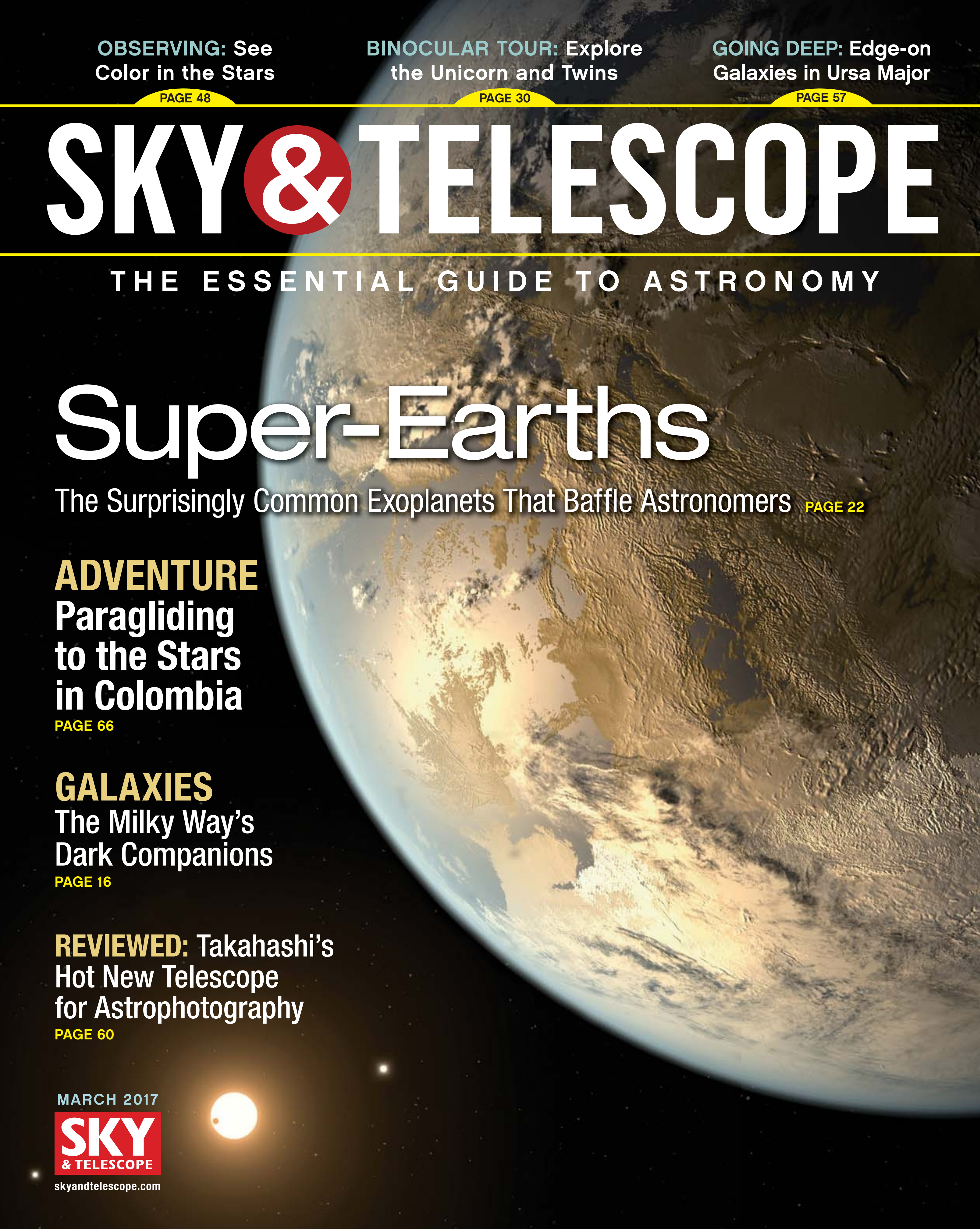

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SKY & TELESCOPE

THE ESSENTIAL GUIDE TO ASTRONOMY

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MARCH 2017

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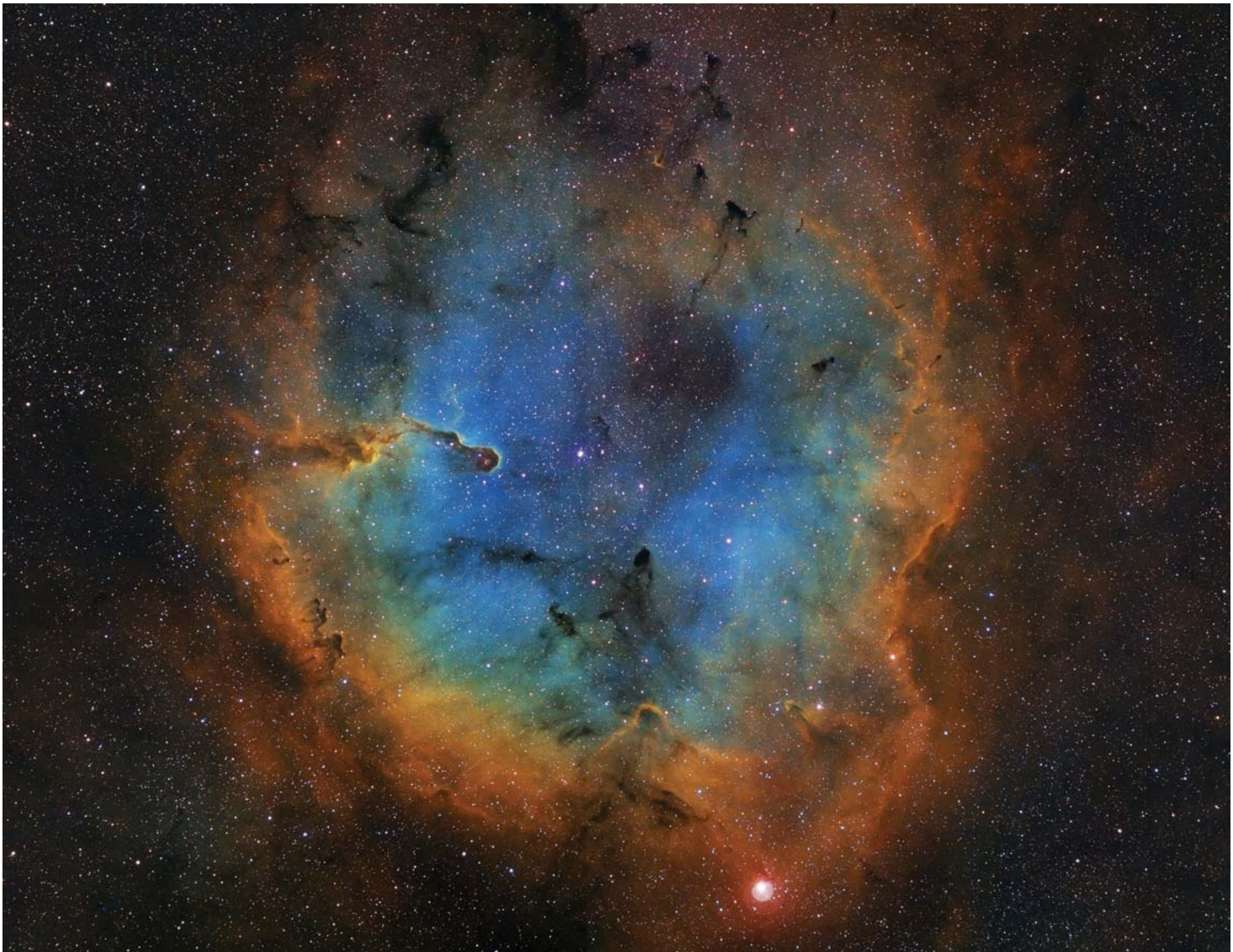

