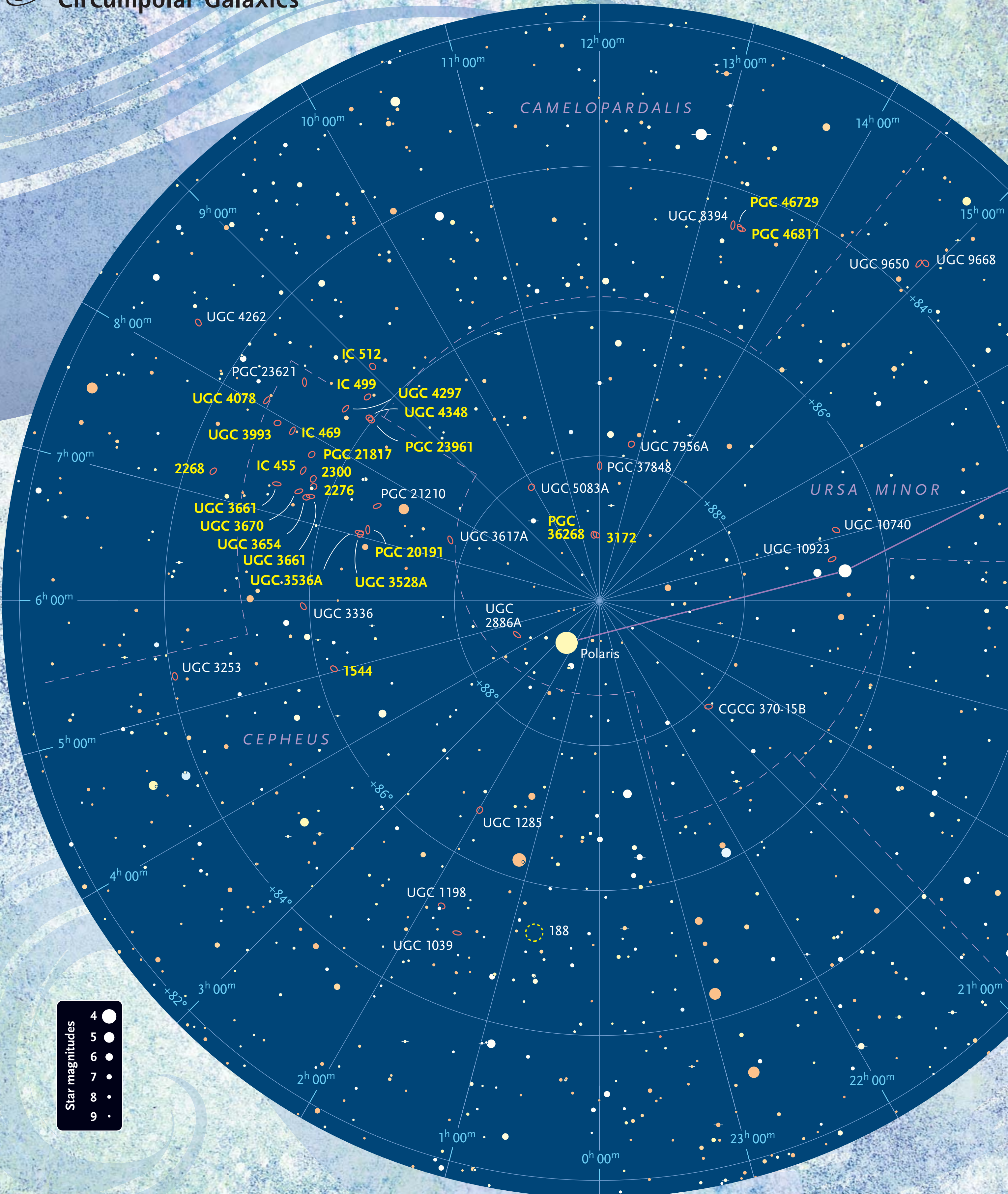
Ancient astrolabes performed still more wonders. A shadow square on the back enabled calculations of distance or height. The degree scale around the rim served as a surveyor's protractor. Arab astrolabes found the direction of Mecca. But my modern version seemed wondrous enough. ✦

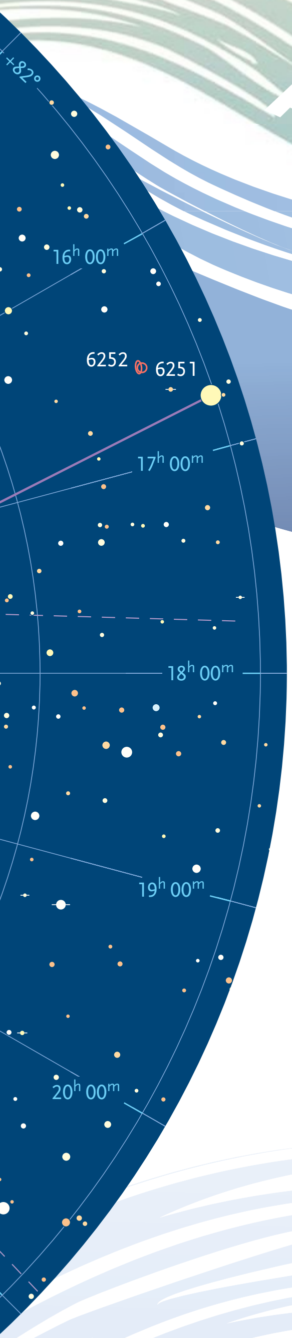
Bruce Watson *is a freelance writer in Massachusetts and the author of* Light: A Radiant History from Creation to the Quantum Age *(Bloomsbury, February 2016).*



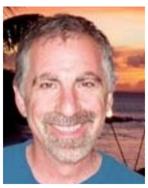
THE TIME MUSEUM

Circumpolar Galaxies





A Trip to the Northern Frontier



Steve Gottlieb

The celestial arctic awaits your arrival.

What's the best-known star in the sky? Although it barely cracks the list of the 50 brightest stars, Polaris is certainly a top candidate. The "North Star" has been an essential navigational aid for centuries and it's the first star many of us learn to identify as a youngster. Since Polaris marks the rotational pivot for the north celestial hemisphere, from any given location you'll find it in the same position all night, every night.

Although Polaris is familiar to stargazers, that's not the case with neighboring deep-sky objects. Maybe you've seen NGC 188, an ancient open cluster just 4° away. But as far as galaxies, the polar cap is unexplored territory for most amateurs — there are few signposts to aid in star-hopping in this barren region and navigating with equatorial mounts can be problematic.

To survey the celestial arctic, I decided to track down galactic quarry north of +85° declination with my 18-inch reflector. During a 24-hour period, these targets wheel (at most) 5° above or below Polaris and vary less than 10° in elevation. So in terms of sky placement, I wasn't too concerned with their specific right ascension or declination. As a bonus, observers without motorized mounts will find it unnecessary to constantly re-center these galaxies — sky motion is very sluggish near the pole!

Opening the *Uranometria 2000.0 Deep Sky Atlas* to Chart 1 (+84° to +90° declination), I noticed a striking distribution. Most of the action (29 of 43 galaxies) happens in a strip between 5 and 9 hours of right ascension, suggesting a galaxy cluster occupies the region. Although nine of these galaxies were discovered visually and carry NGC or IC designations, none were found during William Herschel's extensive sweeps. How had he missed these?

Herschel's most northerly discoveries were NGC 6251 and NGC 6252, a faint pair of galaxies in Ursa Minor at +82° declination. Only a few of his 1,112 sweeps were near the pole, as it was mechanically difficult to operate his 18.7-inch (20-foot focal length) telescope and record accurate positions in this direction. John Herschel fared no better: with only two exceptions, one being NGC 188, his discoveries were all south of +80° declination.

Albert Marth, observing in the mid-1860s from Malta with William Lassell's 48-inch equatorial reflector, stayed south of the zenith while discovering nearly 600 "nebulae." Starting in 1870, Édouard Stephan began a systematic search for nebulae using the 31-inch silver-on-glass Foucault reflector at the Marseille Observatory. During the next 15 years, he netted over 400 new objects, but his observations were also constrained between –12° and +46° declination. So by the time John Dreyer compiled the *New General Catalogue* in 1888, the extreme north celestial cap was largely "cosmos incognito."

The nearest NGC galaxy to the pole (just under 1° away) is **NGC 3172**, which John Herschel discovered on October 4, 1831. He dubbed it "Polarissima" but later modified the nickname to "Polarissima Borealis" to distinguish it from "Polarissima Australis" (NGC 2573). He found the latter only ½° from the south celestial pole while observing from the Cape of Good Hope.

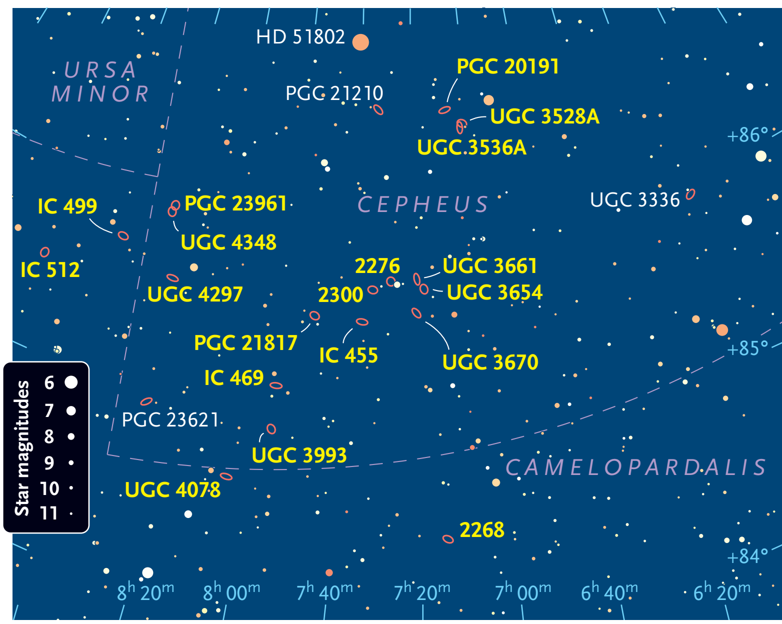
Through my 18-inch at 285× Polarissima Borealis appears as a pale patch about 0.4′ in diameter, enveloping a brighter core. A 13th-magnitude star lies 1.5′ northwest. **PGC 36268**, a challenging 16th-magnitude companion 1.6′ away, is on the ragged edge of visibility and difficult to confirm. NGC 3172 will probably require a 10-inch or larger scope, but I'd like to hear your results.

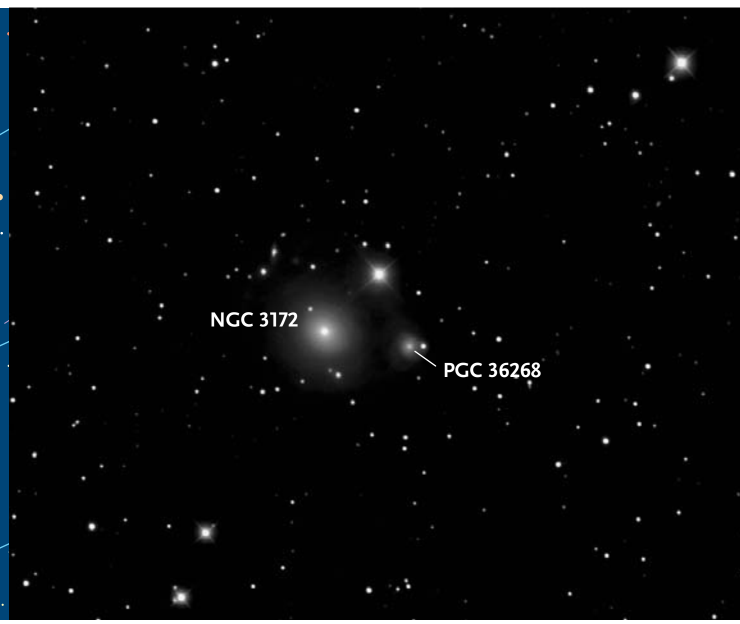
German astronomer Wilhelm Tempel discovered magnitude-13.2 **NGC 1544** in 1876 with an 11-inch Amici refractor at the Arcetri Observatory in Florence, Italy. The second most northerly NGC galaxy at +86° declination, NGC 1544 is a loner with no significant galactic neighbors, at least none within a couple of degrees. Overall, it's fairly faint and small, but the 0.4′ halo sharply concentrates into a bright, nearly stellar nucleus. A pair of 14.5-magnitude stars with a 10″ separation is pinned against the north edge and a wider 18″ duo rests off the northwest side.

The most interesting region for galaxy hunting surrounds **NGC 2276** and **NGC 2300**, a disrupted spiral and the elliptical companion 6′ to its southeast. Halton Arp cataloged the pair as Arp 114 in his 1966 *Atlas of Peculiar Galaxies*, labeling NGC 2276 as Arp 25 due to its disrupted arms. In addition, these are considered the two brightest members of LGG 145 (Lyon Groups of Galaxies). The group resides at a distance of 100 million light-years and includes the concentration of galaxies depicted in the *Uranometria* atlas.

August Winnecke, director of the Strasbourg Observatory, discovered magnitude-11.4 NGC 2276 in June 1876 using a 6.4-inch refractor. Winnecke recorded it as "faint, 1′ diameter, barely compressed." Through my 18-inch, I found a moderately bright, asymmetric 2′ glow that intensifies slightly towards the center. The halo is dappled with a few faint H II knots, the brightest at the northwest edge, and with careful study I had a strong impression of the spiral structure. An annoying 8th-magnitude star is parked 2.3′ west-southwest of the galaxy; you may find it helpful to keep it just outside the edge of the field of view.

POLARISSIMA BOREALIS The most familiar northern galaxy is NGC 3172, which appears as a circular glow about 1° below the celestial north pole. Less well-known is PGC 36268, a tough target even under ideal observing conditions.





DAVID RATLEDGE

ADAM BLOCK / MOUNT LEMMON SKYCENTER / UNIVERSITY OF ARIZONA

STUDY IN CONTRASTS Halton Arp included this spiral–lenticular pair in his *Atlas of Peculiar Galaxies* (1966) largely because of the "somewhat peculiar" and "perturbed" arms of NGC 2276.

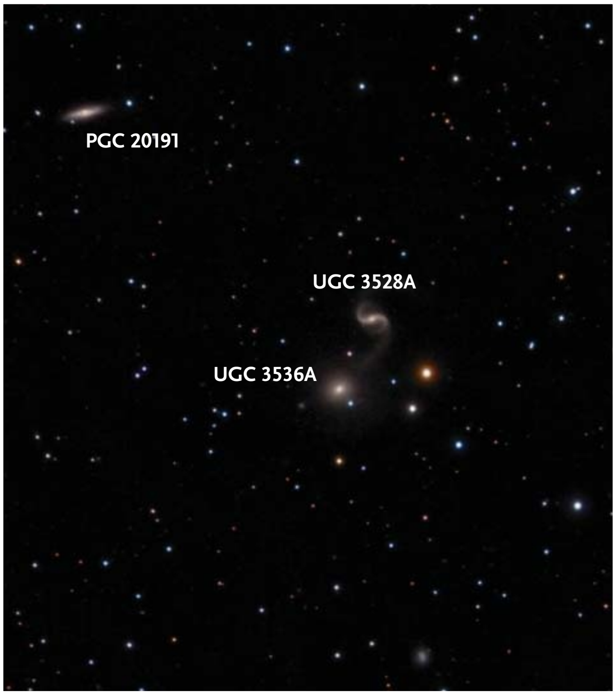
NGC 2300 has a 1.5′ envelope bulging slightly east and west. The halo condenses sharply to a prominent core that increases steadily toward the center. With a fairly high surface brightness, this 12th-magnitude galaxy should show distinctly through a 6-inch scope from a dark site. French astronomer Alphonse Borrelly, a most proficient comet hunter credited with as many as 18 discoveries, identified this elliptical around 1871 with a 7.2-inch refractor at the Marseille Observatory.

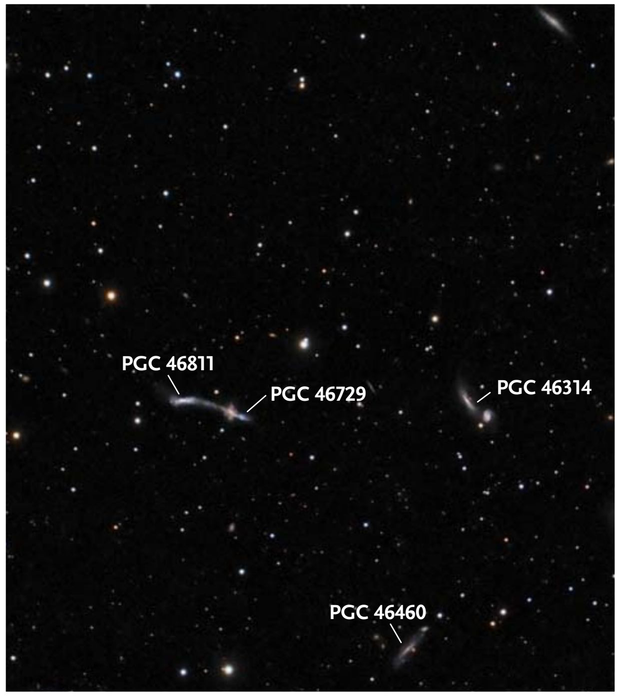
A 1993 study using the ROSAT X-ray satellite observatory revealed this duo is embedded in an immense cloud of hot gas about 1 million light-years across and containing roughly 500 billion times the mass of the Sun. As the leading edge of NGC 2276 plows through the gas, it triggers vigorous starburst activity. In addition, NGC 2276 has produced 5 supernovae since 1962, the most recent explosion in 2005. The gas cloud itself should have dissipated long ago; that it hasn't suggests it's been held together by the gravity of unseen dark matter.

The 14th-magnitude lenticular galaxy **IC 455** is much smaller and fainter than either member of the previous pair, but it's a snap to capture about 11′ south-southeast of NGC 2300. The 35″ × 25″ halo contains a small bright core punctuated by a star-like nucleus. Search for **PGC 21817** approximately 15′ to the east of IC 455. Using 285×, I found a 15″ fuzz spot, though it was easier to detect than its 15.3 blue magnitude would suggest. This diminutive glow pins down the northwest vertex of a quadrilateral formed with three nearby 10.5- to 11th-magnitude stars.

While comet hunting in Cepheus on September 20, 1890, E. E. Barnard ran across IC 455 (as well as NGC 2276 and 2300) using Lick Observatory's 12-inch refractor. Barnard never published his discovery, and the credit went to accomplished British amateur William Frederick Denning, who found IC 455 less than a month later with his 10-inch With-Browning reflector. Denning is renowned for his detailed observations of meteor showers, comets, novae, and planets, but he also swept up 15 far northern galaxies while searching for comets.

Several challenging galaxies surround NGC 2276 and 2300. I picked up **UGC 3661**, a ghostly edge-on, 8′ due west of NGC 2276. Using averted vision at 225×, I just glimpsed a phantom streak, roughly 25″ in length and ¼ as wide. Magnitude-14.3 **UGC 3654** forms a 4′ pair to the southwest, but a distracting 13th-magnitude star attached to its northeast end nearly masks the view. A close look revealed a tiny 0.3′ nebulous glow extending





RICK JOHNSON (2)

REACHING OUT *Left:* Deep-sky imaging reveals the subtle stretch of UGC 3528A's southern spiral arm toward its companion, elliptical galaxy UGC 3536A. *Right:* PGC 46811 and PGC 46729 combine, possibly with a third galaxy, to create a messy galactic train wreck.

southwest from the star. If you're successful with these, look 8′ south-southeast for the challenging **UGC 3670**. Only its faint 20″ core was seen at 285×.

IC 469, 43′ southwest of NGC 2300, is one of the easier members of the LGG 145 group to spot. The flattened halo spans 2′ × ¾′ and brightens towards the center. IC 469 marks the center of an isosceles triangle formed by a 9th-magnitude star 3.8′ north, and two 10th-magnitude stars 4.5′ southwest and 3.7′ south. **UGC 3993**, 14′ further south, is small and round with a moderate concentration to a bright nucleus. A faint, uncataloged double star with a separation of 10″ hovers to the east.

Host to the core-collapse Supernova 2003kx in 2003, 15th-magnitude **UGC 4078** floats in a starry field 20′ southeast of UGC 3993 and 5′ west of an 8.5-magnitude star. The uniform, low surface brightness patch appears 40″ long and ⅓ as wide, extending east and west. Just over 1° southwest is the multi-arm spiral **NGC 2268**, another Borrelly discovery. This fairly bright magnitude-11.5 oval spreads 2′ × 1′. Its relatively large core gradually intensifies down to a pinpoint nucleus.