IC 1396. FLI camera with 50 megapixel KAF-50100 sensor. Image Courtesy Wolfgang Promper.

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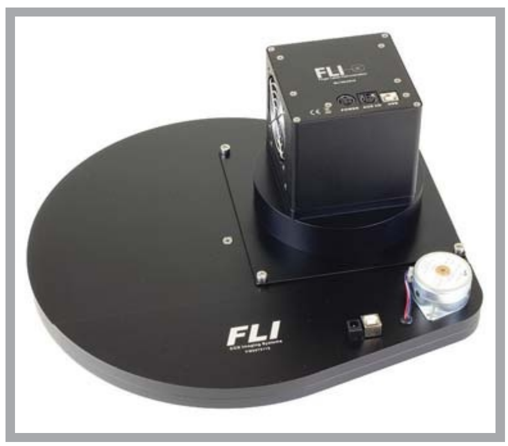

MicroLine ML50100 Camera on CFW10-7 Filter Wheel

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NASA AMES / JPL-CALTECH / T. PYLE

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A Shrewd Dumbness

IN ASTRONOMY, you have to be comfortable with oxymorons. Take, for example, Keith Bechtol's article on dwarf galaxies (page 16). *Dwarf galaxies?* That's as self-contradictory as *pygmy mammoth* or *jumbo shrimp*. Bechtol talks about "dense halos" of dark matter. You might as well call a rainbow or an aura dense — yet it's called for, as you'll see if you read his piece. He mentions heavy elements. How can atoms possibly be deemed heavy? "O heavy lightness!" says Romeo of his love for Juliet.

Bechtol goes on to describe how simulations help astronomers visualize invisible dark matter. He might have written, "No light, but rather darkness visible," but Milton got there first. Invisible ink! Sight unseen!

Bechtol also throws around terms that, while not classic oxymorons, might be considered near misses. Spacetime. Light-year. Celestial sphere. Unlike, say, "visualize invisible," the two terms thrust together in these examples are not inherently mutually exclusive. But before Einstein, claiming that space and time are *not* mutually exclusive might have rolled eyes. *Celestial sphere?* That's virtually as oxymoronic as *planisphere* (from the Latin words for *plane* and *sphere*).

We dub this (NGC 299) an "open cluster" without thinking about the intrinsic paradox in the term.

ESA / HUBBLE & NASA

Flip through issues of *S&T* and you'll happen upon many other potential candidates. Binary star. Absolute magnitude. Star cloud. Geostationary orbit. Awfully good, aren't they? Averted vision. Color temperature. Lookback time. Remote sensing. "Misshapen chaos of well-seeming forms!" (Romeo again, on the same subject.) Who would have thought astronomers would give Shakespeare a run for his money? Preposterous ("before-after")!

Oxymorons come in handy in astronomy because we're dealing with phenomena about whose properties we're often part confident, part stumped. The word *oxymoron* comes from the ancient Greek *oxus* ("sharp, keen") and *moros* ("dull, foolish," as in moron). The writer Garry Wills has translated the term as "shrewd dumbness." Many astronomers might concede that a shrewd dumbness is more or less what they bring to bear when contemplating gravitational waves or fast radio bursts or other wild and woolly cosmic enigmas.

Of course, it's not dumbness as much as befuddlement. Astronomers are not dimwits, after all, just absolutely unsure. And that's what drives science forward, a desire to replace bewilderment with comprehension, to make the darkness visible. At least that's my unbiased opinion.

Peter

Editor in Chief

SKY&TELESCOPE
The Essential Guide to Astronomy

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

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GOTO
How to do it right

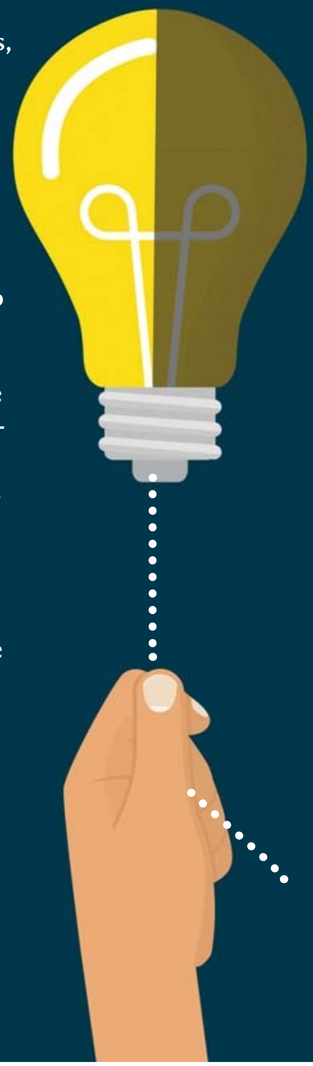
Light Pollution Success Story

More than a year ago (*S&T:* Oct. 2015, p. 6), I described how my local organization, Dark Skies, Inc., had worked since 2000 to minimize light pollution in our two adjoining small towns of Westcliffe and Silver Cliff in Colorado's Wet Mountain Valley and to have them certified as an IDA International Dark Sky Community. We had no idea that a media storm was about to engulf us — in a good way!