As we're now just south of the +85° declination circle, let's head back further north, where I found **IC 499** (magnitude 12.5), a moderately bright oval, perhaps 50″ across, with a very low surface brightness outer periphery. The galaxy's condensed central region rises to a minute nucleus. A 14th-magnitude star nudges the southwest side of the halo, and a 12th-magnitude star perches just off the northeast side. The wider field of view includes a scattering of brighter stars.

Now let's head 20′ northwest of IC 499 to **PGC 23961** (magnitude 14.4), a fuzzy 15″ spot sitting within a small triangle of 11.5-magnitude stars. **UGC 4348** (magnitude 14.2), a close neighbor 2′ to the south, was a toughie. I only caught fleeting glimpses due to its anemic surface brightness but could tell it stretched north and south. **UGC 4297** is an easier edge-on spiral 20′ southwest of IC 499. Its halo extends 45″ long and ⅓ as wide, harboring a well-defined compact core.

Diminutive **IC 512** is a face-on spiral galaxy with a slightly out-of-round 1.5′ halo. The core brightens only weakly, but with close attention I was able to discern the central bar. A dim but distinctive 9′ string of stars passes just east of the galaxy. Look for IC 512 some 25′ southeast of IC 499 and 12′ west-southwest of an 8th-magnitude pale orange star. An 8-inch should display both galaxies under dark skies at a rural site.

Deep images display long tidal plumes emanating from the spiral arms of **UGC 3528A**, with the southern extension stretching to **UGC 3536A**. This interacting pair attracted the attention of Russian astronomer Boris Vorontsov-Velyaminov, who cataloged it as VV 248 in his 1959 *Catalogue of Interacting Galaxies* (*S&T:* Sept. 2014, p. 60), as well as that of Arp, who listed it as Arp 96. Through the eyepiece, blue magnitude-15.4 UGC 3528A is a hazy patch, about 24″ × 18″, with no visible core. UGC 3536A, a mere 1.5′ southeast, is slightly smaller, but has a higher surface brightness and steadily increases to a quasi-stellar nucleus. A 14.7-magnitude star is pinned against the southwest edge.

This pair shares the field with **PGC 20191** just 7′ to the northeast. I found a faint oval, 25″ long and ½ as wide, with a scarcely brighter core. The trio carries its own designation — KTG 11 from the *Karachentseva Isolated Triplets of Galaxies* (*S&T*: May 2015, p. 59) — and is located at a distance of 200 million light-years, twice as far as the LGG 145 group.

The last stop on our arctic expedition is **Arp 204** (also VV 39), a messy galactic train wreck involving two or three disrupted galaxies. **PGC 46811** is dim, elongated, and evenly lit, while **PGC 46729**, 1.3′ to the west, was marginally glimpsed at 288×. The thin, tidal bridge that connects the galaxies was beyond my visual capabilities, but it was satisfying just to track down this system.

So, what was the final tally? On one night observing at a remote site in the Sierra Nevada range (7,200 feet elevation), I captured 35 pole-hugging galaxies, including a few just below my +85° cut-off limit. If you decide to explore the northern frontier, do your homework beforehand and then head to dark skies. To help navigate, you'll need highly detailed finder charts with faint limits for stars and deep sky objects. A complete list of all 35 galaxies is available at **http://is.gd/circumpolar**. ✦

*A dedicated visual observer, Contributing Editor **Steve Gottlieb** keeps an eye on the northernmost skies for us from California. He welcomes your questions and comments at **steve_gottlieb@comcast.net**.*

Extreme Northern Galaxies

Object	Type	SB	Mag(v/B)	PA	Size	RA	Dec.
NGC 1544	S0/a	13.1	13.2	130°	1.3′ × 0.9′	05^h 02.6^m	+86° 13′
UGC 3528A	SBc	—	15.4B	63°	0.8′ × 0.6′	07^h 02.5^m	+86° 35′
UGC 3536A	E/S0	12.7	13.6	—	0.7′ × 0.6′	07^h 03.4^m	+86° 33′
PGC 20191	Sa	—	15.1B	109°	0.8′ × 0.3′	07^h 08.3^m	+86° 39′
NGC 2268	SAB(r)bc	13.4	11.5	63°	3.2′ × 2.0′	07^h 14.3^m	+84° 23′
UGC 3654	S0	11.8	14.3	17°	0.4′ × 0.3′	07^h 17.8^m	+85° 43′
UGC 3661	Sc	—	15.1B	12°	1.1′ × 0.3′	07^h 19.8^m	+85° 46′
UGC 3670	Sbc	—	15.4B	40°	1.0′ × 0.5′	07^h 20.1^m	+85° 35′
NGC 2276	SAB(rs)c	13.5	11.4	20°	2.8′ × 2.7′	07^h 27.2^m	+85° 45′
NGC 2300	E/S0	12.8	11.1	80°	2.8′ × 2.0′	07^h 32.3^m	+85° 43′
PGC 21817	E/S0	—	15.3B	64°	0.8′ × 0.6′	07^h 48.0^m	+85° 33′
UGC 3993	S0	13.4	12.8	35°	1.6′ × 1.2′	07^h 55.7^m	+84° 56′
UGC 4078	Sbc	13.6	14.3	82°	2.1′ × 0.3′	08^h 04.4^m	+84° 38′
UGC 4297	Sa	12.9	13.6	83°	1.6′ × 0.4′	08^h 28.5^m	+85° 36′
PGC 23961	Sbc	12.9	14.4	—	0.7′ × 0.6′	08^h 33.7^m	+85° 59′
UGC 4348	SABb	14.7	14.2	21°	1.5′ × 1.2′	08^h 34.0^m	+85° 57′
IC 455	S0	12.9	13.3	82°	1.1′ × 0.7′	07^h 35.0^m	+85° 32′
IC 469	SAB(rs)ab	13.3	12.6	90°	2.2′ × 1.0′	07^h 56.0^m	+85° 10′
IC 499	Sa	13.2	12.5	80°	2.1′ × 1.1′	08^h 45.3^m	+85° 44′
IC 512	SAB(s)cd	13.0	12.2	175°	1.8′ × 1.3′	09^h 03.9^m	+85° 30′
NGC 3172	S0	13.7	14.1	39°	1.1′ × 0.7′	11^h 47.2^m	+89° 06′
PGC 36268	Sbc	—	16.5B	—	0.5′ × 0.4′	11^h 40.7^m	+89° 05′
PGC 46729	Multiple	—	16.5B	52°	0.7′ × 0.4′	13^h 22.7^m	+84° 30′
PGC 46811	Sbc	—	16.0B	91°	0.8′ × 0.3′	13^h 23.6^m	+84° 30′

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.

A Finely Finished 14-inch

A few finishing touches often separates a good scope from a great one.

WOW — HE THOUGHT of everything. That's what went through my mind as I watched Victoria, British Columbia telescope maker Miles Waite assemble his 14-inch Dobsonian reflector. When he was done, I stood impressed with the scope's overall appearance and the particularly fine craftsmanship in evidence. But it's all the little thoughtful touches and attention to detail that makes this scope extra special.

Miles is typical of many telescope makers I've met over the years — he wanted an instrument customized to his specific observing needs that also appealed to his aesthetics. But the road to completion for this scope was perhaps a little longer and more winding than most. Having successfully made a 9¼-inch mirror before, he was ready to try his hand at something more ambitious. "I would say that in this case, the mirror chose me," Miles says. "A friend owned a commercial fishing boat and had a couple of surplus 14-inch diameter porthole windows he was removing when aperture fever struck and I immediately had visions of making a big telescope mirror."

Victoria, British Columbia telescope maker Miles Waite designed and built this superb, portable 14-inch f/4.7 truss-tube Dobsonian.

GARY SERONIK

One thing about working on a telescope mirror is that it gives you lots of time to think, and Miles used that time to work out the details of his dream scope. Eventually the planning and construction got ahead of the mirror's progress. "Most of the scope's structure was nearing completion, and my mirror wasn't finished yet," he recounts. "So, I decided to purchase a primary with the intention of swapping it for my own optic when it was done."

The scope pictured here is the result. It's a lightweight, compact instrument with a f/4.7 focal ratio that places the focuser at eye level when the scope is aimed at the zenith. The telescope is made largely from aluminum stock. As Miles says, "One of the biggest challenges was bolting everything together accurately and securely; the only welding I did was a bit of brazing on the spider secondary holder bracket."

So what about those thoughtful touches I mentioned earlier? There are several, but let me highlight just a few that illustrate the care Miles put into the design. First, the Achilles heel of most open-frame Dobs is the truss system that joins the front of the scope to the rear. Many are fiddly, and some invite potential disaster with poles and hardware precariously attached until the assembly is completed. All six truss members in Miles's scope are joined together as a single unit that unfolds and attaches to the rest of the scope with captive bolts — there's nothing to lose in the dark or fall on the primary mirror. (But there's a mirror cover in place, just to be extra sure!)

I also like the nifty way the front sections of the side bearings fold in for a compact configuration that makes transporting the scope easier. These "ears" swing into position and are locked in place by a pair of ordinary cabinet latches. The scope also utilizes digital setting circles, but you might not notice them at first glance. Miles has done a superb job of routing the various wires that

GARY SERONIK

The scope breaks down into three main parts for transport: the secondary mirror cage, primary mirror assembly, and truss unit.

connect the encoders to the display unit so they're largely out of sight. The holder for the display is also a very nice touch — it's at a convenient height and location for easy access while using the scope.

A telescope is often more than the sum of its parts, and that's the case here too. Looking at the dozens of components that went into making this scope, I couldn't help but be impressed by the level of detail and care that went into every single piece. I shudder to think of the hours it must have taken to fabricate and finish them all. But the effort paid off. The resulting telescope has the look of something that emerged from a high-tech manufacturing facility, rather than an amateur's garage. "At star parties I've been asked what brand this scope is," Miles says. "People have a hard time believing that I actually made it!"

As Miles summarizes, "The satisfaction from working with my hands, problem solving, and the finished product made it all worthwhile." One day, he might even get around to finishing that porthole mirror!

Readers wishing to learn more about the scope can contact Miles via e-mail at jmwaite@shaw.ca. ✦

*Contributing editor **Gary Seronik** is an experienced telescope maker and observer who has overseen the ATM department since 1998. You can contact him through his website, **www.garyseronik.com**.*

Vibrant star trails, captured in a 6-hour total exposure, circle above wintry hills in Acadia National Park, Maine. See page 28 for more on circumpolar observations.

In This Section

PHOTOGRAPH: JEREMY P. GRAY

Sky at a Glance

FEBRUARY 2016

1 **MORNING:** Little orange Mars is 2 or 3° from the last-quarter Moon; the pair is highest before dawn.

3 **MORNING:** The waning crescent Moon rises around 2 or 3 a.m. local time. Look for the bright light of Saturn about 5° below it, and Antares about 8° right or lower right of Saturn.

6 **DAWN:** Modest Mercury and vibrant Venus are drawing ever closer; the thin crescent Moon joins them in the southeast this morning.

8–18 **DAWN:** Mercury and Venus shine just 4° apart.

15–16 **NIGHT:** The Moon, just past first quarter, is in the Hyades tonight. It occults Aldebaran for viewers on the west coast of the United States after midnight, low in the west; see page 45.

18 **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 10:50 p.m. EST (7:50 p.m. PST); see page 46.

21 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 7:39 p.m. EST.

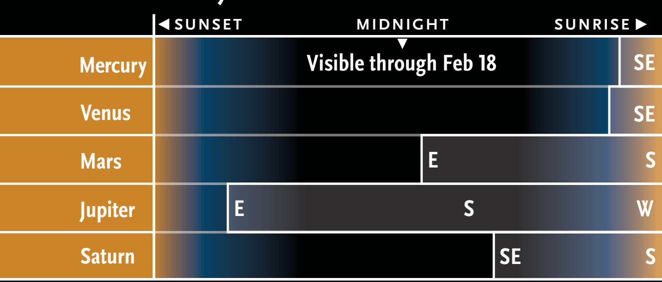
21–22 **ALL NIGHT:** Look for Regulus, the brightest star in Leo, near the full Moon.

23–24 **ALL NIGHT:** The waning gibbous Moon rises in the east, with Jupiter keeping it company. Watch as the Moon moves eastward, away from Jupiter, during the night. Sigma (σ) Leonis, the Lion's hind foot, gleams about 2° from the bright planet.

29 **MORNING:** Look for Mars about 5° below the nearly last-quarter Moon.

Planet Visibility

SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH



Moon Phases

New February 8 9:39 a.m. EST

First Qtr February 15 2:46 a.m. EST

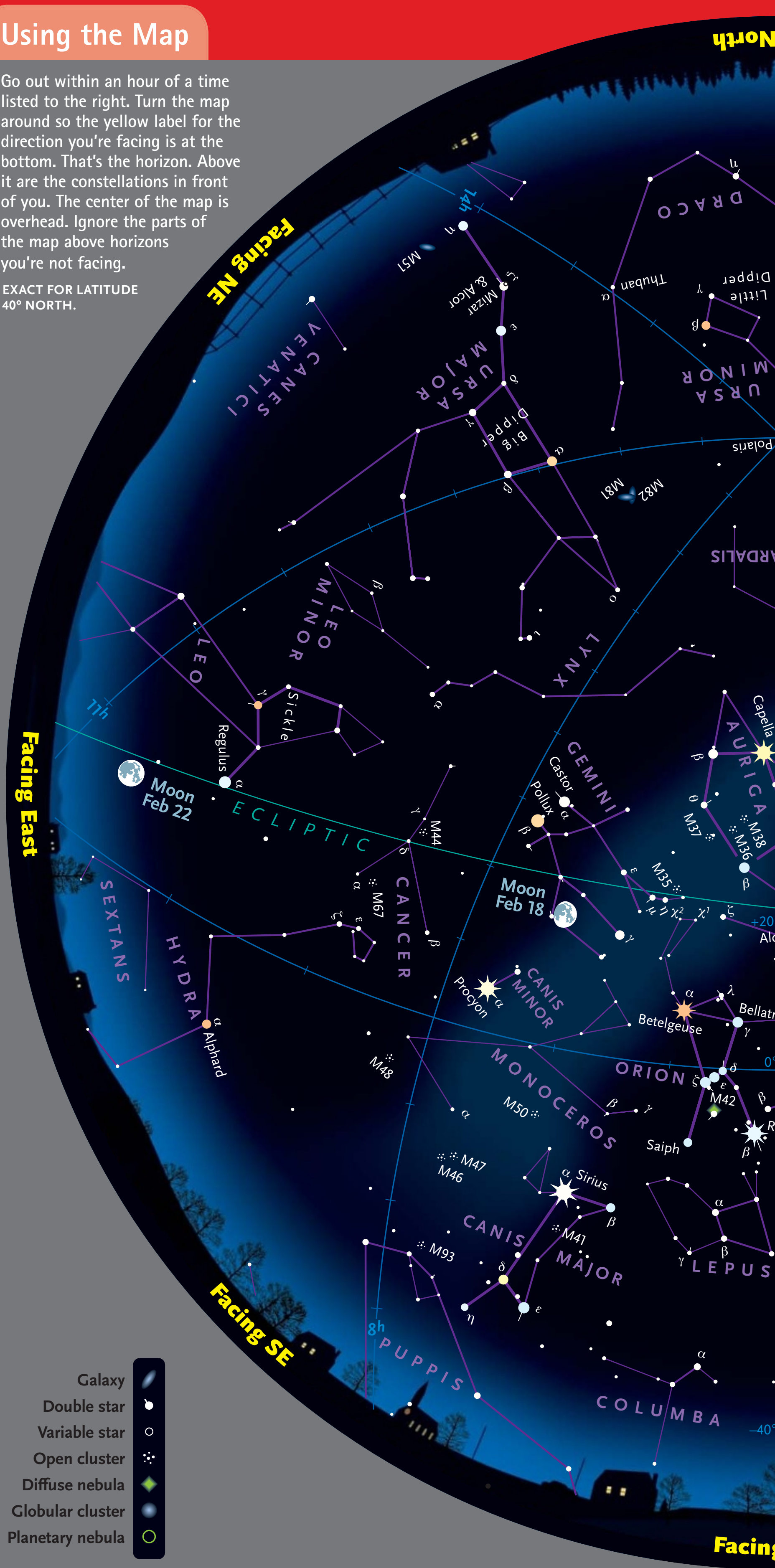
Full February 22 1:20 p.m. EST

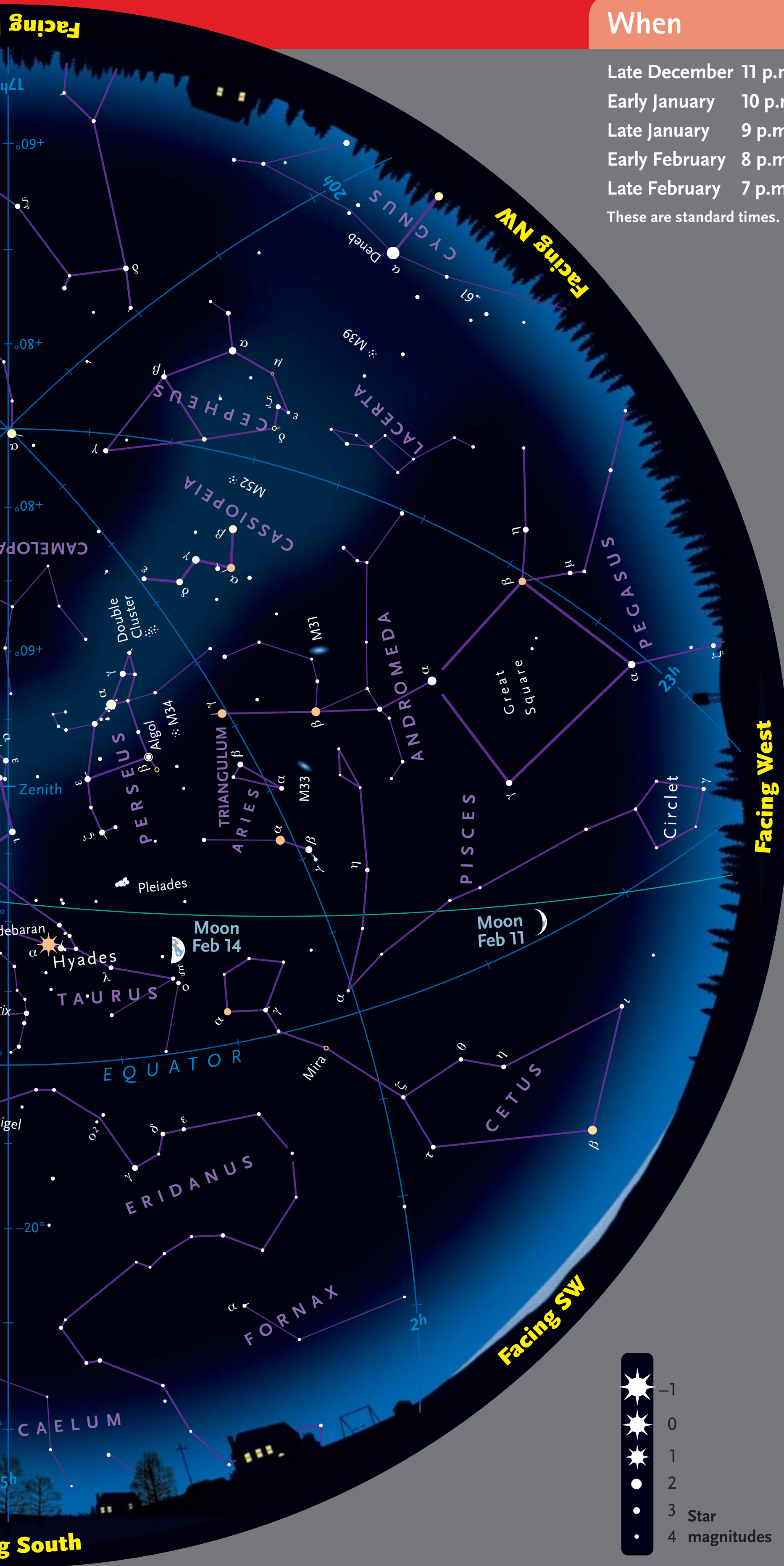
SUN	MON	TUE	WED	THU	FRI	SAT
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29					

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 December	11 p.m.
Early January	10 p.m.
Late January	9 p.m.
Early February	8 p.m.
Late February	7 p.m.

These are standard times.