First, a *New York Times* reporter wanted to do a story on our fight against light pollution. He came with a photographer for several days and conducted video interviews of local citizens. We also put on a special star party for them. Apparently, the various news agencies watch each other, because in short order we were contacted by CNN's documentary unit (Great Big Story), *USA Today,* and NBCUniversal's "Sunday Today" show. Now NHK World, one of Japan's national TV services, wants to do a video feature too.

To support these requests, our members have provided lodging recommendations, driven the crews around, taken them to dinner, arranged interviews with local governmental officials and citizens, and called out the public to attend impromptu star parties using Facebook. The reaction by the local citizens has been incredible and a very satisfying vote of approval. And a common reaction of the reporters and media crews is, "I'd love to live here!"

Ed Stewart
Westcliffe, Colorado



Astronomical Numbers

I thoroughly enjoyed Matt Wedel's "Twelve Steps to Infinity" (*S&T:* Dec. 2016, p. 24). It reminded me of a way I have helped people visualize large numbers. You could call it "Six Steps to a Trillion." (1) Imagine something slightly smaller than a BB, such that 10 of them span 1 inch. (2) So 100 of these will fit in 1 square inch. (3) Stack 10 of these layers, and you have 1,000 in a cubic inch. (4) For simplicity, assume 10 inches equals 1 foot; then 10×10×10 cubic inches (1 cubic foot) will hold a million BBs. (5) Imagine a cube-shaped container that measures 10×10×10 "feet"; it will hold a billion BBs. (6) Pile up 1,000 of these containers, and you'll have a trillion BBs. If such an enormous cube is difficult to imagine, just think of an American-style football field filled with BBs to a depth of roughly 17 feet (including both end zones) or 18 feet (without them). This shows even big numbers, common in astronomy, can be grasped by the human mind.

Tom Wright
San Diego, California

"Twelve Steps to Infinity" struck a resonant chord. I likewise need to remind myself to "shatter the bowl of the sky, to see space as space." I find it a useful fiction to revert to Huygens' (and Newton's) misconception that all stars have the same absolute magnitude. For me, this self-deception never fails to bring forth the three dimensionality of space — and the darker the heavens, the more striking the impression.

Marcus Honnecke
North Park, Colorado

A Record Now Out of Reach?

"Pushing The Limit" (*S&T:* Nov. 2016, p. 68) was a nice read about the efforts of real amateurs, right up to the part describing a 32-inch machine, created by a consortium, that was installed on the grounds of a professional observatory with the help of a university to construct the site and install the telescope. Pardon me, but that no longer looks like amateur astronomy. Set against the previous record-setting efforts, it's as if the visiting team brought Babe Ruth along to play your local hometown team. Future efforts at the faint-object record are now a game for millionaires only. That just seems sad.

H. Wayne Hall
Colorado Springs, Colorado

Stargazing with Merit

I'm a Boy Scout who completed the requirements for an astronomy merit badge several years ago. Now I'm trying to earn the communication merit badge. So I am writing to you to tell you that *Sky & Telescope* has had a large influence on my life. Since starting my subscription, I've learned so much about the night sky. And there's always something to look at when I go out — I just simply look in the magazine, and I'll see things to spot. I've been subscribing for about six years now, and I will continue for much longer. So thank you.

Jared Yeager
Marion, South Carolina

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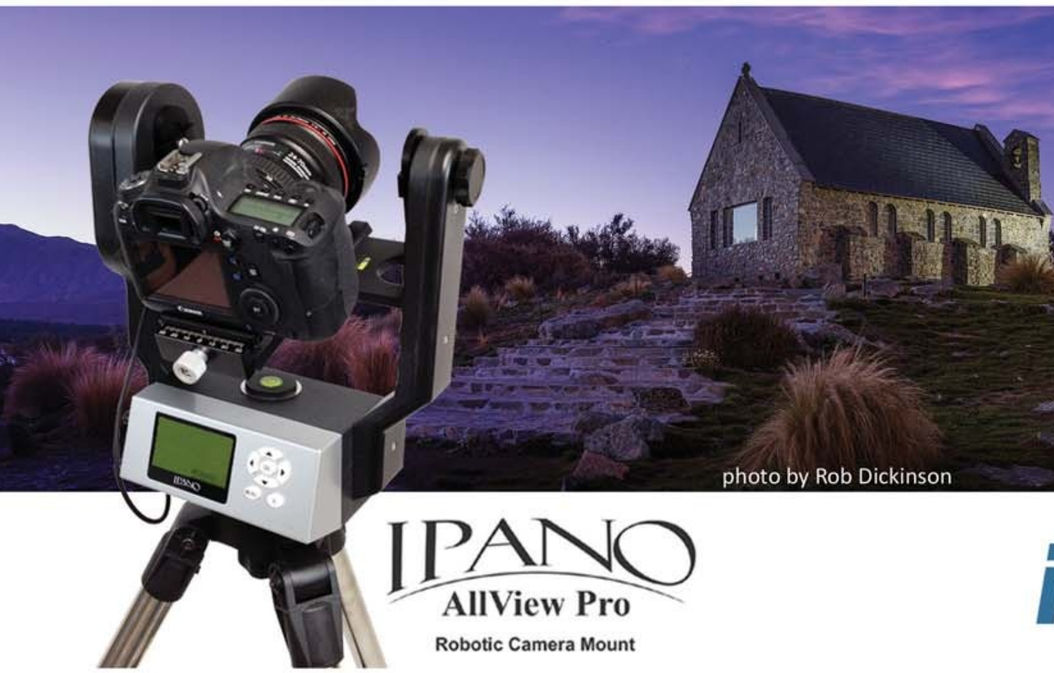

The iPano AllView Pro, a precise computerized robotic camera platform that serves to automate the tedious image capture steps needed to create gigapixel panoramic, hemispherical, and spherical images, as well as panning time lapse movies. The iPano doesn't only point the camera and trigger the shutter, it automatically calculates the number and position for every shot needed to complete the final image.

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Uranus Can Be Subtle

I've been in and out of astronomy since the 1960s but have never looked for Uranus. So I tried last October 24th and 25th using your charts (*S&T:* Oct. 2016, p. 50), but I couldn't find it. Then, seeing December's chart (p. 49), I said, "OK, I'll find it now." And I did! I looked again on October 29th, and in my 70-mm refractor at 117×, I could tell it wasn't a star. Thanks for the help — that made my day.

Ed Bailey
Daniels, West Virginia

▲ A digital camera records the blue hue of Uranus more distinctly than the human eye can see. Note the somewhat brighter north polar region at left.

Regarding "Scoping the Tints of Uranus and Neptune" (*S&T:* Nov. 2016, p. 50), I have always seen Uranus as a very light blue with, when apparent, lighter-white mottlings that might be atmospheric features. Neptune has always been gray — with just a hint of green, sometimes. Meanwhile, the argument over the validity of visual observations of Uranus drags on. I think the case has been proved, but a lot more evidence is needed to back up my opinion. This is why I'm so evangelical about getting observers to record Uranus regularly. Only in this way we can get, and make, real comparisons among observations.

Kevin Bailey
Swindon, United Kingdom

Editor's note: *Be sure to read the author's introduction to observing Uranus and Neptune — and his color quibble with the late Sir Patrick Moore — in the September 2016 issue, p. 52.*

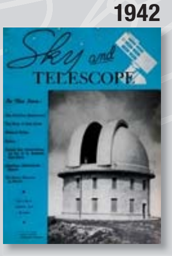
FOR THE RECORD

- In the image of the Metronome asterism (*S&T:* Nov. 2016, p. 39), the labeled star is HD 35175.
- A portion of Laszlo Sturmann's explanation of the optical relay system on Mount Wilson's 100-inch telescope (*S&T:* Jan. 2017, p. 6) should read, "Think of the Meade objective as a very long focal-length 'eyepiece' that, just like any other eyepiece, forms a real image of the entrance pupil of the telescope."
- AR Scorpii (*S&T:* Jan. 2017, p. 11 and p. 84) is not the first pulsing white dwarf, as the titles suggest. Instead, it represents the first known white dwarf binary with pulsar-like outbursts.

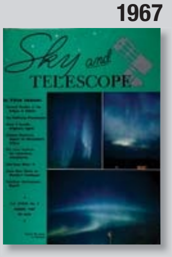
SUBMISSIONS: Write to *Sky & Telescope,* 90 Sherman St., Cambridge, MA 02140-3264, U.S.A. or email: letters@skyandtelescope.com. Please limit your comments to 250 words.

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

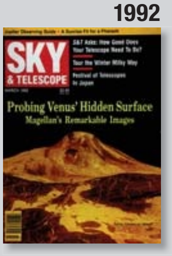
1942



1967



1992



March 1942

Spurious Bands "Dr. W. A. Hiltner and R. G. Fowler, of the University of Michigan Observatory, . . . reported that several spurious bands had appeared in [Eastman Kodak's new] 103-F emulsion at 5300 A and 5700 A, which had caused some confusion in astronomical spectroscopy. For instance, [Milton L.] Humason and [Rudolph] Minkowski, at Mt. Wilson, reported bands present in a supernova at these wave lengths, but later identified them as due to sensitization bands in the 103-F emulsion."

All too often, new detection methods lead to misinterpretations and false alarms. Just last August the SETI community was abuzz about odd radio emissions coming from the direction of HD 164595, a Sun-like star 94 light-years away in Hercules. More careful analysis showed the signals were actually from a Russian military satellite.

March 1967

New Messier Object "Since [French astronomer Charles] Messier's time, his catalogue has been revised so thoroughly and frequently that one might think little new could be said about it. Nevertheless, while collecting material for a book on Messier, I have uncovered several new items of interest.

"[For example, his] drawing of the Andromeda nebula, published in 1807, shows M32 below it and NGC 205 to the upper right. The label for the latter describes it as very faint and as discovered by Messier himself in 1773. Therefore the author suggests that NGC 205 may also be called M110."

Thus 50 years ago Kenneth Glyn Jones (British Astronomical Association) added one more entry to the list of fuzzy objects that Messier hoped never to mistake for a comet.

March 1992

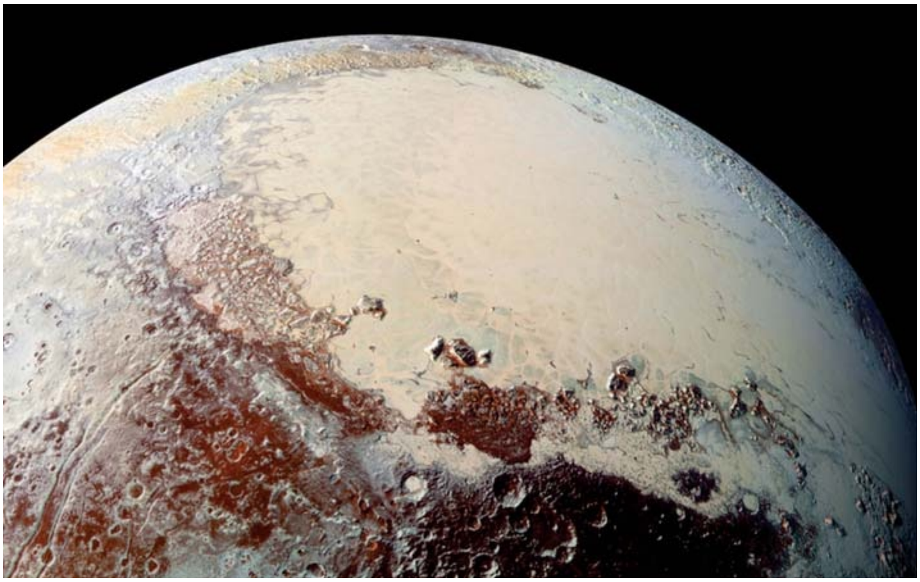
Cro-Magnon Supernova "About 35,000 years ago a star exploded in the solar system's backyard, briefly shining as brightly as a quarter Moon. Two groups of scientists independently announced this conclusion at a meeting of the American Geophysical Union on December 13th after discovering evidence unearthed in Greenland and Antarctica.

"Drilling deep into the polar ice, French and Russian researchers found that the abundance of beryllium-10 is twice normal in a layer about 600 meters down. This isotope forms when cosmic rays smash apart atmospheric oxygen and nitrogen nuclei, so Earth must have undergone increased cosmic-ray bombardment when this layer of ice was deposited. . . . Several supernova remnants of about the right age have been detected about 150 light-years away — closer than any supernova observed in history."

In 2005, toward the end of his life, astronomer Aden B. Meinel (University of Arizona) was working to connect this and other detections of beryllium-10 with changes in human evolution going back 800,000 years.

SEAN WALKER

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



▲ Nitrogen, carbon monoxide, and methane ices appear to be concentrated in this bright, craterless expanse, informally called Sputnik Planitia. Colors are close to natural.

PLUTO

Sputnik Planitia Made Pluto's "Heart" Wander

THE BIG, NITROGEN-ICE-FILLED basin informally called Sputnik Planitia has apparently caused Pluto's entire crust to shift over time.