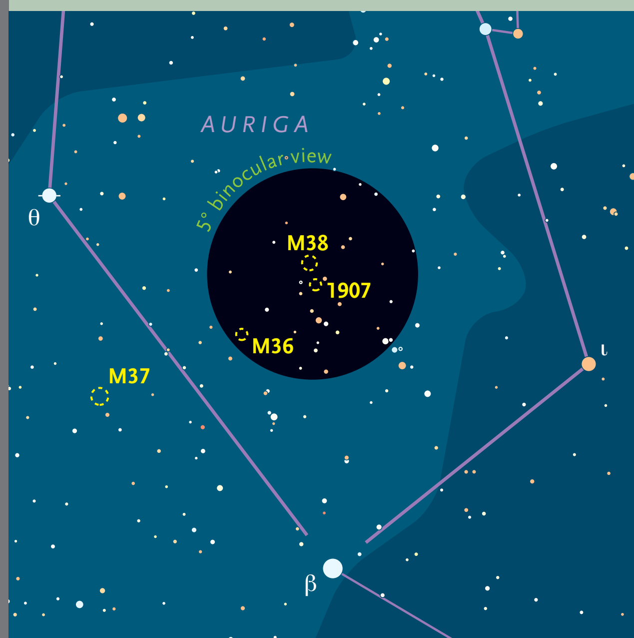
Gary Seronik
Binocular Highlight

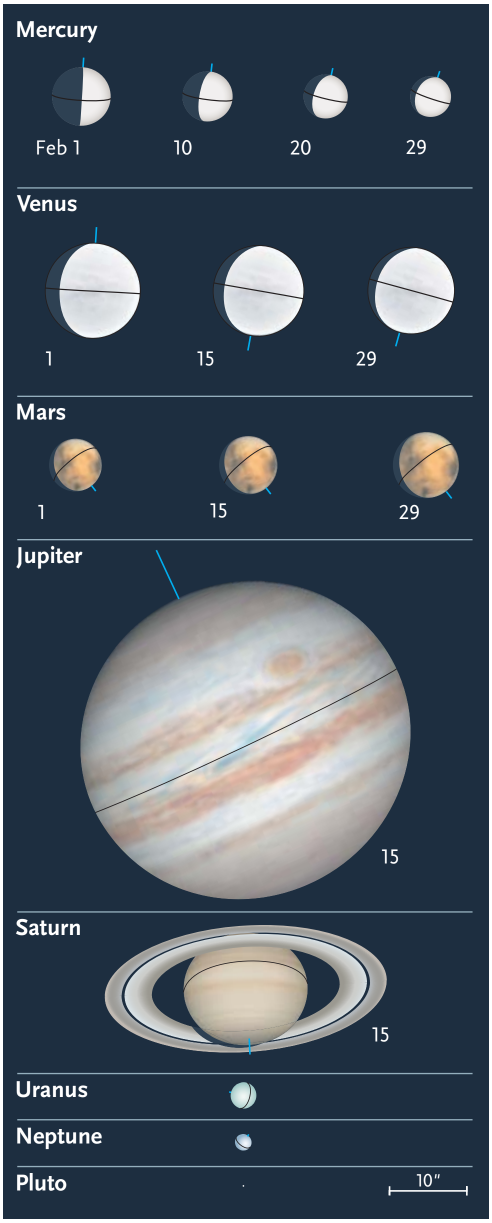
Clusters Aplenty in Auriga

The winter sky is tremendously bountiful for binocular observers — enough showpiece objects cross the meridian on February evenings to keep you busy for hours. For me, one of the most enjoyable stretches of sky is found in Auriga, which features the fine Messier trio of M36, M37, and M38.

The Auriga open clusters are appealing for a number of reasons, not least because each one is distinct. And noting their differences is a good way to sharpen your observing skills. Let's begin with the easternmost cluster, **M37**. Although easy to see in my 10×30 image-stabilized binoculars, M37 is the toughest of the bunch when it comes to resolving individual stars. Even in my 15×45 ISBs, it's just a round, slightly grainy haze of starlight. Shift your gaze roughly one binocular field westward to pick up neighboring **M36**. This is the easiest of the three to see and resolve. In my 10×30s, it's a compact grouping with perhaps a half dozen individual stars visible. The extra magnification and light grasp of the 15×45s doubles the star count and fills in the cluster's arrowhead shape.

Moving another bino field westward brings you to my favorite of the three, **M38**. Although it's the least obvious, it's still an easy catch under decent skies. M38 is an opulent gathering with a few individual cluster stars flickering in and out of view against a box-shaped haze. What makes this cluster extra appealing is the company it keeps. M38 is positioned in a rich field crossed by a couple of attractive strings of 6th- and 7th-magnitude stars, and, if you have dark skies, there's even a little bonus open cluster nearby, **NGC 1907**, which shows up reasonably well in my 15×45s. ✦





Sun and Planets, February 2016

	February	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$20^h\,55.1^m$	–17° 23′	—	–26.8	32′ 28″	—	0.985
	29	$22^h\,44.7^m$	–7° 58′	—	–26.8	32′ 18″	—	0.991
Mercury	1	$19^h\,12.0^m$	–20° 37′	25° Mo	0.0	7.6″	49%	0.886
	10	$19^h\,47.9^m$	–20° 54′	25° Mo	–0.1	6.5″	66%	1.039
	20	$20^h\,42.1^m$	–19° 26′	23° Mo	–0.1	5.7″	79%	1.178
	29	$21^h\,36.4^m$	–16° 18′	19° Mo	–0.3	5.3″	86%	1.272
Venus	1	$18^h\,42.5^m$	–22° 23′	32° Mo	–3.9	12.4″	85%	1.349
	10	$19^h\,30.3^m$	–21° 34′	30° Mo	–3.9	11.9″	87%	1.397
	20	$20^h\,22.5^m$	–19° 39′	27° Mo	–3.9	11.5″	89%	1.447
	29	$21^h\,08.2^m$	–17° 07′	25° Mo	–3.9	11.2″	91%	1.489
Mars	1	$14^h\,50.9^m$	–14° 51′	87° Mo	+0.8	6.8″	90%	1.372
	15	$15^h\,17.5^m$	–16° 45′	94° Mo	+0.6	7.6″	90%	1.229
	29	$15^h\,41.9^m$	–18° 17′	102° Mo	+0.3	8.6″	90%	1.088
Jupiter	1	$11^h\,33.2^m$	+4° 24′	139° Mo	–2.4	42.5″	100%	4.638
	29	$11^h\,22.5^m$	+5° 38′	170° Mo	–2.5	44.3″	100%	4.447
Saturn	1	$16^h\,51.0^m$	–20° 49′	57° Mo	+0.5	15.8″	100%	10.511
	29	$16^h\,58.4^m$	–20° 58′	84° Mo	+0.5	16.5″	100%	10.074
Uranus	15	$1^h\,05.1^m$	+6° 16′	52° Ev	+5.9	3.4″	100%	20.565
Neptune	15	$22^h\,42.7^m$	–9° 01′	13° Ev	+8.0	2.2″	100%	30.919
Pluto	15	$19^h\,09.9^m$	–20° 56′	39° Mo	+14.2	0.1″	100%	33.801

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

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

Fred Schaaf

A Thousand Stars

Count the possibilities in the night skies of winter.

Take me into your loving arms
Kiss me under the light of a thousand stars
Place your head on my beating heart
I'm thinking out loud
Maybe we found love right where we are.
— Ed Sheeran and Amy Wadge, *Thinking Out Loud*

I like the mention of "the light of a thousand stars" in the chorus of Ed Sheeran's hit song. Not fewer than a thousand stars, so we know these young lovers are blessed with a sky that's at least relatively free of light pollution. But the song also doesn't engage in unknowledgeable hyperbole and claim a million stars.

The more I've thought about it, the more intriguing I've found the concept of a thousand stars. We can explore the topic not just mentally indoors but also visually outdoors — where the bright traditional constellations of winter offer some wonderful opportunities to see numerous stars, both with naked eye and optical aid.

Thinking about a thousand stars. How many thousands of stars can be seen with the naked eye? The answer depends first on sky conditions — including light pollution, of course — both near the zenith and at lower altitudes in the sky, where more light is absorbed and scattered. But there's another factor as well: the viewer's observing skill. It takes practice to get better at using "averted vision" (looking slightly away from a target object so that its light falls on the outer parts of the retina where there are greater numbers of light-sensitive rod cells).

I've always told people that more than just one or two thousand stars can be seen under ideal conditions with the naked eye. Perhaps the ancient Greeks used a special word, "myriad" (meaning 10,000), because the most prominent display of great number in nature was the stars. They may have estimated that roughly "a myriad" of stars could be seen in the sky.

But exalting in a sky of just a thousand stars has its own merits. A "thousand" is a determinate number, and it's within the reach of people with less-than-ideally dark skies. The *Millennium Star Atlas* tells us there are 893 stars at magnitude 4.49 or brighter and 2,822 at 5.49 or brighter. If the naked-eye limit is supposed to be 6.5, the total grows to 8,768 naked-eye stars. But some observers have seen stars as dim as magnitude 8.0 with the naked eye, so we can imagine a number closer to a myriad.

A thousand winter stars. Snow cover can worsen our faint limit by several magnitudes. Even the light produced by a fairly dark night sky can make our limiting magnitude markedly brighter. To see the faintest stars, cup your hands around your eyes or block as much of the sky from view as possible with trees or dark buildings.

On winter evenings, the region to keep in clear view is the group of constellations centered on Orion. No one constellation has 1,000 naked-eye stars in it, but if you take the stars brighter than 6.5 in the Orion group — Orion (204), Taurus (223), Auriga (152), Gemini (119), Canis Minor (47), and Canis Major (147) — and add them together, you get 892. Add the 73 stars of Lepus and you're closer to 1,000. Add Monoceros (138) and you're over a thousand.

According to the *Millennium Star Atlas,* the richest areas of the heavens (regions like Crux and Cygnus) can display, in ideal conditions, more than 3,000 stars in a typical field of 7×50 binoculars. In winter, try the region of Orion's Belt and Sword, or parts of Puppis, to see a thousand stars in binoculars. With a telescope, you'll need to check out one of winter's rich open clusters. Even the Double Cluster in Perseus and M37 in Auriga offer mere hundreds of stars — but are still glorious. ✦

Night Walk

TIINA TÖRMÄNEN

Jupiter Blazes in the Night

Look to the morning for the other bright planets.

February begins with no bright planets in the sky at dusk, but as the month progresses, brilliant Jupiter begins rising due east in evening twilight. Mars doesn't come up until the midnight hour, when its increasing brightness and color draw our attention. Jupiter reaches its highest after Mars appears, and Mars is followed by similarly bright Saturn, rising in Ophiuchus. Finally, two hours or less before the Sun comes up, Venus rises, followed closely by Mercury, lifting all the bright planets into visibility at once.

DUSK AND EVENING

Jupiter is gloriously bright and visible this month. It climbs over the east horizon around 8 or 9 p.m. local time as February begins but only about 25 minutes after sunset as the month ends. It brightens a trace from magnitude –2.4 to –2.5 while its apparent diameter in telescopes grows two arcseconds — from more than 42″ to more than 44″ — before month's end. The kingly planet now is retrograding (moving westward against the stars) in southeastern Leo; it will reach opposition and come closest to Earth on March 8th.

Dim **Uranus** is still visible in February as evening twilight ends. Find it with the charts in last September's issue, page 48, or at **skypub.com/urnep**. **Neptune** is lost in evening twilight this month.

LATE NIGHT TO DAWN

Mars starts February 1.1° north of the 3rd-magnitude double star Alpha (α) Librae (Zubenelgenubi) and moves eastward — most of the way across Libra — over the course of the month. Its time of rising backsteps less than an hour during the same period, from near 1 a.m. at the start of the month to midnight at the end.

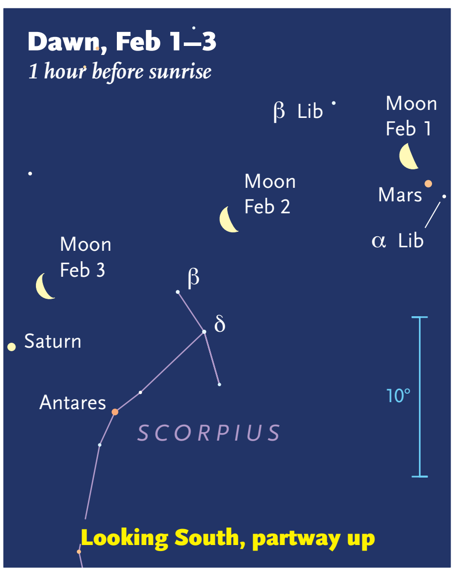
Mars shines in the large gap between Spica and Antares, kindling from slightly brighter than these stars to approximately twice as bright. Its magnitude improves from +0.8 to +0.3 this month, a brightness range in which the campfire orange-gold color becomes more prominent to the naked eye. The angular size of Mars grows only from 6.8″ to 8.6″ during February, so you'll need a good telescope, good seeing, and Mars near its highest — which it reaches in morning twilight — to glimpse a surface feature other than the north polar ice cap. You may also notice that Mars looks slightly out-of-round this month because of a shadowed edge caused by our line of sight to it differing from the Sun's. Mars is at western quadrature (90° west of the Sun) on February 7th.

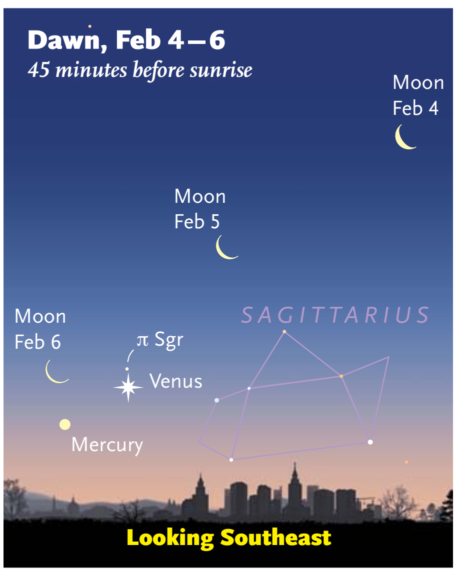
Mars is on its way to opposition on May 22nd and a closest approach to Earth on May 30th, when it will reach 18.6″ in diameter and shine almost as bright as Jupiter.

Saturn rises after 3 a.m. as February opens and around 1:30 a.m. as it closes. The golden planet starts the month only 7½° northeast of Antares, then creeps a bit eastward from the noticeably dimmer star over the course of a few weeks. Saturn maintains a magnitude +0.5 all month, providing an interesting brightness comparison to Mars. Its rings are now tilted a glorious 26° from edgewise. Telescopic observations are best made at the beginning of dawn, when Saturn approaches the meridian.

DAWN

Venus is nearing the end of a long morning apparition, rising before morning twilight at the beginning of February but only an hour before sunrise at the end. The angle of the ecliptic with respect to the eastern horizon is shallow at dawn this

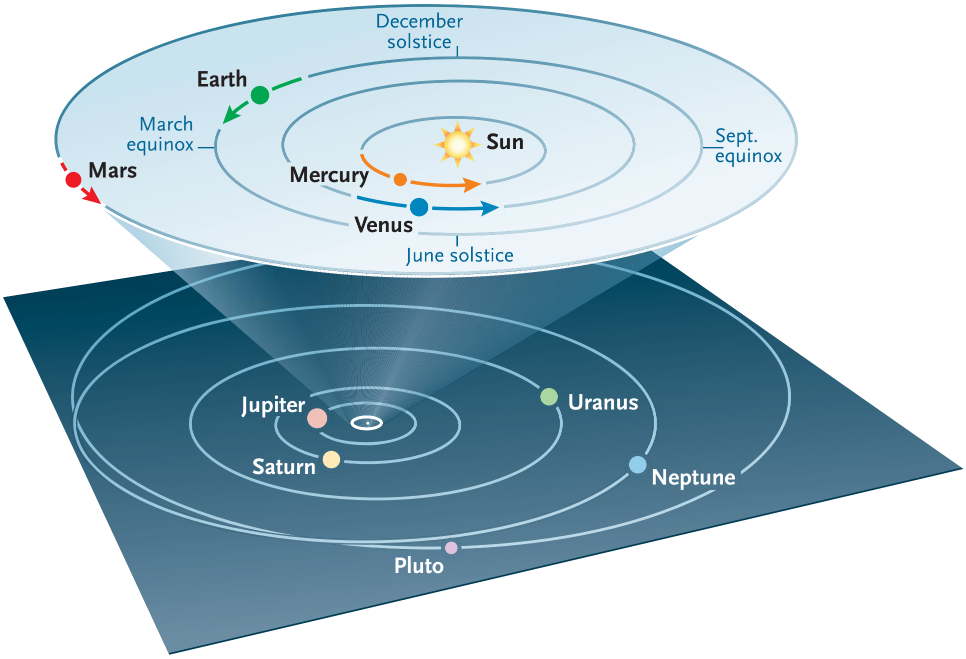




These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. The blue 10° scale bar is about the width of your fist at arm's length. For clarity, the Moon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

ORBITS OF THE PLANETS

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



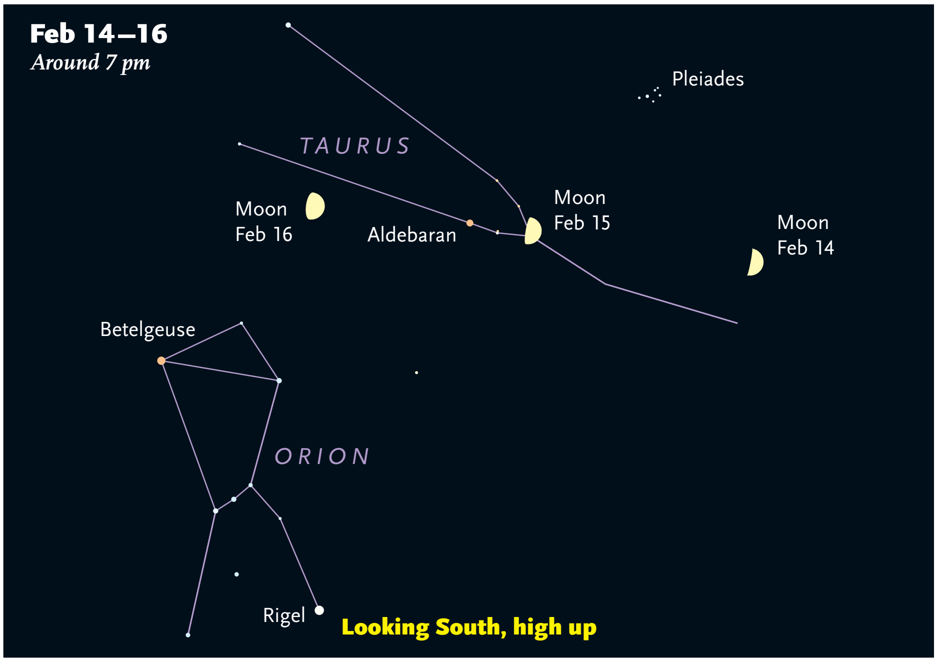
time of year for observers at mid-northern latitudes, so Venus is especially low. Even so, it's bright, shining at magnitude –3.9. Telescopes display its diameter shrinking from 12″ to 11″, while its gibbous phase increases from 85% to 90% lit.

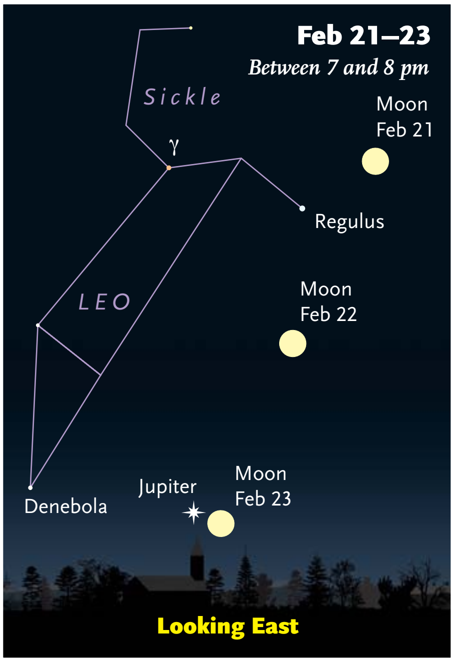
Mercury shines fairly near Venus all month. The small planet was highest for viewers around latitude 40° north on January 31st and reaches greatest elongation from the Sun (26°) on February 7th. It beams brightly at about zero magnitude all month but slides very low in dawn by late February. Its least separation from Venus — a "quasi-conjunction," not a true one in right ascension — occurs on February 13th, when Mercury is 4° east (lower left) of Venus. But even then, the pair is less than 10° high 30 minutes before sunrise.

Pluto is about 1° north of Venus on February 5th, but too dim to see in the dawn light all month.

MOON PASSAGES

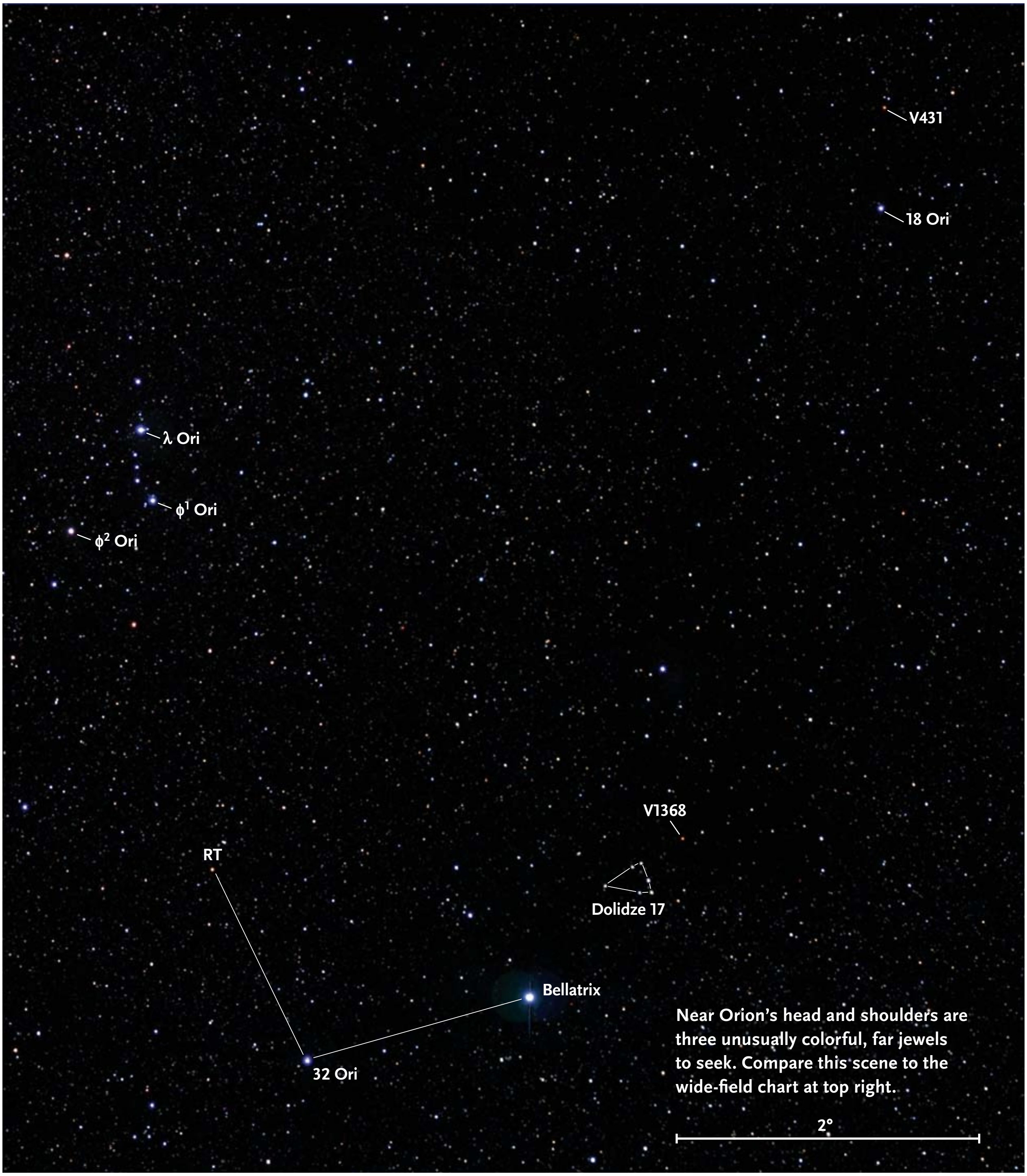
The **Moon** is a thick waning crescent not far upper left of Mars and Alpha Librae on the morning of February 1st. Two dawns later, the thinning crescent stands upper right of Saturn and far upper left of Antares. Before dawn on February 6th the very slender Moon forms a fine compact triangle with Venus to its right and Mercury below it. In the evening sky on February 15th, the waxing gibbous Moon glides among the Hyades and for some observers occults Aldebaran (see page 45). The fat waxing gibbous Moon is upper right of Regulus on the evening of February 21st, and the just-past-full Moon rises close to Jupiter on February 23rd. ✦





Redder Stars in Orion

Betelgeuse is just the teaser. Dig up these very red carbon stars hiding high in its vicinity these winter nights.



Near Orion's head and shoulders are three unusually colorful, far jewels to seek. Compare this scene to the wide-field chart at top right.

DIGITIZED SKY SURVEY

Learn how to use detailed star charts to find the faintest things with your telescope: skypub.com/charts.

Alan MacRobert

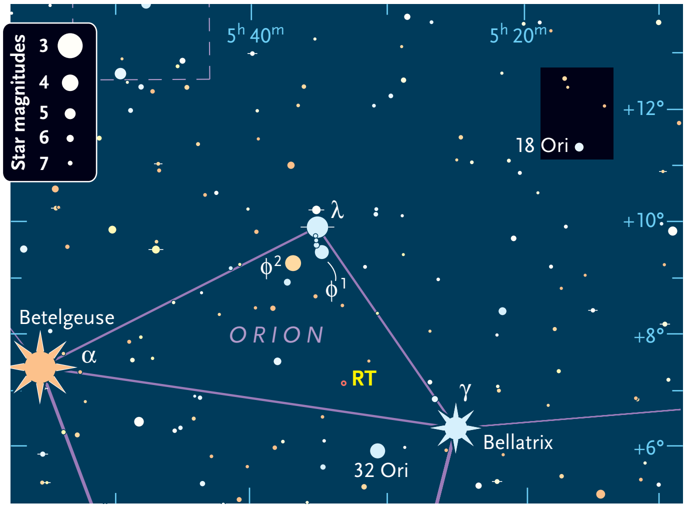
The brightest "red" star in the sky? Most of us know that's Betelgeuse in Orion's shoulder. Closely following Betelgeuse is Antares, which helps give Scorpius its title of "the Orion of summer." Both are type-*M*2 supergiants about 500 or 600 light-years away.

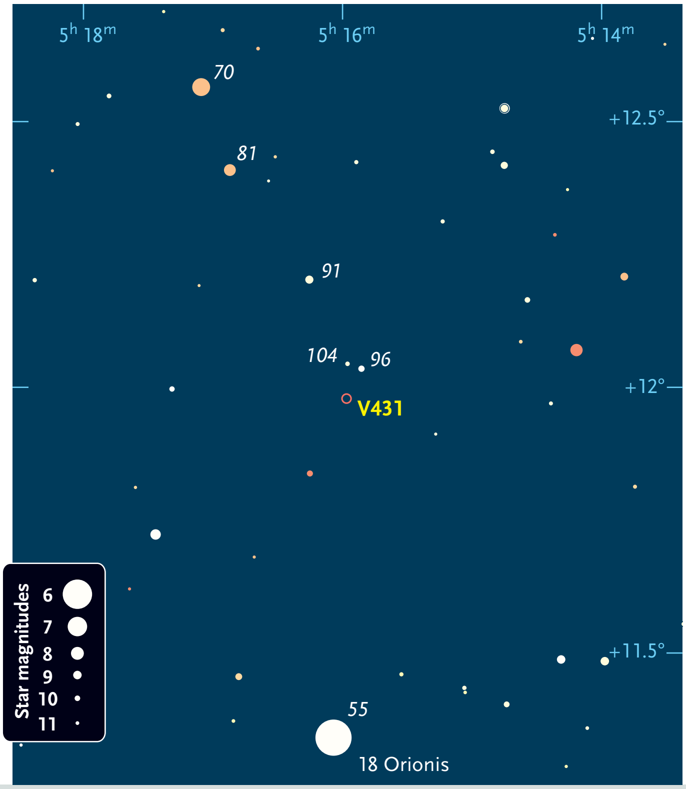
But as most of us also know, *M* stars are not red but deep yellow-orange. Nearly all those we see are giants or supergiants; the brightest red dwarf in the sky is the little *M*2 star Lalande 21185 in the hind feet of Ursa Major, a binocular or small-scope pickup at visual magnitude 7.5. Look at it carefully in an 8-inch or larger scope, and you'll see that it's even less red than Betelgeuse or Antares. All dwarf stars are a bit less red than giants of the same spectral class; this is due to their compactness and, therefore, much stronger surface gravity. In strong gravity, a star's surface material is compressed and dense. That makes it show the same spectral lines as a slightly cooler and hence redder giant. A giant's visible surface is under such weak gravity and low pressure that it's practically a vacuum.

Carbon Filters

But real red? No star is as red as a traffic light or a Christmas-tree light. But the reddest shades of orange can be found among the *carbon stars*: red giants (for the most part) that possess more carbon in their atmospheres than oxygen.

Most giants have more than enough oxygen to scavenge up all carbon and, at the temperatures and pressures in an *M* star's atmosphere, turn it into colorless carbon monoxide. But if carbon atoms outnumber oxygen atoms, some of the excess forms C_2 vapor, a red gas. So the star is overlayered with a red filter. Sometimes the excess carbon also forms fine particles of soot — star





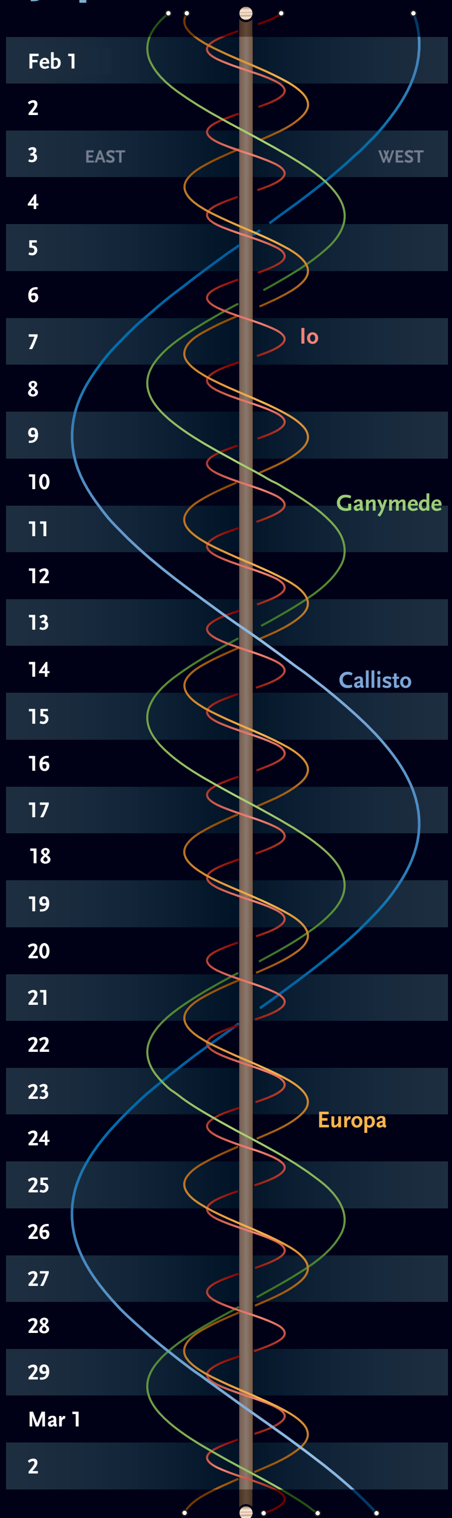
For all its familiarity, Orion hides the red carbon stars RT, V1368, and V431 Orionis in its upper portions. They're all findable with a 3-inch scope. On the wide-field chart at top, the black box shows the area of the closeup below you'll need for V431. On the closeup, italic numbers are visual magnitudes of comparison stars with the decimal point omitted.

Hyades and Aldebaran Occultations

Through the evening and late into the night of February 15–16, most North Americans can watch the Moon (just past first quarter) crawl along the southern arm of the Hyades V pattern, munching on stars one by one. Which stars you'll see occulted, and when, depends on where you are. The brighter ones include Gamma, 75, Theta^1, and Theta^2 Tauri. Disappearances happen on the Moon's dark limb.

Then comes Aldebaran. By the time the Moon reaches it only the West Coast will still have a view, and even there the Moon will be low in the west on its way to setting. The dark limb covers Aldebaran at 1:05 a.m. PST for Los Angeles, 1:03 a.m. for the San Francisco area, and around 1:10 a.m. for Portland. The northern limit of Aldebaran's occultation (the graze line) passes about 40 miles south of Seattle.

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 0h (upper edge of band) to 24h 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.

smoke — that further reddens the star, like the Sun seen through woodsmoke or heavy particulate pollution over a city.

Since Betelgeuse and upper Orion are so familiar these evenings, here are three carbon stars you probably didn't know about that lurk there, hiding in plain (telescopic) sight.

RT Orionis is an easy starter to find. It varies slowly and semiregularly between visual magnitude 8.0 and 8.9. It's a simple two-step star-hop starting from Bellatrix, Orion's dimmer shoulder, as shown on the photo two pages back. From Bellatrix go 1.5° east-southeast to hit 4th-magnitude 32 Orionis. From there swing 120° counterclockwise, go almost the same distance again, and you're on RT. Its color helps give it away.

While you're at it, **32 Orionis** is a special sight itself: a tight double star that will test your scope and the night's seeing. Its two components differ in brightness by a factor of four, at magnitudes 4.2 and 5.8, making them a tough split at their separation of just 1.3″.

On the other side of Bellatrix is **V1368 Orionis**, fainter at about magnitude 9.8 and only slightly variable. Jump from Bellatrix to the loose triangular cluster or asterism Dolidze 17, marked on the photo. Its six stars, 7th and 8th magnitude, form a distinctive symmetrical pattern 0.3° wide. From its north corner look another 0.3° northwest, and there you are. Again, the star's color helps it stand out.

Farther off in the bleak winter wilderness is **V431 Orionis**. Start from Lambda (λ) Ori, Orion's little 3rd-magnitude head. Use the wide-field chart on the previous page to step 5° west-northwest to 18 Orionis, magnitude 5.5. That gets you into the closeup chart below it. V431 is 0.6° due north from 18 Ori. It varies more than the others but spends most of its time between magnitudes 9 and 11.

The closeup chart gives comparison-star magnitudes for estimating its brightness. But with a target so different in color from the stars around it, visual magnitude estimates are notoriously unreliable. For one thing, our eye lenses yellow with age! Older folks see the world through yellow filters. This means they systematically estimate reddish stars brighter compared to white ones than young people do.

Looking Wider

Interested in pursuing carbon stars further? Contributing editor Bob King lists a dozen of the brightest, with descriptions, at "Carbon Stars Will Make You See Red": **http://is.gd/kingcarbonstars**. One of these is BL Orionis, visual magnitude 6.0 to 7.0, off to the east of Orion's Club on the border of Gemini.

Finder charts for 13 of the reddest of the red, and a table of 21 with their color indexes, can be found with Brian Skiff's article about observing them in the May 1998 *S&T,* page 90.

And the Astronomical League (the umbrella organization for more than 300 U.S. astronomy clubs) runs a Carbon Star Observing Program, at **http://is.gd/alcarbonstars**, with award certificate and pin. There you'll find instructions and a carefully chosen table of 100 of these rubies all over the sky.

Minima of Algol

Jan.	UT	Feb.	UT
1	9:53	1	22:54
4	6:42	4	19:44
7	3:31	7	16:33
10	0:20	10	13:22
12	21:09	13	10:12
15	17:59	16	7:01
18	14:48	19	3:50
21	11:37	22	0:39
24	8:26	24	21:29
27	5:16	27	18:18
30	2:05		

These geocentric predictions are from the new heliocentric elements Min. = JD 2440953.5087 + 2.8673075*E*, where *E* is any integer, courtesy AAVSO. For a comparison-star chart and more info, see SkyandTelescope.com/algol.

Daily Jupiter Sights for February

Jupiter comes to opposition on March 8th. So in February it's already high before midnight, and at 43″ to 44″ across its equator it's about as big as it will appear this year.

Any telescope shows Jupiter's four big Galilean moons. Binoculars almost always show at least two or three. Identify them using the diagram at far left.

All the February interactions between Jupiter and its satellites and their shadows are tabulated below.

Here are the times, in Universal Time, when Jupiter's Great Red Spot should cross the planet's central meridian. The dates, also in UT, are in bold. (Eastern Standard Time is UT minus 5 hours.)

January 1, 3:57, 13:53, 23:48; **2,** 9:44, 19:40; **3,** 5:35, 15:31; **4,** 1:27, 11:22, 21:18; **5,** 7:14, 17:09; **6,** 3:05, 13:00, 22:56; **7,** 8:52, 18:47; **8,** 4:43, 14:39; **9,** 0:34, 10:30, 20:25; **10,** 6:21, 16:17; **11,** 2:12, 12:08, 22:04; **12,** 7:59, 17:55; **13,** 3:50, 13:46, 23:42; **14,** 9:37, 19:33; **15,** 5:29, 15:24; **16,** 1:20, 11:15, 21:11; **17,** 7:07, 17:02; **18,** 2:58, 12:53, 22:49; **19,** 8:45, 18:40; **20,** 4:36, 14:31; **21,** 0:27, 10:23, 20:18; **22,** 6:14, 16:09; **23,** 2:05, 12:01, 21:56; **24,** 7:52, 17:47; **25,** 3:43, 13:39, 23:34; **26,** 9:30, 19:25; **27,** 5:21, 15:17; **28,** 1:12, 11:08, 21:03; **29,** 6:59, 16:55; **30,** 2:50, 12:46, 22:41; **31,** 8:37, 18:33.

February 1, 4:28, 14:24; **2,** 0:19, 10:15, 20:11; **3,** 6:06, 16:02; **4,** 1:57, 11:53, 21:48; **5,** 7:44, 17:40; **6,** 3:35, 13:31, 23:26; **7,** 9:22, 19:18; **8,** 5:13, 15:09; **9,** 1:04, 11:00, 20:56; **10,** 6:51, 16:47; **11,** 2:42, 12:38, 22:33; **12,** 8:29, 18:25; **13,** 4:20, 14:16; **14,** 0:11, 10:07, 20:02; **15,** 5:58, 15:54; **16,** 1:49, 11:45, 21:40; **17,** 7:36, 17:32; **18,** 3:27, 13:23, 23:18; **19,** 9:14, 19:09; **20,** 5:05, 15:01; **21,** 0:56, 10:52, 20:47; **22,** 6:43, 16:38; **23,** 2:34, 12:30, 22:25; **24,** 8:21, 18:16; **25,** 4:12, 14:08; **26,** 0:03, 9:59, 19:54; **27,** 5:50, 15:45; **28,** 1:41, 11:37, 21:32; **29,** 7:28, 17:23.

These times assume that the spot will be centered at System II longitude 230°. It will transit 1⅔ minutes earlier for each degree less than 230°, and 1⅔ minutes later for each degree greater than 230°. Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting.

A light blue or green filter slightly helps the contrast and visibility of Jupiter's reddish and brownish markings. ✦

Phenomena of Jupiter's Moons, February 2016

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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Courtesy IMCCE / Paris Observatory.

A New Angle on Crisium

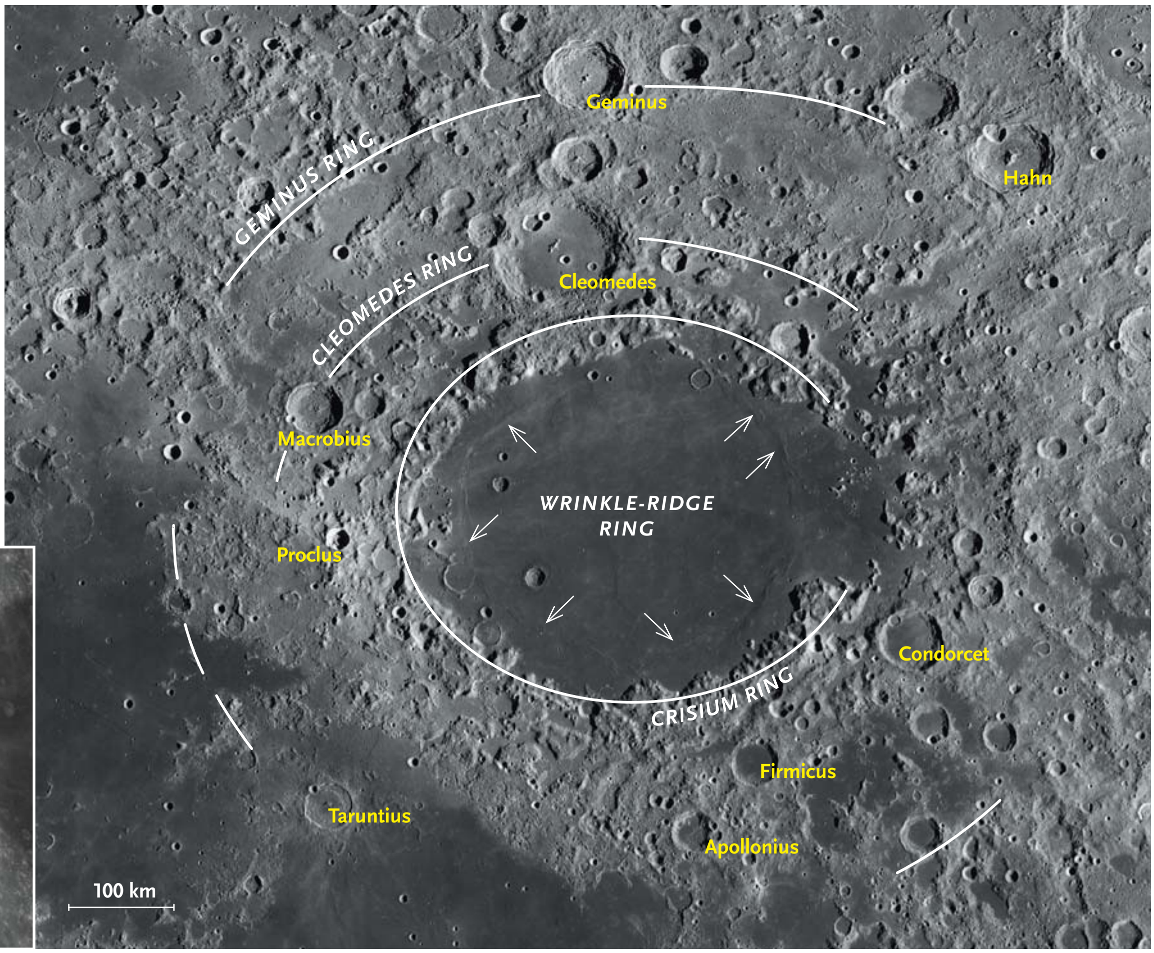
How did the distinct oval on the Moon's eastern limb come to exist?