Sputnik Planitia is the western half of a larger, heart-shaped bright feature nicknamed Tombaugh Regio that's situated on the hemisphere facing away from the big moon Charon. About 1,000 km (600 miles) across, the plain's surface is crater free (and thus very young), rimmed by tall water-ice mountain ranges, and exhibits glacier-like flows. Many suspect it's an ancient impact basin that, over time, has been partly filled by a thick layer of frozen nitrogen, methane, and carbon monoxide.

Now two analyses conclude that Sputnik Planitia lies almost directly opposite Charon not by accident but instead because the feature literally dragged the crust of Pluto around to the current arrangement. Geophysicists refer to this crustal shifting as *true polar wander.* It's the tendency of spinning objects to reorient themselves so that locations with mass excesses end up on the equator and mass deficiencies at the poles.

In the December 1st *Nature*, four geophysicists led by James Keane (University of Arizona) make the case that the big basin initially existed much farther north, near latitude 60°, and gradually migrated equatorward. They modeled how this shift, coupled with the gradual freezing of a global subsurface ocean early in Pluto's history, would stress and fracture the world's surface. These fractures match the ones found on Pluto.

To trigger the basin's equatorward shift, Francis Nimmo (University of California) and other New Horizons scientists calculate in an accompanying *Nature* article that the nitrogen ice filling Sputnik Planitia would have to be at least 40 km (25 miles) deep. That's implausibly thick, so Nimmo's team argues that the excess mass needed to drag the feature toward the equator comes from a broad, near-surface bulge in the subsurface ocean that underlies the basin. Such a bulge could have welled upward when the impact carved the initial hole in Pluto's ice crust.

Not everyone is convinced that Sputnik Planitia is an impact basin, though. Douglas Hamilton (University of Maryland) and others suggest in the same *Nature* issue that the *ice* formed first, slowly producing a basin beneath it as it built up. In this scenario, the plain initially formed at its current location, not near the pole, because Pluto's highly tilted spin axis makes these lower latitudes the coldest on the little world.

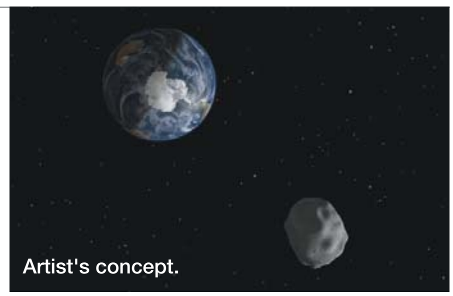
■ J. KELLY BEATTY

SOLAR SYSTEM

Near-Earth Asteroid Tally Surpasses 15,000

THANKS TO TWO aggressive search programs, the count of near-Earth asteroids (NEAs) has surpassed the 15,000-object milestone. Most NEAs are too small to be spotted far away, and it's only within the week or so when they skim near our planet that they make their existence known. These days almost all NEAs are swept up by the Catalina Sky Survey in Arizona or by the wide-field Pan-STARRS 1 telescope in Hawai'i. Even with all those space rocks flying around, there's very little risk that a known, sizable asteroid will strike Earth for the foreseeable future. The object with the highest *cumulative probability* of impact (that is, the risk over dozens of close approaches) is 2010 RF_{12}, which has a 1-in-15 chance of hitting in 2095 — but it's only about 7 m (23 ft) across, almost certainly too small to make it to the ground.

Meanwhile, Vishnu Reddy (University of Arizona) and colleagues report in the December *Astronomical Journal* their discovery of one of the smallest NEAs yet: 2015 TC_{25}, about 2 m wide. The little rock is highly reflective and bare of dust, probably in part because of its fast spin.



Artist's concept.

■ J. KELLY BEATTY

PLUTO: NASA / JHU-APL / SWRI; ASTEROID: NASA / JPL-CALTECH

PRO-AM PROJECT

Worldwide Comet Campaign

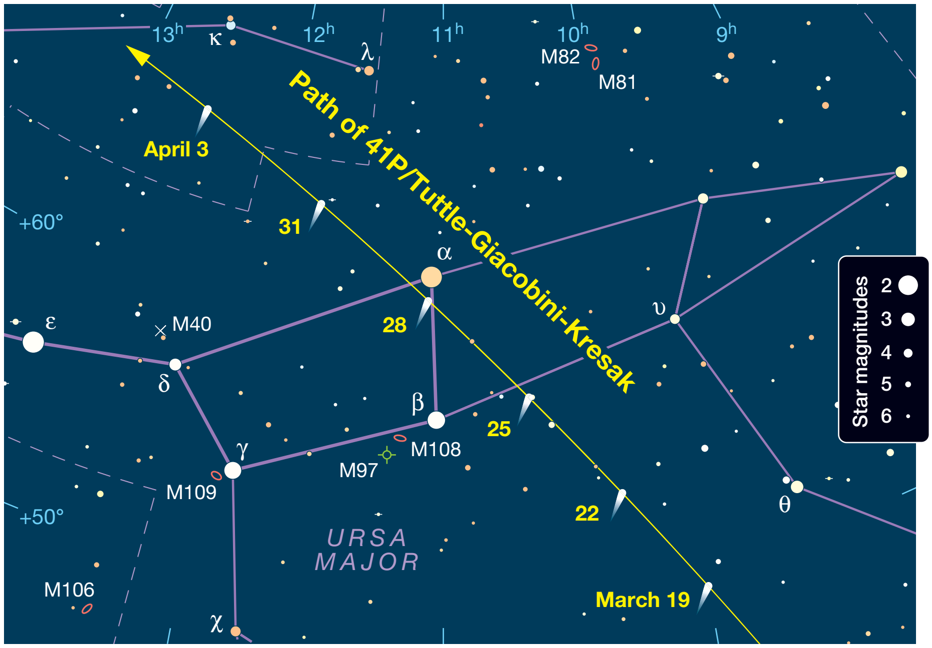
THE NONPROFIT Planetary Science Institute (PSI) has put out a call to amateur and professional astronomers to help document three comets making close flybys of Earth over the next two years.

The comets — 41P/Tuttle-Giacobini-Kresak, 45P/Honda-Mrkos-Pajdusakova, and 46P/Wirtanen — will all pass our planet at very close distances, ranging from 11.9 to 22.5 million km (7.4 million to 14 million miles). Comets 41P and 45P will reach their closest approaches in early 2017; Comet Wirtanen will do so in late 2018.

To take advantage of this rare opportunity, the 4*P Coma Morphology Campaign seeks detailed images of each comet's coma from locations spread across the globe. You can submit photos taken in regular light showing dust features or taken through narrowband filters that enhance gaseous emissions. PSI suggests the best time to obtain images will be from about mid-February through mid-March 2017 for Comet 45P and from the end of January through July 2017 for Comet 41P.

The campaign will specify the best times for Wirtanen in 2018.

Through the pro-am effort, astronomers hope to determine key characteristics about each of the three comets: the nucleus's rotation rate, the onset and evolution of outbursts or fragmentation, and changes in coma and tail structure.



S&T: LEAH TISCIONE

▲ When Comet 41P/Tuttle-Giacobini-Kresak passes closest to Earth (0.14 astronomical unit) in late March, it will hurry across the circumpolar constellations Ursa Major, Ursa Minor, and Draco.

Another group, the Pro-Am Collaborative Astronomy (PACA) Project, welcomes not only photos but also visual observations. Interested observers should send requests to join the Facebook groups PACA_4145P and PACA_46_Wirtanen.

Even if you don't participate in a campaign, visual observers can still join the fun by following all three comets from their faint beginnings to what we hope will be bright and satisfying apparitions. Comet 45P may reach magnitude +6 by mid-February, bounding from Aquila in the morning sky to Coma Berenices in the evening in the span of just two weeks. About the time Comet 45P enters Leo at the end of February, Comet 41P heats up, moving north along the border between Leo and Cancer in the evening sky. Come early April, Comet 41P may become faintly visible with the naked eye as it crosses from the Big Dipper into Draco.

■ BOB KING

● Find detailed finder charts & how to join the PSI campaign at https://is.gd/4pcometcampaign.

IN BRIEF

Clarendon (c): Meteorite Find of a Lifetime

Thanks to an announcement in the Meteoritical Society's bulletin, the second-largest chondrite ever found in the U.S. has been donated to Texas Christian University. Frank and DeeDee Hommel discovered the meteorite, called Clarendon (c), on their working dude ranch near Clarendon, Texas. The stone weighs 345 kg (760 lbs). It's now part of the public Monning Meteorite Collection.

■ RUBEN GARCIA

Read the behind-the-scenes story of how the author helped Clarendon (c) to its new home at https://is.gd/clarendonc.

Big, Far-Out Kuiper Belt Object

Astronomers led by David Gerdes (University of Michigan) have discovered a Kuiper Belt object, designated 2014 UZ$_{224}$, that's currently 91.6 a.u. from the Sun, or nearly three times farther out than Pluto is. Only two other known KBOs are more distant: Eris (96.2 a.u.) and an object designated V774104 (103 a.u.). The 1,140-year-long orbit of 2014 UZ$_{224}$ is quite elongated. The new find's diameter could be anywhere from 400 km across (if its surface is highly reflective) to 1,200 km (if it's very dark); the larger end of this range could qualify it for dwarf planet status. Discovery details at https://is.gd/2014_UZ224.

■ J. KELLY BEATTY

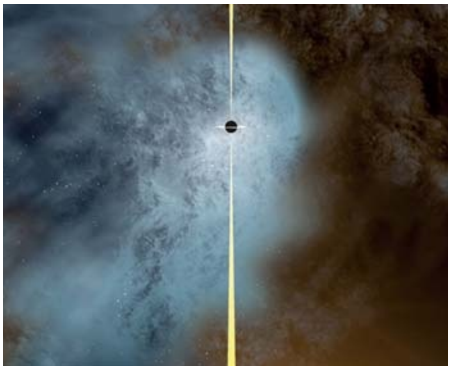
New Clues on Beagle 2

Researchers with De Montfort University and the University of Leicester (both UK) provide further insight into what happened to the UK's failed Beagle 2 Mars lander in 2003. NASA's Mars Reconnaissance Orbiter (MRO) found the lander in 2015. Using an innovative technique called *reflection analysis*, the team matched the most likely lander configuration with unprocessed MRO images. The as-yet unpublished results suggest the lander only unfolded three of its four solar panels, the last one potentially blocking the radio antenna's transmissions.

■ DAVID DICKINSON

Read more about the team's analysis at https://is.gd/beagle2panels.

BLACK HOLES



Runaway Black Hole Flees Behemoth Galaxy

ASTRONOMERS HAVE SPOTTED a supermassive black hole in a stripped-down galaxy racing away from a near-fatal close encounter.

James Condon (NRAO) and colleagues came upon the object in a recent radio search of nearby galaxies. The accreting black hole they found lies about 30,000 light-years from a brilliant, massive elliptical galaxy in the center of a cluster. That is much too far from the galaxy's core to belong to it.

Follow-up Hubble and Spitzer observations revealed that the radio source, called B3 1715+425, sits in its own little galaxy, which has the mass of some 6 billion Suns — comparable to that of the Small Magellanic Cloud and atypically tiny to be hosting a supermassive black hole. A trail of ionized gas extends from the tiny galaxy to its much bigger sibling.

Using spectra, the astronomers determined that the little galaxy is speeding away from the larger one at about 2,000 km/s (4 million mph). As Condon's team explains in an upcoming *Astrophysical Journal*, the speedy galaxy was likely stripped of most of its stars and gas by the "Jabba the Hut" elliptical during a slingshot pass. The core of the galaxy — and its supermassive black hole — survived. In another billion years, the black hole will be invisible, wandering undetected through intergalactic space.

■ **MONICA YOUNG**

• Watch a video explaining the result at https://is.gd/runawaybh.

SCIENCE & SOCIETY

IAU Standardizes 212 Traditional Star Names

BRINGING ORDER to chaos, the International Astronomical Union (IAU) has approved standardized spellings and designations for the traditional names of 212 bright stars.

In a series of resolutions from 1922 to 1930, the international body approved standard spellings, abbreviations, and borders for the 88 official constellations. This reform eliminated much confusion, including grave problems with respect to newly discovered variable stars, whose designations name the home constellation. Although there was widespread hope that a similar procedure would be applied to traditional star names, such as Sirius, a lack of urgency and the incredible messiness of the problem kept that from happening.

Until now. The official 212 names bring the total number of IAU-approved star names to 227, including Proxima Centauri, the closest star to the Sun.