In the decades before we accepted the impact origin of lunar craters, some researchers interpreted their circular shapes as a telling argument *against* impacts. Why so? Since incoming projectiles almost certainly come from all directions, they reasoned, some craters should have *elliptical* shapes. The error of this reasoning is that the energy of impacts is so great that they're effectively point-source explosions, and these produce circular craters.

But many impacts must occur from projectiles coming in obliquely — in fact, 45° should be the most common impact angle. In order to investigate how these oblique impacts affect crater shapes, Apollo-era scientists conducted a set of experiments at a special facility at NASA's Ames Research Center in California. Using a "vertical gun" that could shoot small projectiles extremely fast — up to 7 kilometers (4½ miles) per second — the experiments could duplicate the collision of a cosmic fragment with the Moon.

The researchers found that even at impact angles of 30° to 40° above horizontal, the high-energy impacts made circular craters. However, at impact angles shallower than about 25°, the resulting crater was still circular — but its ejecta did not spread evenly all around. Instead, it became concentrated in the downrange direction. The most characteristic feature was a "zone of avoidance" — an area with no rays — in the direction from which the projectile came.

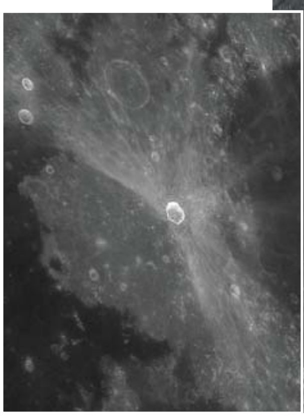
Proclus is the most conspicuous example of a lunar crater formed by an oblique impact, and the zone of



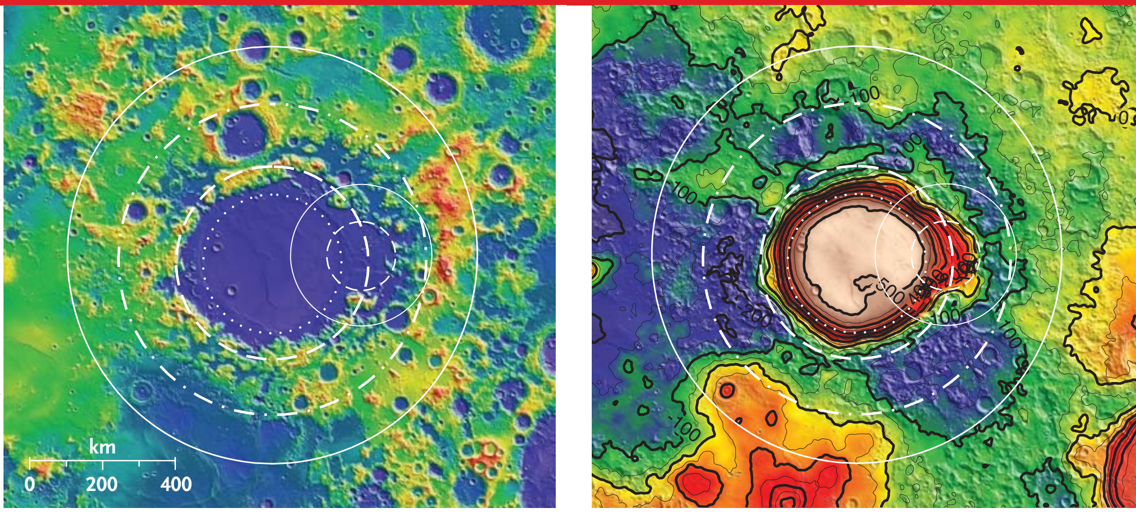
NASA / LUNAR RECONNAISSANCE ORBITER

Right: Mare Crisium, situated near the Moon's eastern limb, has a distinctly elongated shape. Lunar geologists have identified several segments of the original basin's multiple rings.

Below: Just to Mare Crisium's west is Proclus, a fresh, 27-km-wide crater. The obvious gap in its rays implies that the impacting object came in at a low angle from the west (lower left).



BOB PILZ



SCIENCE ADVANCES / G. NEUMANN ET AL. (LEFT: NASA / LRO; RIGHT: NASA / GRAIL)

Concentric white circles identify the proposed basin rings of Crisium and the proposed "Crisium East" to its immediate right. The left map depicts elevation (red is 7 km higher than the darkest blue), and the right map shows gravity enhancements (red and white indicate buried mass concentrations).

avoidance in its rays clearly shows during full Moon.

If some craters formed by projectiles striking obliquely, then some giant impact basins probably did as well. In 1992 Robert Wichman and Peter Schultz (Brown University) proposed that a projectile coming from relatively low in the west excavated the Crisium basin. But it happened so far in the past, before about 3.9 billion years ago, that not enough ejecta remains recognizable today to define a zone of avoidance. Instead, Wichman and Schultz noticed that **Mare Crisium**, when looked at from above, has an oval shape. The lava plains filling the basin stretch about 575 km (360 miles) from east to west but only about 430 km (270 miles) from north to south. They concluded that the projectile likely struck at a low enough angle to elongate the basin in the east-west direction.

This has been the generally accepted understanding for more than 20 years, but new data from NASA's Gravity Recovery and Interior Laboratory (GRAIL) spacecraft offer an alternative interpretation. Scientists led by Gregory Neumann (NASA Goddard Space Flight Center) propose that Crisium resulted from *two* impact events. They base this interpretation on the discovery that, for well-defined impact basins, the inner basin ring — often defined by a concentric pattern of mare ridges — is commonly the same diameter as a gravity "high" created by a mass concentration (or *mascon*) beneath the basin's center. Moreover, earlier studies showed that the main basin has roughly twice the diameter of this inner ring. If all this is true, Crisium's central mascon defines a circular basin with a diameter of about 1,080 km (670 miles). Its low, scarp-like rim is observable east and west of **Geminus** crater.

Neumann and his team interpret an extension of the mascon to the far eastern side of Mare Crisium as the gravity signature of a second, smaller basin with a diameter of 370 km that they dub "Crisium East." This proposed basin has no visible ring structures, but it accounts for the gap in the massive mountains that confine Crisium's mare flows everywhere except on the far eastern margin.

So lunar scientists now have two conflicting explanations for the elongation of Crisium: one oblique impact or two near-vertical impacts. You can conduct your own inquiry by using the QuickMap interactive mosaic (**http://is.gd/smi00w**) of Lunar Reconnaissance Orbiter images. Or use your own telescopic images, taken with different librations and angles of illumination, to search for the rings of the Crisium and putative Crisium East basins. You can use Photoshop to merge and reproject those images (*S&T:* Jan. 2005, p. 142) into the overhead perspective needed to recognize the true shapes.

Whichever interpretation ends up being correct, the Crisium region is rich both visually and scientifically. ✦

The Moon • February 2016

Phases

LAST QUARTER
February 1, 3:28 UT

NEW MOON
February 8, 14:39 UT

FIRST QUARTER
February 15, 7:46 UT

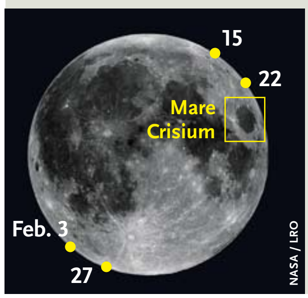
FULL MOON
February 22, 18:20 UT

Distances

Perigee	February 11, 3ʰ UT
226,401 miles	diam. 32′ 35″
Apogee	February 27, 3ʰ UT
251,893 miles	diam. 29′ 31″

Favorable Librations

Vallis Baade	February 3, 27
Hayn (crater)	February 15
Gauss (crater)	February 22



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

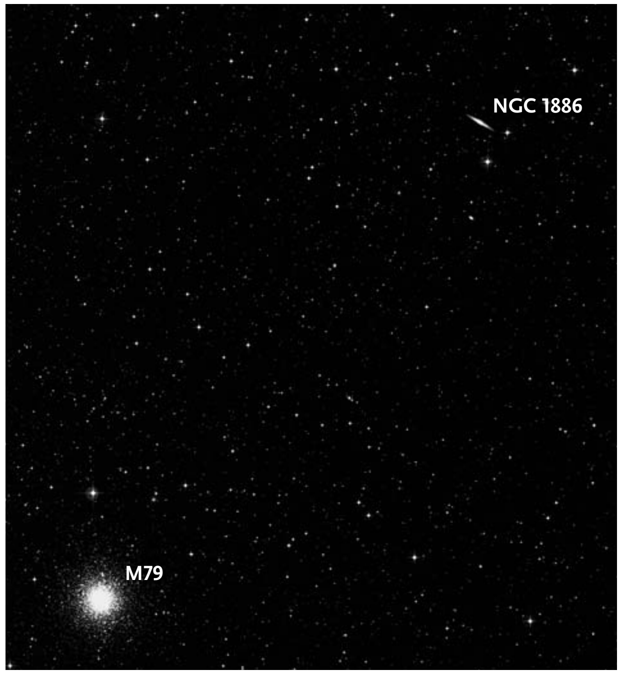
Lepus, a Hare-Raising Tale

Can there be too much of a good thing for winter observers?

Beneath Orion's feet we find the constellation Lepus, whose brightest stars shine timidly at 3rd magnitude. In a similarly shy manner, Lepus plays no prominent role in Greco-Roman mythology. But there is a cautionary tale attributed to Latin author Gaius Julius Hyginus, whose life spanned years from BC to AD on our calendar. The story tells of a young man, enamored with hares, who brought a pregnant one to the Greek island Leros. When the leverets were born, many of the islanders were also taken with the creatures and began raising hares themselves. It wasn't long before Leros was teeming with hares. Their destruction of the island's crops was so severe that famine ensued. With much effort, the inhabitants finally drove the hares from their island, then placed an image of a hare among the stars as a warning against acquiring too much of good thing.

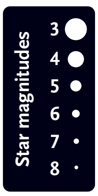
The best-known deep-sky wonder in Lepus is the globular cluster **Messier 79**. It sits 3.9° from Beta (β) Leporis, and an imaginary line from Alpha (α) through Beta points toward it. This makes M79 rather easy to find; in a moderately dark sky it can be seen in binoculars or a 50-mm finderscope. Through my 9×50 finder, it looks like an out-of-focus star with a faint halo. My 130-mm refractor at 102× shows a 4½′ globe with a sparsely populated halo and a very dense, bright, 1½′ core. The halo is well-resolved into stars, with a relatively bright one buttoning down its northern edge. The cluster's interior shows partial resolution almost to its center. M79 is very pretty in my 10-inch reflector at 220×. This glittering throng of suns grows steeply brighter toward the center, while its outer reaches sport several radial arms of stars. Brighter stars adorn the halo's outskirts, mostly running northwest through east to south. M79 displays fairly distinct levels of crowding. The sparse halo spans about 5′, the inner halo is about half that diameter, and the very dense inner core is about 1′ with star specks tumbled across a blazing backdrop.

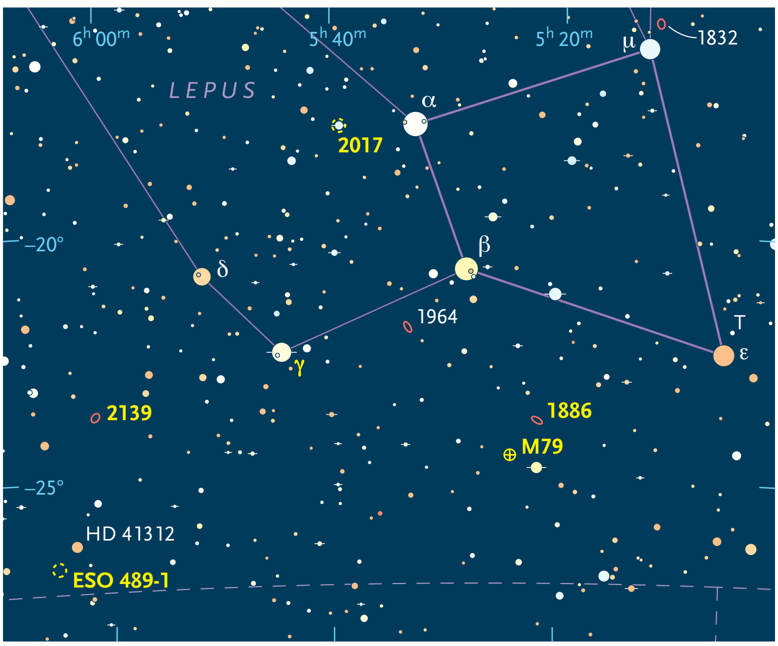
The 120,000 stars of M79 dwell 42,000 light-years away from us. Some sources claim that M79 is part of the Canis Major Dwarf Galaxy, which is being cannibalized by our Milky Way, but it's by no means certain that the CMa Dwarf even exists. Other researchers consider it likely that the overdensity of stars taken for the dwarf is simply a feature of the Milky Way's galactic warp or spiral structure.



POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

Look for NGC 1886 about 54′ northwest of M79. This slim edge-on galaxy is a tough target, particularly in suburban skies, but a careful star-hop and practiced averted vision will help.





Always fond of flat galaxies, I sought out nearby **NGC 1886**, a miniature version of the Needle Galaxy (NGC 4565 in Coma Berenices). Look for it 54′ northwest of M79 and east of an 11′-long line of stars, magnitudes 9.3 to 10.0. If you follow the line from southeast to northwest, you'll see the galaxy sitting beside the second star in the line. Through my 10-inch scope at 166×, NGC 1886 is a wispy streak of light tipped east-northeast. It appears quite faint and is best seen with averted vision, so I had no hope of spotting the dark lane that runs its length. I suspect that would take a very large telescope. Is a view of the dark lane beyond reach with even the largest scopes of amateur skygazers? Tell me if you snare it.

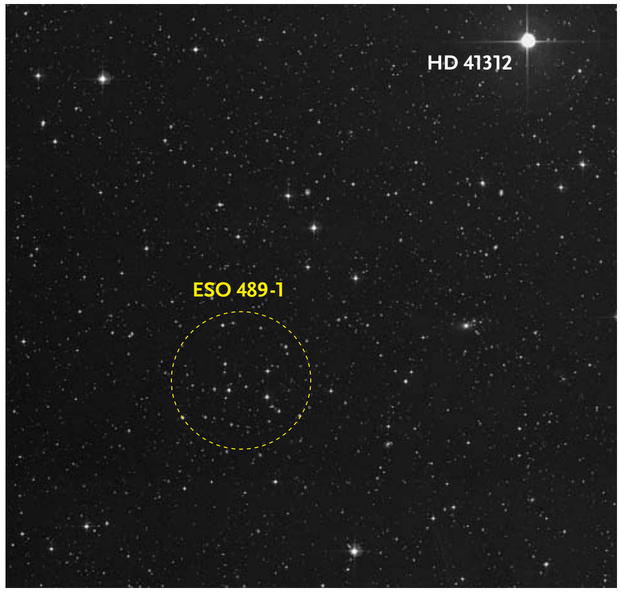
Tucked in the southeastern corner of Lepus, **ESO 489-1** is a lovely collection of stars that may be an open cluster remnant, the relic of a cluster whose stars have mostly dispersed. Such groups are depleted in low-mass stars but possess a comparatively high fraction of stable multiple systems. ESO 489-1 is thought to be about 3,200 light-years distant and roughly 700 million years old.

ESO 489-1 is parked 36′ southeast of the yellow-orange, 5.0-magnitude star HD 41312 (SAO 171180). In my 10-inch reflector at 44×, it's an easily noticed group of stars, 10th magnitude and fainter. The four brightest form a 3.3′ × 2′ parallelogram at the cluster's center. Viewed at 90×, about 20 stars join the parallelogram, many in raggedy chains spanning 10′.

An imaginary line drawn from Beta to Gamma (γ) Leporis and then extended the same distance will take us to our next target, the spiral galaxy **NGC 2139**. My 10-inch scope at 44× merely shows a small, round smudge, a bit brighter toward the center, bracketed by a 10th-magnitude star south and a star pair north-northwest, magnitudes 11 and 12½. At 118× the galaxy appears mottled and slightly oval. It spans about 1½′ and embraces a brighter core and stellar nucleus. There's a dim star near NGC 2139's northern edge, and two extremely faint stars are intermittently visible at its western flank.

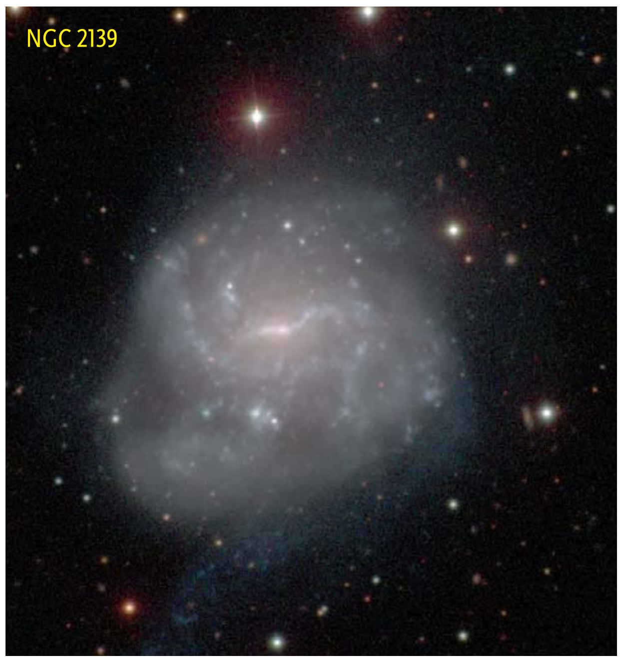
NGC 2139 looks positively fluffy in deep images. It's a late-type spiral, which means that it has fleecy arms and a small core. NGC 2139 bears distorted features that could be evidence of a merger with another galaxy some tens of millions of years ago. The event may have also sparked formation of the large star cluster, perhaps 800 thousand solar masses, that's slightly offset from the galaxy's center. This remarkable galaxy is roughly 95 million light-years distant.

Gamma (γ) Leporis, one of the pointer stars we used to locate NGC 2139, is a colorful double star that's easily split at low power. Its components are widely separated even at 17× through my 105-mm refractor. The orange, 6.3-magnitude companion hovers north of its yellow-white, 3.6-magnitude primary. The noted 19th-century double-star observers William H. Smyth and Thomas William Webb described the secondary as pale green and garnet, respectively. In her book *Double Stars for Small Telescopes,* Sissy Haas enthusiastically describes this showcase pair: "Fantastic colors — this is a bright



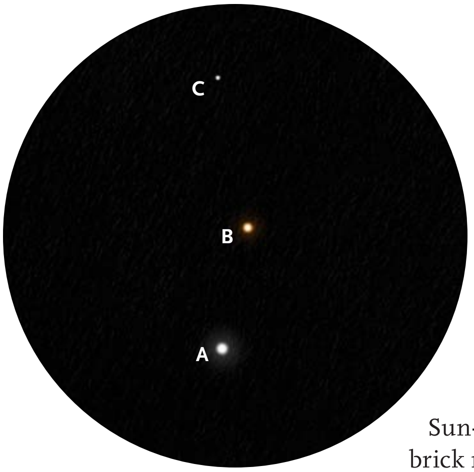
POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

ESO 489-1, a possible open cluster remnant, twinkles southeast of HD 41312. Use the yellow-orange *K*3III star, HD 41312, as a waymark.