Why hasn't this been more of a problem in the past? Largely because most of these "popular" star names aren't really all that popular — and never have been. The name Sirius has been in continuous use with minor spelling variations for more than two millennia, but that's a rare exception. Roughly half the names in the IAU list, while traditional sounding, were in fact invented after 1800. I count just 18 of them as universally recognized by amateur and professional astronomers, and all of these have been standardized, or nearly so, for 100 years: Aldebaran, Altair, Antares, Arcturus, Betelgeuse, Canopus, Capella, Castor, Deneb, Fomalhaut, Polaris, Pollux, Procyon, Regulus, Rigel, Sirius, Spica, and Vega.

If you can point out all 18 of these stars in the sky, pat yourself on the back: you're a highly educated stargazer.

■ **TONY FLANDERS**

Read more at https://is.gd/iau212.

MARS

Curiosity Finds "Egg Rock" Iron Meteorite

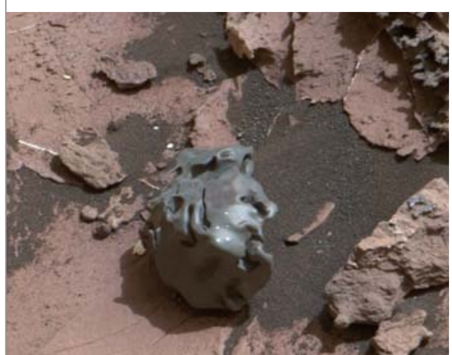
NASA'S INTREPID Mars Science Laboratory rover recently got a close-up view of a bizarrely shaped space rock that landed on the slope of Mount Sharp.

Dubbed "Egg Rock," the golf-ball-sized object has a polished, silvery-gray surface. Analysis with the ChemCam spectrometer confirms that it's an iron-nickel meteorite, whose outer surface melted and vaporized during the meteorite's plunge through Mars's tenuous atmosphere. Iron meteorites represent fragments of the cores of asteroids that *differentiated*, a process in which the lightest minerals float to the surface and the heaviest ones sink to the center while the body is cooling after formation.

This isn't the first time scientists have spotted a meteorite on Mars. The Opportunity rover found the first one back in 2005, named "Heat Shield Rock," followed by the 0.6-m (2-ft) "Block Island" meteorite in 2009. In May 2014, Curiosity spotted the enormous, 2-meter-wide "Lebanon," the largest meteorite found to date on Mars.

Such discoveries on Mars are interesting because more of the meteorite survives intact, owing to the much thinner Martian atmosphere. Finds such as Egg Rock will also reveal how weathering over time affects meteorites on Mars versus Earth.

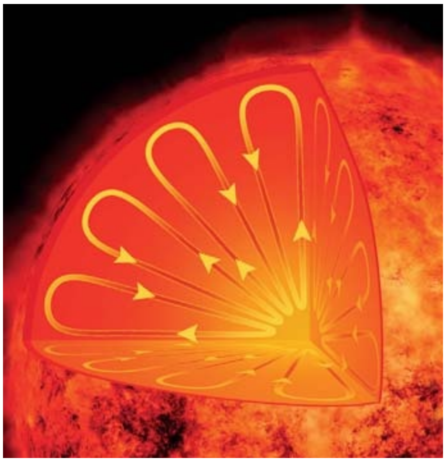
■ **DAVID DICKINSON**



▲ Close-up of the golf-ball-sized Egg Rock meteorite on Mars.

BLACK HOLES: BILL SAXTON / NRAO / AUI / NSF; MARS: NASA / JPL-CALTECH / MSSS

STELLAR



◀ The lowest-mass stars, including Proxima Centauri, are "fully convective": they transfer energy from their cores to their surfaces via the conveyor-belt-like motion of convection.

Proxima Centauri Has Sun-Like Cycle

Observations confirm that the closest star to our solar system has a regular magnetic cycle similar to our Sun.

This star, Proxima Centauri, is an *M* dwarf. Astronomers thought that such stars wouldn't have regular magnetic cycles like we see on the Sun, where the north and south poles flip every 11 years. Such globally coherent magnetic fields arise because our star's outer, convective layer of ionized gas slides across the lower, non-convective layer faster at the equator than it does at the poles, called *differential rotation*. This process stirs up plasma and creates a cyclic field.

But stars smaller than about 35% the Sun's mass — including Proxima Cen — are convective the whole way through. Thus, although these stars often unleash countless flares, their activity is localized and shouldn't be cyclic.

Nevertheless, astronomers have turned up some *M* dwarfs with activity cycles — including, potentially, Proxima Cen. Bradford Wargelin (Harvard-Smithsonian Center for Astrophysics) decided to investigate whether a cycle really existed. He and his colleagues amassed multiwavelength observations spanning 22 years. The team found that Proxima Cen indeed has a 7-year cycle, with its X-ray and ultraviolet emission (which comes from flares) going up when the star's optical brightness goes down (that is, when starspots plaster the surface). The 7-year cycle agrees with some previous studies that narrowed in on a 7- to 8-year range. The result appears October 8th in *Monthly Notices of the Royal Astronomical Society*.

Relatedly, computer simulations by Rakesh Yadav (also Harvard-Smithsonian Center for Astrophysics) and others in an upcoming *Astrophysical Journal Letters* now confirm that slow-spinning *M* dwarfs like Proxima Centauri, which rotates about every 83 days, *do* have differential rotation and magnetic cycles.

It all comes down to how well the magnetic field controls the star. Quickly spinning stars are generally young, with very strong magnetic fields that hold the star's plasma rigidly in place as it rotates, preventing differential rotation, Yadav explains. Chaotic convection near the surface "shreds" the star's strong global field, creating small-scale activity that powers flares.

Conversely, as a star slows down, its global magnetic field weakens. Such a field can't hold the plasma hostage anymore, and the equator breaks away from the poles, spinning faster. The differential rotation creates widespread shears and, thus, a coherent flip-flopping field.

■ CAMILLE M. CARLISLE

STELLAR

Two Stars, Three Planet-forming Disks

Planets generally form in a single disk of gas and dust around a star, even in stellar binary systems. But astronomers have now found a young pair of protostars that host three potentially planet-forming disks, all wildly tilted with respect to one another.

The two members of the binary protostar IRS 43 are currently both about the mass of the Sun and only 100,000-some years old, shrouded in dust and gas. Previous radio observations have revealed that a gaseous disk about 700 a.u. across encircles both stars.

Using ALMA, Christian Brinch (University of Copenhagen, Denmark) and others discovered that there are in fact *three* protoplanetary disks — one around each star and one around the pair. Based on the Doppler shift of the gas's spectral lines, the team determined the orientation of each disk, revealing the bizarre arrangement.

The team doesn't know if the system was born this way or was thrown into chaos by another, now-gone star. If the gas sticks around for another million years, the misalignment will slowly correct itself. The study appears in the October 10th *Astrophysical Journal Letters*.