CARNEGIE-IRVINE GALAXY SURVEY (LUIS C. HO / AARON J. BARTH / SONG HUANG / ZHAO-YU LI / CHIEN Y. PENG)

The "fluffy" structure of NGC 2139 will show as a circular smudge of light, slightly brighter at the core, in your eyepiece.



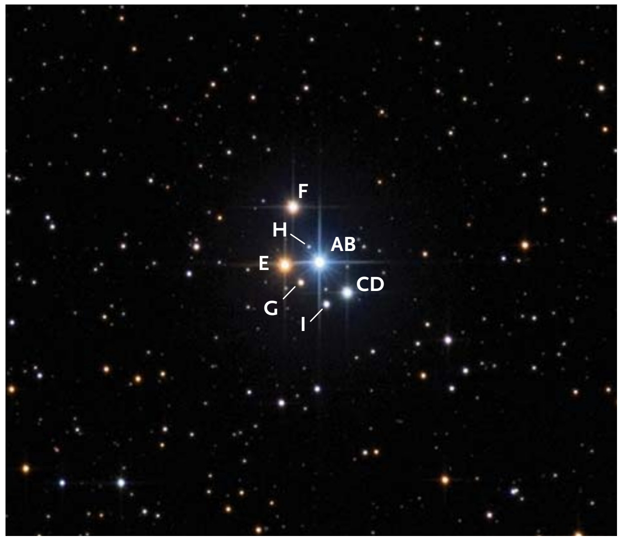
Jeremy Perez sketched the A, B, and C components of Gamma Leporis as viewed through his 6-inch Newtonian reflector at 240×. The colorful components split easily even in smaller scopes.

Sun-yellow star with a brick red companion; both colors are seen vividly" (see also *S&T:* Nov. 2015, p. 28). What hues do you see?

The suns of Gamma Leporis have kept pace with one another as they moved through space over the last two centuries, indicating that they are probably true companions. Their 95.0″ apparent separation shows that their true separation is at least 848 times the Earth-Sun distance. Taking the stars' masses into account, this implies a minimum orbital period of 17,000 years. Gamma is a near neighbor to our Sun, only 29 light-years away from us.

Our next object is **NGC 2017**, which has been variously called an open cluster, a possible open-cluster remnant, an asterism, and a multiple star. Sources claiming that it's a known cluster also mention infrared and radio emission from the object, which makes it clear that this is an identification error. The mistake springs from a mistyped title in the SAO/NASA Astrophysics Data System, an internet portal for journal papers in astronomy and physics (**http://ads.harvard.edu/**). The actual paper is about NGC 2071, a star-forming region in Orion. NGC 2017 is listed as a multiple star with nine components in the online Washington Double Star Catalog (WDS), but physical relationships among the stars are undetermined.

Whatever its true nature, NGC 2017 is a pretty find through a telescope. When John Herschel discovered it in 1835, he sketched the aggregation and called it "an elegant group of 6 large stars." My 105-mm refractor reveals four stars at 17×, five stars at 47×, and six stars at 87×. They're arranged in two nearly parallel lines of three stars each, running southeast-northwest. Starting at the long line's northern end, the stars gleam yellow-white, blue-white, and white. The northernmost star in the short line burns distinctly orange, but the others are too faint to judge. Three WDS stars weren't noted by Herschel or me: close companions to the group's southernmost star and its brightest star, as well as a dim star 41″ northwest of the brightest star. The entire collection would fit within a petite 4.0′ × 2.1′ oval. ✦



Sergio Eguivar took this LRGB image of the multiple-star system NGC 2017 under rural skies with a 6-inch Newtonian reflector.

Sights in the Southern Hare

Object	Type	Magnitude (v)	Size/Sep	RA	Declimation
Messier 79	Globular cluster	7.7	9.6′	05^h 24.2^m	–24° 31′
NGC 1886	Edge-on galaxy	12.7	3.1′ × 0.4′	05^h 21.8^m	–23° 49′
ESO 489-1	Cluster remnant?	9.2	11′	06^h 05.0^m	–26° 44′
NGC 2139	Flocculent galaxy	11.6	2.6′ × 1.9′	06^h 01.1^m	–23° 40′
γ Leporis	Double star	3.6, 6.3	95″	05^h 44.5^m	–22° 27′
NGC 2017	Star group	5.9	4.0′	05^h 39.3^m	–17° 51′

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.

Richard Jakiel

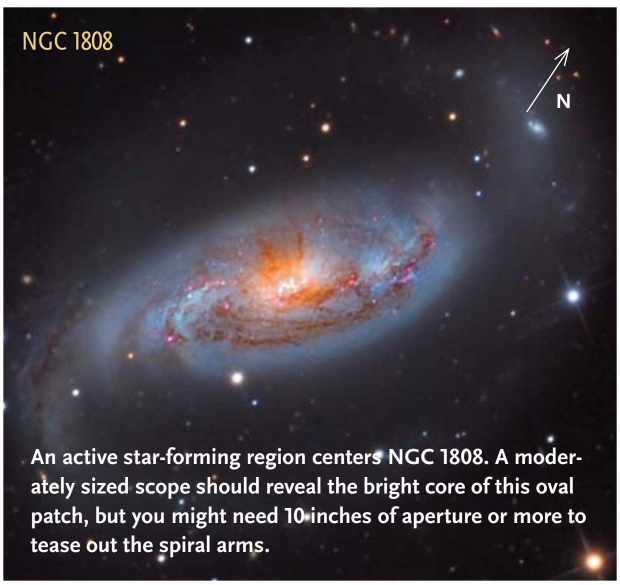
Hunting Beneath the Dog

Or, how to catch a galaxy in Canis Major, Lepus, and Columba.

When we think of observing near the winter Milky Way, what usually comes to mind is a myriad of splashy star clusters and bright nebulae. The average observer doesn't associate this part of the sky with galaxy hunting, yet even near the Milky Way's star clouds you can find many fine examples. You just need to know where to look!

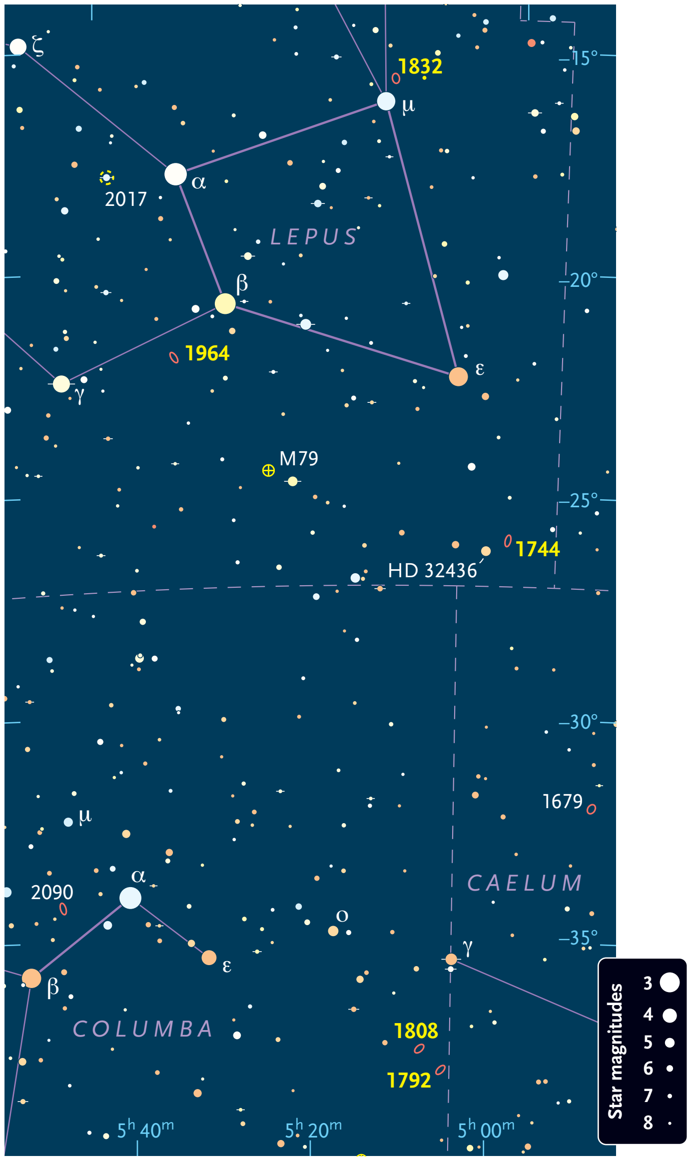
The region around and below Canis Major is a particularly good place to track down unfamiliar galaxies. There are many possible starting points for this survey, but let's go for a bright, pretty pair of 10th-magnitude spirals located in the southerly constellation of Columba. **NGC 1792** and **NGC 1808**, the largest members of a small galaxy group located about 35 million light-years from Earth, form a true dynamic pairing. You can find them by moving 2.5° due south of Gamma (γ) Caeli, or by a more leisurely southwest-trending star-hop from Omicron (o) Columbae. Both galaxies show evidence of past close encounters. NGC 1792 is an emission-line galaxy; its highly luminous far-infrared radiation can be attributed to galactic dust heated by the young stars in its disk. Visually, you may detect its small, bright core and patchy spiral arms. Slightly larger and brighter, NGC 1808 is a nice barred spiral with an active galactic nucleus (AGN). This is an attractive wide-field pairing, as the objects are separated by about ½° and show the same southwest-northeast orientation in the telescope.

Moving northward into Lepus, you'll encounter several nice spiral galaxies. About 4° south-southwest of Epsilon (ε) Leporis and only ½° west of 5th-magnitude HD 32436 floats **NGC 1744**, a large, low surface bright-



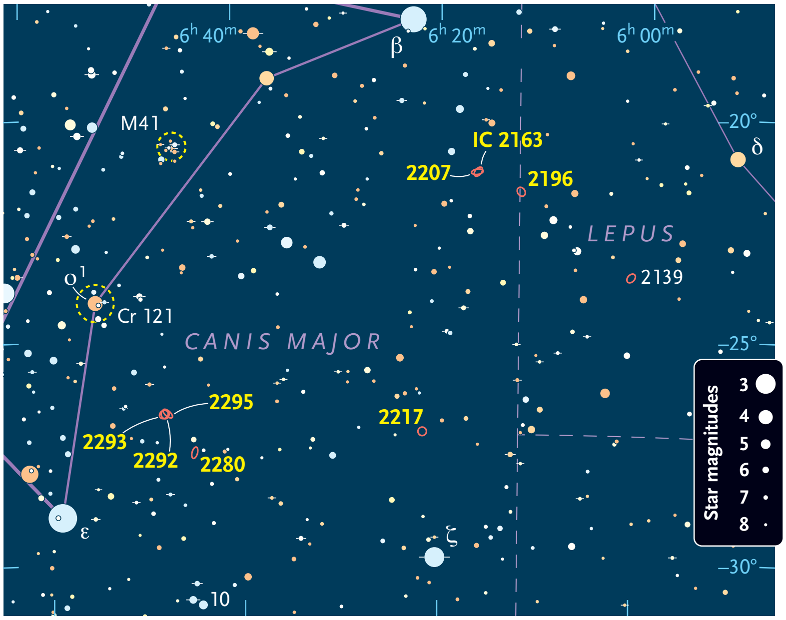
An active star-forming region centers NGC 1808. A moderately sized scope should reveal the bright core of this oval patch, but you might need 10 inches of aperture or more to tease out the spiral arms.

SSRO-SOUTH (STEVE MAZLIN / WARREN KELLER / JACK HARVEY / STEVE MENAKER)



ness (LSB) barred spiral. In my old 13.1-inch Dobsonian at 113×, it appears as a faint, diffuse 4′ × 2′ haze oriented north-south with a moderately elongated central bar.

In direct contrast, **NGC 1832** is a small, tightly wound barred spiral presented face-on. Star-hopping doesn't get much easier than this, as NGC 1832 lies only a ½° north-northwest of 3rd-magnitude Mu (μ) Leporis. In my 11-inch Schmidt-Cassegrain, it shows a bright outer halo measuring 2′ × 1.5′ surrounding a tiny stellar core. An 11th-magnitude field star lies just 1′ to the east, while a brighter 9th-magnitude star shines 5′ to the northeast.



Rounding out this Leporid selection is **NGC 1964**, a moderately tilted 10.7-magnitude spiral galaxy. It, too, is relatively easy to find, as it sits a bit south of the halfway point on an imaginary line drawn between the bright stars Beta (β) and Gamma Leporis, or 2° southeast of Beta. In my 11-inch scope at 113×, it's easily visible as an elongated 4′ × 2′ misty glow just to east of an acute triangle of 9th- to 11th-magnitude stars.

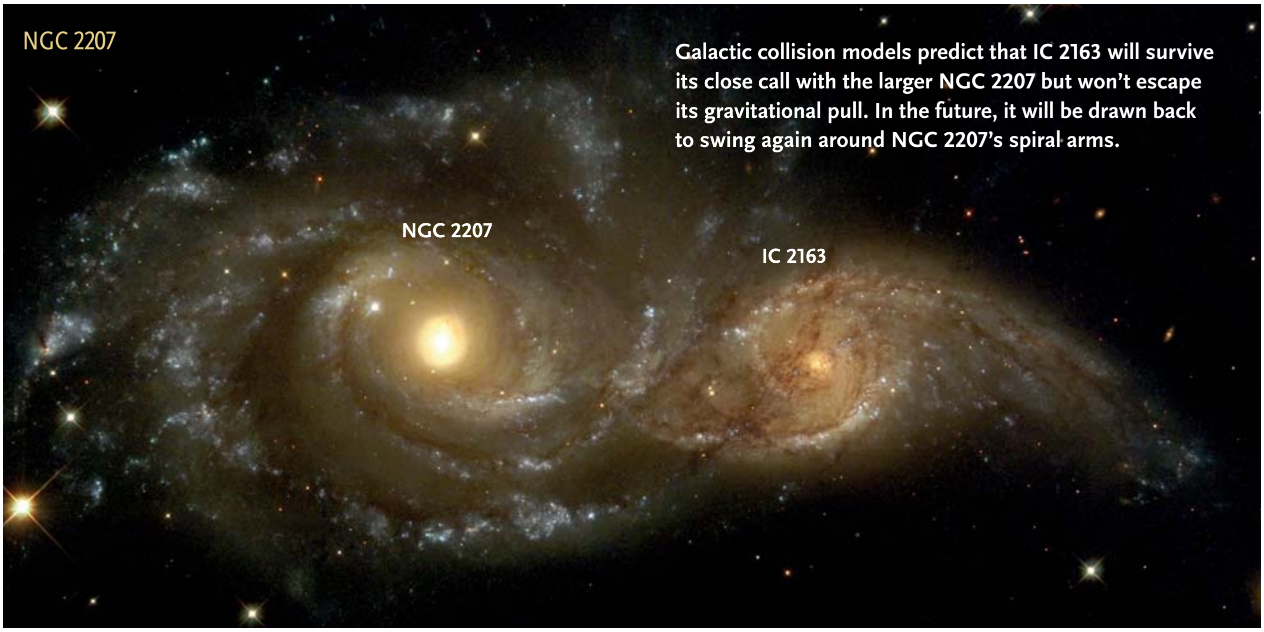
Not all the galaxies in this region are "obscure" or "off the beaten path." One duo in particular has been featured in NASA's Astronomy Picture of the Day (APOD) twice over the past decade. The face-on spirals **NGC 2207** and **IC 2163** form a beautiful interacting pair, their last grazing encounter only 40 million years ago. What really sets these galaxies apart is that, from our point of view, the larger system, NGC 2207, is superimposed on the smaller, IC 2163, a circumstance that has led to all sorts of interesting astrophysical investigations, such as the determination of the thickness of the spiral arms and the true opacity of the dust lanes. In a medium-sized scope, they form an uneven pairing elongated in

Galaxies in Canis Major, Lepus, and Columba

Object	Type	Surface Brightness	Mag(v)	Size	RA	Dec.	Notes
NGC 1744	SB(s)d	13.9	11.3	7.4′ × 3.5′	$05^h\ 00.0^m$	–26° 01′	LSB
NGC 1792	SB(rs)bc	12.6	9.9	5.5′ × 2.5′	$05^h\ 05.2^m$	–37° 59′	Emission-line
NGC 1808	SB(s)a pec	12.4	9.9	5.2′ × 2.3′	$05^h\ 07.7^m$	–37° 31′	Type 2 Seyfert
NGC 1832	SB(r)bc	12.4	11.3	2.5′ × 1.5′	$05^h\ 12.1^m$	–15° 41′	HSB
NGC 1964	SAB(s)b	13.1	10.8	5.0′ × 2.1′	$05^h\ 33.4^m$	–21° 57′	
NGC 2196	SA(rs)ab	13.1	11.1	3.0′ × 2.5′	$06^h\ 12.2^m$	–21° 48′	
NGC 2207	SAB(r)c pec	13.3	10.8	4.8′ × 2.3′	$06^h\ 16.4^m$	–21° 22′	Interacting w/IC 2163
IC 2163	SB(rs)c pec	12.4	11.7	3.0′ × 1.2′	$06^h\ 16.5^m$	–21° 22′	
NGC 2217	SB(rs)0/a	13.4	10.2	5.0′ × 4.5′	$06^h\ 21.7^m$	–27° 14′	
NGC 2280	SA(s)c	13.5	10.5	6.3′ × 2.8′	$06^h\ 44.8^m$	–27° 38′	
NGC 2295	Sab sp	13.1	12.7	2.4′ × 0.7′	$06^h\ 47.3^m$	–26° 44′	Triplet w/NGC 2292/3
NGC 2292	SAB pec	13.1	10.8	4.2′ × 2.3′	$06^h\ 47.6^m$	–26° 45′	Interacting w/2293
NGC 2293	SAB(s)0^+ pec	13.9	10.7	4.3′ × 3.0′	$06^h\ 47.7^m$	–26° 45′	

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

*Contributing Editor **Richard Jakiel** is an experienced observer and astrophotographer living in a suburb of Atlanta, Georgia.*



Galactic collision models predict that IC 2163 will survive its close call with the larger NGC 2207 but won't escape its gravitational pull. In the future, it will be drawn back to swing again around NGC 2207's spiral arms.

NASA / ESA / HUBBLE HERITAGE TEAM (STSCI)

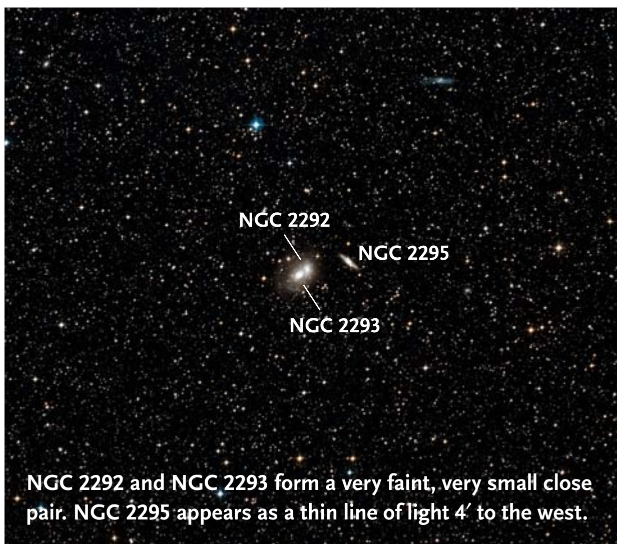
an east-west direction. NGC 2207 is distinctly larger, a 4′ × 2′ glow with a tiny stellar core. The smaller and fainter IC 2163 smudges farther to the east.

While in the area, why not star-hop 1° to the southwest to pick up **NGC 2196**? Small, oval, quite bright, and with a condensed core, it's a fine sight in most telescopes. Finding these three galaxies isn't all that hard: start at Delta (δ) Leporis and follow an approximately 4° east-west chain of 6th- and 7th-magnitude stars until the galaxies float into view of your wide-field eyepiece.

Even deeper in the rich star fields of Canis Major, and around 3° northwest of the brilliant blue giant Epsilon (ε) Canis Majoris (Adhara), is a tight triplet of galaxies. Sometimes designated as VV 178, the trio consists of **NGC 2292** and **NGC 2293**, a close pair of interacting S0/E systems, and the edge-on spiral **NGC 2295**, which sits a mere 5′ to the west. All three objects will easily fit in the field of view of a medium- to high-powered eyepiece of a 10- to 12-inch scope. NGC 2292 and 2293 comprise a double galaxy system with each member nearly identical in size, shape, and surface brightness, with the former perhaps the more condensed of the two systems. In contrast, NGC 2295 is a delicate 1.5′ × 0.5′ glow framed by a pair of 13th-magnitude stars to the north and south. The real challenge is spotting the razor-thin equatorial dust lane with a large telescope — can you see it?

A quick star-hop takes you to a final two galaxies. About 1° to the southwest of the triplet is the diffuse inclined spiral **NGC 2280**. In my 17-inch f/4.5 at 163×, it's visible as a faint 3′ × 1.5′ wash of nebulosity set in an asterism of bright field stars. The face-on barred spiral **NGC 2217** lies almost 3° due north of the wide double star Zeta (ζ) Canis Majoris. The inner portion of the galaxy consists of a prominent bar and tightly wound arms surrounded by a large faint "ring." You shouldn't have too much difficulty picking up the core and elongated bar with a moderately sized telescope; a larger instrument, under good, dark skies, may net you the delicate outer ring.

There are a surprising number of galaxies found in this stretch of sky, and this survey covers only some of the brighter members. If you want a change of pace from splashy winter nebulae and clusters, spend some time checking out this neglected realm of galaxies. ✦



NGC 2292 and NGC 2293 form a very faint, very small close pair. NGC 2295 appears as a thin line of light 4′ to the west.

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

 Jerry Lodriguss

Nikon's Astro Camera

A giant in the photography industry makes its first foray into the astronomy market.

The Nikon D810a DSLR camera

U.S. price: $3,796.95 (body only)

ALL PHOTOS BY THE AUTHOR

CAN I GET A HALLELUJAH! Nikon has finally come out with a true astrophotography camera that isn't plagued by the quirks of past Nikon DSLRs when used for astro-imaging.

The D810a was announced in February of 2015, almost ten years after Canon announced its 20Da, the first dedicated astrophotography DSLR camera. It took Nikon quite a while, but they pulled no punches with a camera that the company claims has "the best image quality in the history of Nikon digital SLR cameras."

Nightscape photographers will love the camera's high-ISO performance, built-in intervalometer, time-lapse functions, electronic front curtain shutter, and "virtual horizon" settings. Deep-sky imagers will be impressed with the camera's low noise, hydrogen-alpha (Hα) sensitivity, and excellent dynamic range.

But be prepared — this is a complicated camera. The user's manual alone is 501 pages, and the camera has 27 buttons, three dials, and one multi-function selector. There are six main menus with 140 submenus, many of which also have multiple selections.

Specifications

The D810a is constructed around a full-frame "FX format" 36.3-megapixel, 7360 × 4912-pixel CMOS array with 4.8-micron-square pixels. It records uncompressed 14-bit files in Nikon's proprietary NEF format that are about 75 megabytes when recorded, and 207 MB when opened in image-processing software and converted to 16-bit depth.

The high image quality of the D810a is attributable to the excellent low-noise performance of its sensor, and its modified long-wavelength filter that passes four times more hydrogen-alpha light than a regular D810. This is great for recording those beautiful red emission nebulae.

The camera's ISO settings range from 200 to 12,800, and Nikon's optical low-pass anti-aliasing blurring filter

WHAT WE LIKE:

- High-resolution, full-frame sensor with good Hα sensitivity
- Electronic front-curtain shutter
- Built-in intervalometer
- M* mode long-exposure settings

WHAT WE DON'T LIKE:

- Non-articulated LCD screen
- Full-frame sensor's optical requirements

Nikon's D810a full-frame DSLR is the company's first camera designed specifically for astrophotography. Its 36-megapixel sensor includes a modified long-wavelength filter that passes approximately 4 times as much hydrogen-alpha light as Nikon's other DSLR cameras.

has been completely removed. The black point in raw images is slightly clipped, though this shouldn't affect your results whether you intend to use calibration frames or not.

Like most DSLRs today, the camera includes a Live View (Lv) function to help framing and focusing. The feed can be viewed on the camera's LCD screen at 1:1 pixel resolution and can be enlarged up to 23×.

The D810a connects to your computer via a USB 3.0 interface and can also accept Nikon's proprietary 10-Pin shutter release cables. It also includes a special M* exposure mode to access advanced shutter speeds of 4, 5, 8, 10, 15, 20, 30, 60, 120, 180, 240, 300, 600, and 900 seconds, as well as a Bulb setting for even longer exposures.

The electronic front-curtain shutter (d5 in custom settings) eliminates vibrations from mirror slap and the mechanical shutter opening. It's available only in Mirror Lock Up mode (Mup) and must be used with M or M* exposure mode. You can also program an exposure delay of 1, 2, or 3 seconds to ensure vibration-free images.

One great thing about this and other Nikon DSLR cameras is that they continue to use the standard Nikon F mounting bayonet in use since 1959, allowing photographers to use older, manual-focus lenses. I used my old Nikkor AIS manual-focus lenses with the D810a.

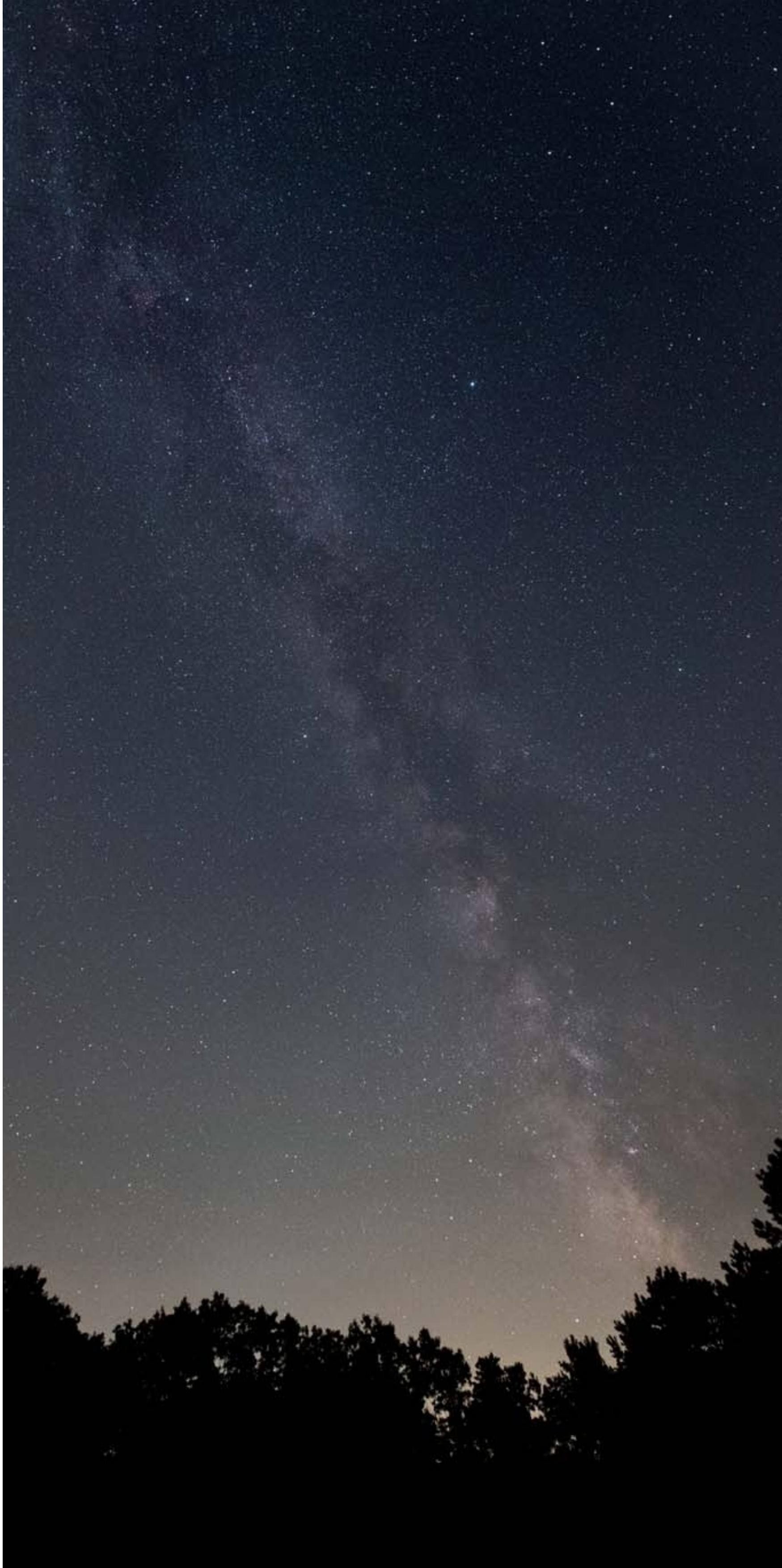
Collecting Photons

The first thing you'll need when shooting with the D810a is a high-capacity memory card or two, because they fill up quick at 75 MB per raw image.

Battery life in the D810a was impressive. Its EN-EL15 battery lasted 5.16 hours in continuous use at 78°F. If you hope to use it throughout a long, cold winter night, plan on investing in a few extra batteries or on using an AC or DC power supply.

When shooting in the M* long-exposure mode,

Menu and control settings in the D810a feature many settings useful for astrophotography, including Interval timer shooting, Self-timer, and High ISO NR (noise reduction).



This image displays the Milky Way spanning from Cepheus to Sagittarius in the large field of view of the AF-S Nikkor 14-24 mm f/2.8G ED lens on the Nikon D810a. The combination covers 104.25 × 81.2° at 14 mm. This single 15-second exposure at f/2.8, ISO 6400 shows the lens is well corrected even when used wide open at f/2.8 on full-frame sensors.

the D810a turns off all exposure indicators and lights. Though helpful, this can make it a bit tricky to see where you stand during an exposure.

The camera includes a helpful built-in intervalometer. This feature allows you to program the length and number of exposures you'll take in a sequence without needing an external device, as is usually required with other cameras. The secret to using it is to set the interval to the length of the exposure *plus* the length of time you want in between exposures. And while you can't stop an exposure once it's started without powering off the camera, you can stop the intervalometer when it is between exposures by pressing the OK button.

The D810a offers long-exposure noise reduction. This is a common feature in which the camera takes an additional exposure of the same length as the previous image with the shutter closed, then subtracts that image from the last to remove dark current that adds electronic noise to an image. It's best to disable this function, as it doubles the time needed for exposures and really isn't necessary unless you are shooting at extremely high ambient temperatures. An alternative is to shoot these dark frames later and subtract them from your images manually with image-processing software.

Left: **This enlargement shows hot pixels and color noise from a 30-minute exposure at ISO 200 at 65°F ambient temperature.** ***Right:*** **The noise and splotches are completely removed with the special astro noise-reduction function in *Nikon NX-D v1.2.1* image-processing software.**

The D810a reveals its great color performance on nebulae in this roughly 1½-hour photo of the Veil Nebula in Cygnus. The author captured the shot through an Astro-Physics 130EDFGT refractor working at f/4.7, and the individual images were aligned and stacked using *ImagesPlus*.

One issue I had with the D810a was its lack of an articulated LCD screen that you can adjust for convenient viewing when the camera is attached to your telescope. Though not a deal-breaker, it is a neck strainer, especially if you are using a refractor or catadioptric telescope pointed anywhere higher than about 15° above the horizon — in other words, for most every astrophoto.

Like Nikon's other DSLR cameras, the D810a Lv mode image defaults to a correct brightness display, no matter what exposure the camera is set to. Users can enable an exposure simulation option in Lv mode in which the brightness of the display changes as you change the exposure. Press the OK button on the back of the camera while in Lv mode to enable this feature.

While shooting, be sure to save RAW images in 14-bit NEF lossless file format. The camera offers many other options such as a RAW Small format with one quarter the pixel count. This may seem attractive but should be avoided as it is not a true RAW file, and it is not actual pixel binning like that done in an astronomical CCD camera — this setting simply down-samples your image after the fact, rather than grouping pixels to make them act as a larger, more light-sensitive pixel unit.

Unlike some other DSLR models with Lv mode, the D810a isn't useful for high-resolution planetary imaging, because the Lv mode video stream is heavily compressed.

Color Balance

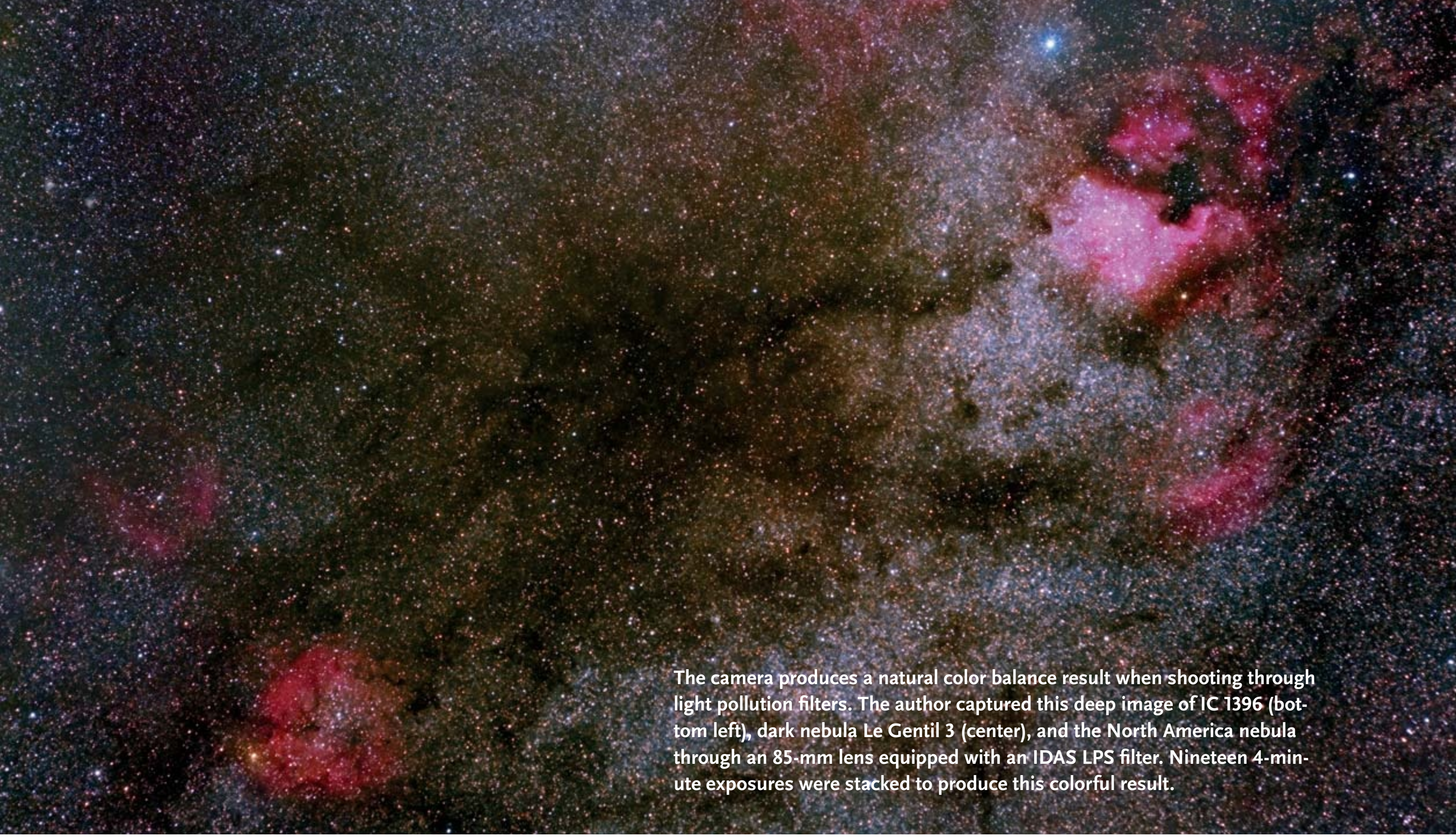
Nikon states that the D810a is not recommended for general daylight photography. But in practice, the camera produces very good color for normal daytime subjects, such as family snapshots.

Like most DSLRs, the camera's automatic white-balance settings produce inconsistent results with astronomical subjects. Choose "Direct Sunlight" or, better yet, program your own custom white-balance settings to get the best results when shooting nighttime targets.

Once you start shooting with the Nikon D810a, the camera's extended Hα sensitivity immediately becomes apparent. Even short exposures of 15 seconds or so reveal the large, red nebulous regions in Cygnus with untracked shots using the AF-S Nikkor 14-24mm f/2.8G ED lens supplied with our test camera for this review.

Nightscapes and Time-Lapse Imaging

As mentioned earlier, the D810a has a number of features that are extremely useful for astrophotographers, particularly those who specialize in "nightscape" photography. In addition to the built-in intervalometer, the camera includes an electronic "virtual horizon" feature that helps you quickly level your camera and the subject in the picture frame. The intervalometer allows for fixed-



The camera produces a natural color balance result when shooting through light pollution filters. The author captured this deep image of IC 1396 (bottom left), dark nebula Le Gentil 3 (center), and the North America nebula through an 85-mm lens equipped with an IDAS LPS filter. Nineteen 4-minute exposures were stacked to produce this colorful result.

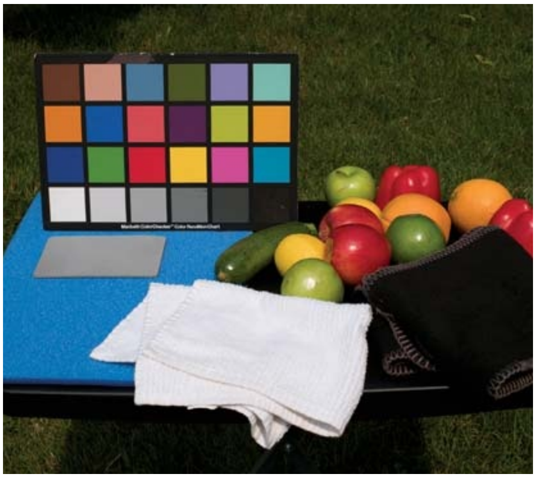
tripod star trails and time-lapse sequences, as well as multiple individual shots.

Using the continuous high (CH) or continuous low (CL) modes, you can shoot an unlimited number of images continuously with a shutter speed of 4 seconds or longer, at least until you fill the memory card or exhaust the battery. Instead of a 999-frame limit found in most DSLRs, the D810a can record up to 9,999 frames using the interval timer function, permitting you to shoot sequences you can later assemble into time-lapse movies.

The time-lapse feature is independent of the intervalometer and creates compressed movies. It includes a useful smoothing function that attempts to adjust the exposure variations between frames that can result in brightness flickering. Unfortunately, the feature doesn't save the individual image frames. Serious time-lapse photographers should stick with the intervalometer function and save RAW files for more control in processing and assembly of the final movie.

Through a Telescope

As suggested by my tests with camera lenses, the D810a is excellent for deep-sky astrophotography through a telescope. The camera has extremely low thermal signal compared to other DSLRs. I shot a single 30-minute exposure at ISO 200 with an ambient air temperature of 65°F and was amazed at the large dynamic range and how well controlled the noise was. The resulting image displayed no banding or pattern noise.



Left: **Daylight performance with the D810a is very good despite Nikon's disclaimer.**

Below: **The D810a full-frame sensor will reveal problems that aren't as apparent in cameras with smaller sensors. Vignetting and mirror box shadowing are exaggerated in processing to show these effects in this image shot with an Astro-Physics 130EDFGT triplet apochromatic refractor at *f*/4.7 with AP's original 0.75x focal reducer. Flat field calibration frames can correct these illumination issues.**

This single 8-minute exposure through an old Nikkor 180mm f/2.8 ED AIS lens operating at f/3.5 shows off the camera's performance from a very dark site. This busy area of the Milky Way includes (from top) Sharpless 2-54, M16, M17, and Sharpless 2-37 at bottom right.

Software Compatibility

The camera comes with *Nikon Capture NX-D* 1.2.1 image-processing software, which includes a good noise-reduction feature that removes hot pixels and color noise blotches from your long exposures. While this program has some excellent camera-specific features that reduce vignetting and some chromatic aberration in camera lenses in its extensive database, it's written for conventional photography and doesn't include other astronomy-specific features such as alignment or image stacking.

Nikon's optional *Camera Control Pro 2* software will run the D810a from your PC or Mac, but keep in mind the software will not interface with your telescope mount, and costs an additional $150.

For serious astrophotography, consider purchasing a third-party control program that includes many helpful features to get the most out of your time with the D810a. The proprietors of *BackyardNIKON* (**otelescope.com**) and *ImagesPlus* (**mlunsold.com**) kindly supplied me with working beta versions of their camera-control programs to run the D810a during my long-exposure deep-sky imaging sessions. Both programs worked well. I calibrated, aligned, stacked, and processed all of the deep-sky photos accompanying this review using *ImagesPlus*.

Summing It Up

It is great to see Nikon enter the astrophotography market with an excellent, well-executed, high-end, professional-model, full-frame DSLR camera body.

Those shooting from very dark sites will really appreciate the low read noise of the D810a. Its low thermal signal combined with the astro noise reduction feature in the Nikon software work so well that you'll hardly need to shoot dark frames anymore!

This sensor's large format and high resolution can produce outstanding results if you have an optical system capable of taking advantage of it — scopes paired with the D810a should be top of the line and able to produce pinpoint stellar images across a 24×36-mm field. This is an instance of "be careful what you wish for," because the D810a can reveal optical problems you didn't know you had and cause additional expenses you might not have expected both in terms of memory and processing requirements, as well as the need for top-notch, well-corrected optics.

The bottom line is that the D810a is an outstanding camera for long-exposure deep-sky imaging, and it is undoubtedly going to be the go-to camera for nightscape and time-lapse photography.

It's nice to see Nikon finally focus on astrophotography and give Canon some real competition, which can only be good for DSLR imagers everywhere. ✦

Jerry Lodriguss specializes in astrophotography with DSLR cameras. See his latest work at ***www.astropix.com****.*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▼ **MEGA REDUCER** Astro-Physics announces the Quad Telecompressor Corrector ($1,520) for its 130 StarFire GTX and EDFGT telescopes. This large-format 0.72× reducer shortens the focal length of the 130-mm f/6.3 StarFire GTX from 819 to 598 mm (f/4.6), allowing you to record wider expanses of the sky. The four-element Quad TCC fits into the scope's 3.5-inch focuser, producing pinpoint stars across the entire field of a 35-mm sensor, and also works with Telescope Engineering Company (TEC) refractors with additional spacers offered by Astro-Physics.

Astro-Physics
11250 Forest Hills Rd.,
Machesney Park, IL 61115
815-282-1513; astro-physics.com

▲ **BUDGET RITCHEY** Industry newcomer Third Planet Optics rolls out a series of Ritchey-Chrétien astrographs for the budget-minded astrophotographer. The largest of the series, the TPO 16" f/8 Ritchey-Chrétien Truss Tube OTA (starting at $6,995), is built to resolve tiny features in your deep-sky images. This OTA is manufactured from CNC-machined aluminum and carbon-fiber truss tubes to ensure collimation stability when pointed anywhere in the sky. Its quartz optics utilize 99% reflective dialectric coatings and will reach thermal equilibrium quickly with the aid of three cooling fans. The telescope comes with a 3-inch dual-speed linear bearing Crayford-style focuser with a generous back focus distance of 400-mm. See the OPT website for additional models and options.

Third Planet Optics
Available from OPT Telescopes
918 Mission Ave., Oceanside, CA 92054
800-483-6287; optcorp.com

3D EYEPIECES Denkmeier unveils its most unique eyepiece set, the L-O-A 21 ($599 per pair). The L-O-A (Lederman-Optical-Array) is a patent-pending design that simulates a 3D view in telescopes equipped with binoviewers. Users simply rotate the "active" eyepiece when aimed at a deep-sky target until the subject appears to be floating among the stars in the field. Six levels of 3D depth are possible depending on the settings used. Each L-O-A 21-mm eyepiece has a generous 65° apparent field and comes in bolt-style eyepiece container. See manufacturer's website for additional details.

Denkmeier
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866-340-4578; deepskybinoviewer.com

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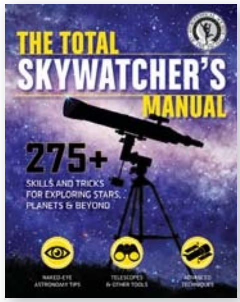
A Fresh Approach

The Total Skywatcher's Manual

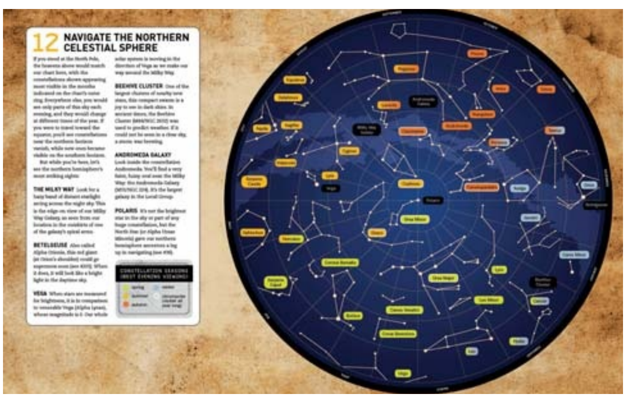
Astronomical Society of the Pacific
Weldon Owen, 2015
272 pages, ISBN 9781616288716, $29.00, flexicover.



DISSECT A STAR. Locate the celestial equator. Find the right field of view. These are just a few of the activities described in *The Total Skywatcher's Manual: 275+ Skills and Tricks for Exploring Stars, Planets & Beyond* by Linda Shore, David Prosper, and Vivian White of the Astronomical Society of the Pacific (ASP). The largest astronomy education organization in the world, the ASP has long served as a source of outreach material and inspiration, and the recent publication of *The Total Skywatcher's Manual* demonstrates why. The society's belief in hands-on education, informed by an obviously deep expertise, has produced an unusually attractive, informative guide to the hobby.

The book's "skills and tricks," ranging in level from the elementary to expert and accompanied by thoughtful diagrams and illustrations, are broken across three main subject headings: "Naked-Eye Astronomy Tips," "Telescopes & Other Tools," and "Advanced Techniques." Verbs form the basis of individual skill descriptions, their headings phrased as imperatives: *observe* planets in retrograde; *nab* the Double Cluster; *assemble* a star clock; *listen* to a meteor shower . . . it's almost impossible to sit still and read when you're constantly commanded to action.

Although you can dip into the material at random, beginners will want to read this book from front to back. The authors introduce activities roughly in order of difficulty, moving from naked-eye through binocular and telescopic observing to citizen science and professional astronomy pursuits. Each numbered section builds on knowledge gained from the previous one. Action 94, "Demystify the Auroras' Colors," for example, is followed by three additional sections on aurorae. From there, the authors slide into a discussion of Earth's atmosphere and other observations related to atmospherics ("Catch a Glimpse of Glories," "Spot a Solar or Lunar Halo").



For the most part, the book unfolds in an organic manner, but three topics — Planets, Star Charts, and Skyhopping — stand out as two-page spreads at regular intervals. Planet sections ("Meet Mars," "Meet Venus") highlight the members of our solar system, but also signal a topic or skill-level change. Star Charts, featuring self-contained lessons within a single constellation, often pair with Skyhopping sections that show the reader how to move between targets in adjacent constellations. Happily, both the northern and southern celestial hemispheres feature in these complementary lessons.

In these days of publish-on-demand and low-cost printing, *The Total Skywatcher's Manual* stands out for its high-level design. This is a lovely — one might even say flashy — but sturdy object. Metal corners on the flexicover thwart accidental bends and tears, as do the rounded page corners inside the book. The elimination of right angles carries through to the illustrations, contributing to an overall appearance of friendliness. But the graphics aren't just warm and welcoming, they're useful. Color is used consistently, labels are bright and easy to read, and illustrations clarify observing instructions. A serif typeface makes longer text sections easier to read while a san-serif typeface provides emphasis in charts and diagrams.

The Total Skywatcher's Manual is a fun book, but more importantly, it's a useful book. Many amateur astronomers worry that our community is shrinking, or at least "graying out." If we put a guide as bright and engaging as this in the hands of every person who expressed an interest in stargazing, our numbers would surely grow. The ASP has long offered us outreach material, but in *The Total Skywatcher's Manual*, they offer us a new outreach approach as well. ✦

S&T *Observing Editor* ***S. N. Johnson-Roehr*** *loves gadgets and tools almost as much as she loves astronomy.*

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▸ VISITOR FROM THE OORT CLOUD

José J. Chambó

Comet Catalina (C/2013 US10) had a 3° tail and shone with a greenish light (due to diatomic carbon) when captured on October 1, 2015, while crossing Centaurus.

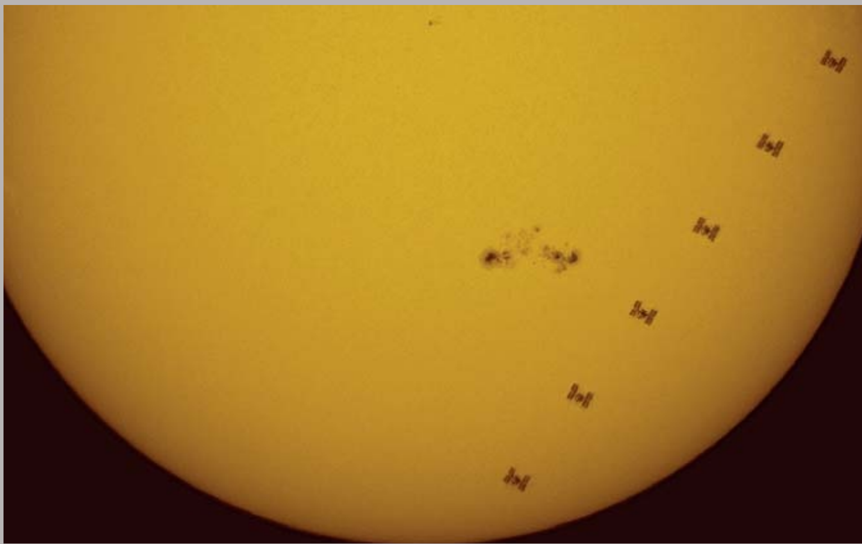
Details: *Takahashi FSQ-106ED apochromatic astrograph and FLI MicroLine ML16803 CCD camera with LRGB filters. Total exposure: 10 minutes.*

▾ CONGESTED SCENE IN ORION

Kfir Simon

The Belt star Alnitak anchors a 1½°-wide view of the Flame and Horsehead nebulae, with bluish NGC 2023 in between.

Details: *16-inch Dream Astrograph and Apogee Alta U16M CCD camera with Hα and RGB filters. Total exposure: 80 minutes.*



◀ **JUST PASSING THROUGH**
Scott Gauer
The International Space Station crosses the Sun (near Active Region 12403) on August 22, 2015. Success required a precise setup location.
Details: *Explore Scientific ED102mm apochromatic refractor, Lunt Herschel wedge, and Imaging Source DMK41 CCD camera. Exposure: 1⁄3333 second captured at 15 frames per second.*

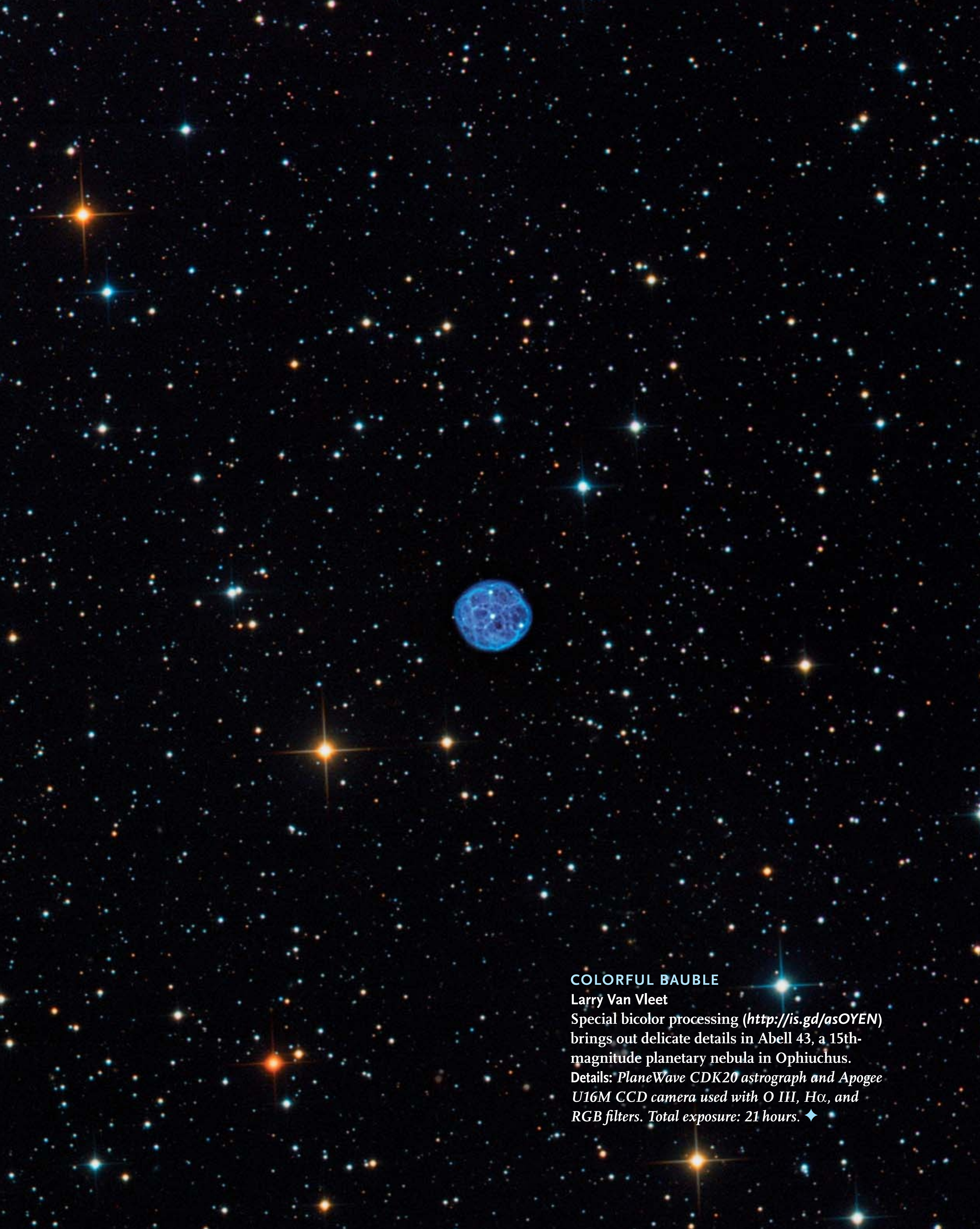
Visit SkyandTelescope.com/gallery for more of our readers' astrophotos.

BREADTH AND BEAUTY
Jerry Gardner
This 5°-wide panorama in hydrogen-alpha light records the Orion Nebula (far right) and other showpiece objects. North is toward left.
Details: *Astro-Tech AT65EDQ apochromatic astrograph and Hutech-modified Canon EOS 6D camera at ISO 1600. Total exposure: 6.3 hours.*

▶ **ONE-ARMED SPIRAL**
Brian Peterson
NGC 4725, a 10th-magnitude spiral galaxy in Coma Berenices, has a bright, well-defined nucleus. A distant background galaxy is at far right.
Details: *Hyperion 12.5-inch astrograph, SBIG STL-11000 CCD camera, and LRGB filters. Total exposure: 19 hours.*

▶▼ **ORION RISING**
Jeff Dai
Two astrophotographers look on as Orion's Belt and Great Nebula rise over Tibet's Zada Soil Forest.
Details: *Modified Canon EOS 6D DSLR camera used at ISO 20,000 and 200-mm lens. Exposure: 8 seconds.*

▼ **VENUS**
Rick Schrantz
Sharp seeing and an ultraviolet filter reveal many details in Venus' cloudy atmosphere on October 7, 2015.
Details: *10-inch reflector, Tele Vue 4× Powermate, and Imaging Source DMK21AU04 CCD camera. Total exposure: 133 seconds (2,000 video frames).*



COLORFUL BAUBLE

Larry Van Vleet

Special bicolor processing (***http://is.gd/asOYEN***) brings out delicate details in Abell 43, a 15th-magnitude planetary nebula in Ophiuchus.

Details: *PlaneWave CDK20 astrograph and Apogee U16M CCD camera used with O III, Hα, and RGB filters. Total exposure: 21 hours.* ✦

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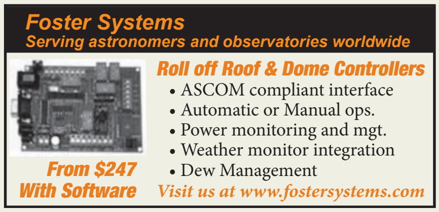

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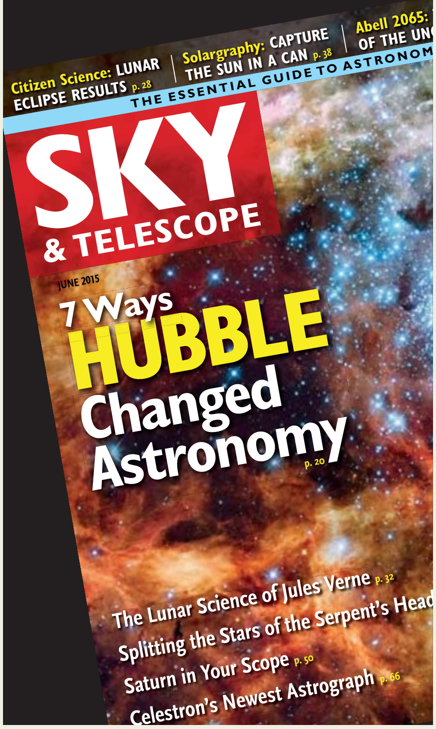

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Saturn Changes You

Observing the ringed planet for the first time can be life-altering.

S&T: SEAN WALKER

Before I became an astronomer, I worked as a naturalist for the Cincinnati Parks, where I was put in charge of a small planetarium. I had no astronomical training and couldn't even find the North Star, but I had the key to unlocking such knowledge. In the basement of the parks building, among little-used old astronomy texts, rested a dusty, 4.5-inch reflecting telescope in a wooden box. I asked my boss if he thought it worked. He said, "Give it a try."

I knew nothing about telescopes or their mysterious accessories. I now recognize what I discovered in the box with the scope as .965" eyepieces, a cheap finder scope, plastic Barlows, and a wooden tripod. In short, this rig was a piece of junk.

But youthful enthusiasm finds ways to make junk work, and soon I had semi-focused images of distant buildings, trees, and, at nightfall, the Moon. I had my existential Moon moment, one of awe and wonder, and I remember feeling proud of myself. I had rescued this forgotten scope, figured out how to use it, and soon found myself observing shadowed craters on the Moon.

Then came Saturn. When I swung the telescope toward it, centered it in the finder, and placed my eye to the eyepiece, I gasped. There it was, a tiny cartoon, an encircled world amid the black expanse of space. I was experiencing sunlight bouncing off an improbable planet almost a billion miles away and arriving in my eye and soul. My passion for astronomy and my future career began right then and there. The Moon was cool, but Saturn made me an astronomer.

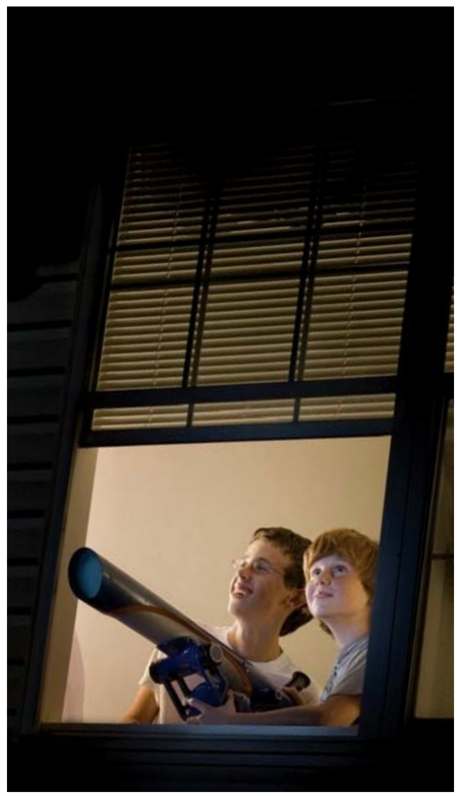
Seventeen years later, after showing thousands of people the ringed planet, I know that we're all different after seeing Saturn. It has a transformative power that excites our imagination like no other astronomical object. Saturn is our childhood symbol for space, and seeing the real thing lights up our faces.

This happens even with the most skeptical, hardest-to-impress audience: teenagers. When I watch the toughest or most bored teens grudgingly put their eye to a telescope, a metamorphosis takes place. For the briefest moment, as the light of Saturn hits their eye and consciousness, I notice their facial muscles relax and their angst disappear, and they emit an inner glow.

Just as suddenly — *bam* — they return to self-consciousness and their typical inert state. I innocently ask, "What do you think?" "It was pretty cool, I guess," is generally the mumbled reply. But I *saw* it. I saw what Saturn did to them. And I know for certain it made an impact when the same students wordlessly return for second looks.

So, fellow astronomers, share your telescope more this Saturn season! For the benefit of those who haven't yet seen the sixth planet from the Sun, put it on your must-do list for 2016 to show it to them. When viewers inevitably ask you, for instance, "How far is Saturn?" you could say about a billion miles, or as John Dobson, the father of sidewalk astronomy, often said, "Way the hell out there!" It doesn't really matter, because while they're ogling Saturn they won't be listening. They'll be grappling with a worldview suddenly upended. ✦

Dean Regas is the Outreach Astronomer at the Cincinnati Observatory and the cohost of the nationally syndicated TV program Star Gazers. *Reach him at* ***dean@cincinnatiobservatory.org***.



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