■ MONICA YOUNG

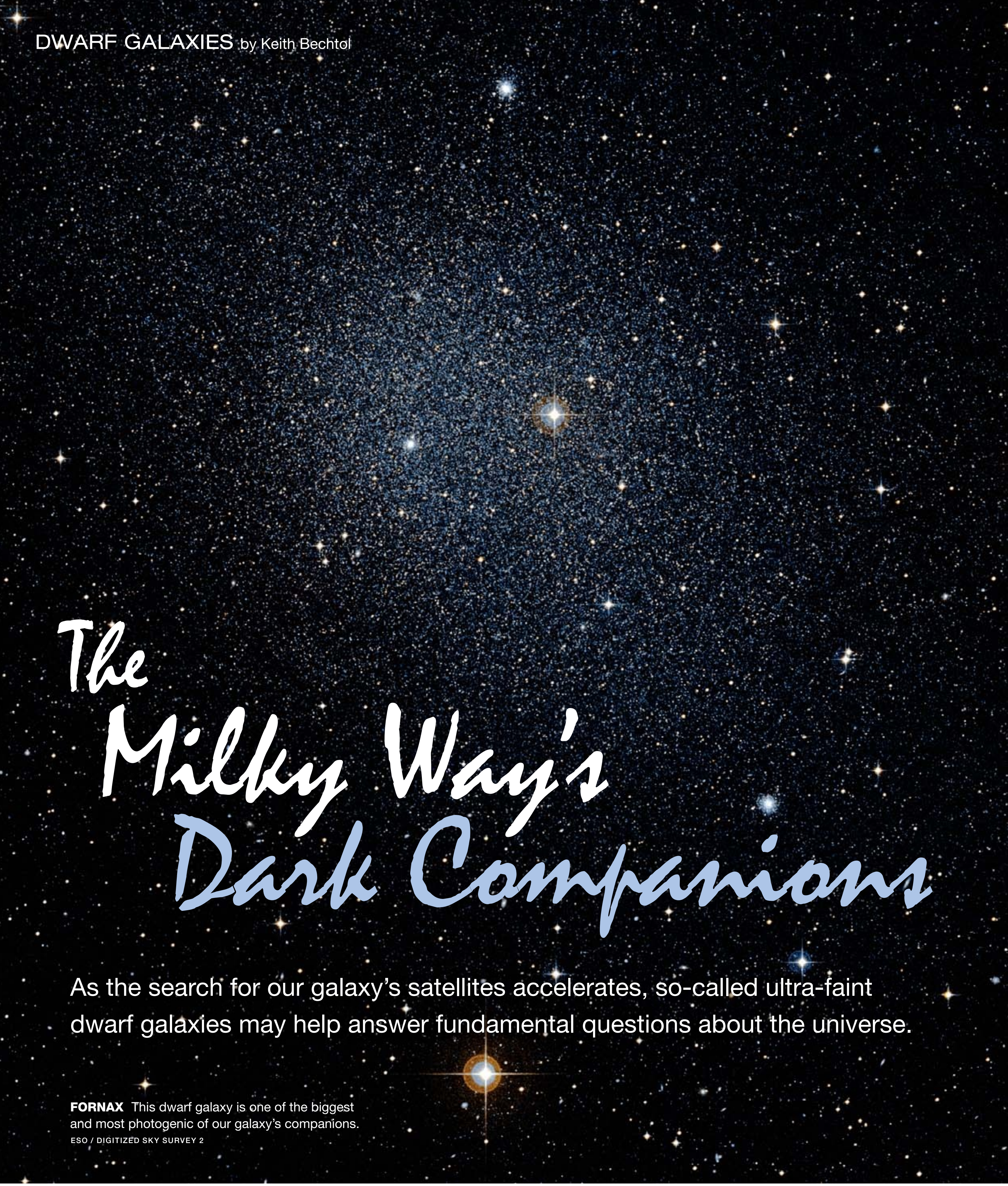
Infrared Image of a Planet-Forming Disk

THIS IMAGE FROM the SPHERE instrument on the Very Large Telescope shows the protoplanetary disk around the baby star HD 135344B. The star is between 4 and 16 million years old. The observations reveal spiral arms and a 25 a.u. "cavity"—the dust-free inner region that SPHERE can't detect. One or more planets might be gravitationally twisting the dusty gas into spiral arms. The faint, spoke-like streaks crossing the arms are probably shadows cast by an inclined inner disk, Tomas Stolker (University of Amsterdam, The Netherlands) and colleagues suggest. Their work appears with two other SPHERE papers in the November *Astronomy & Astrophysics*.

■ MONICA YOUNG

PROXIMA CENTAURI: CHRISTIAN BRINCH / NBI / KU; DISK: ESO / T. STOLKER ET AL.

 by Keith Bechtol



The Milky Way's Dark Companions

As the search for our galaxy's satellites accelerates, so-called ultra-faint dwarf galaxies may help answer fundamental questions about the universe.

FORNAX This dwarf galaxy is one of the biggest and most photogenic of our galaxy's companions.
ESO / DIGITIZED SKY SURVEY 2

One of the joys of observing from a high mountaintop in Chile is the panoramic view of the southern sky. As your eyes adapt to the darkness, the brightest stars appear first, then the fainter ones. The Milky Way arches overhead, and eventually you see two faint fuzzy patches of light near the south celestial pole — the Large and Small Magellanic Clouds. The LMC and SMC are the two largest galactic companions of the Milky Way, and the only two that are visible to the unaided eye.

Over the past century, we have discovered several dozen dwarf galaxies around the Milky Way. The largest of these contain several billion stars, modest collections compared to the roughly 300 billion stars in our own galaxy. At the other end of the spectrum, smaller dwarfs known as *ultra-faint dwarf galaxies* may have only a few hundred ancient stars — a single O star can outshine the faintest examples. Because they give off so little light, we have only been able to spot such dim galaxies within a few million light-years of Earth.

In 2015 astronomers doubled the number of previously known Milky Way companions using data from new sky surveys. If all the newfound stellar systems are confirmed as galaxies, they will bring the total number of known satellites orbiting the Milky Way to more than 50.

Ultra-faint galaxies are the most common type of galaxy; though they are hard to find, there are potentially hundreds of them for every giant like the Milky Way. Despite their unassuming appearance, our tiny galactic neighbors are helping us address big questions about the nature of dark matter, the universe's first stars, and the process of galaxy formation.

The Galaxy-Dark Matter Connection

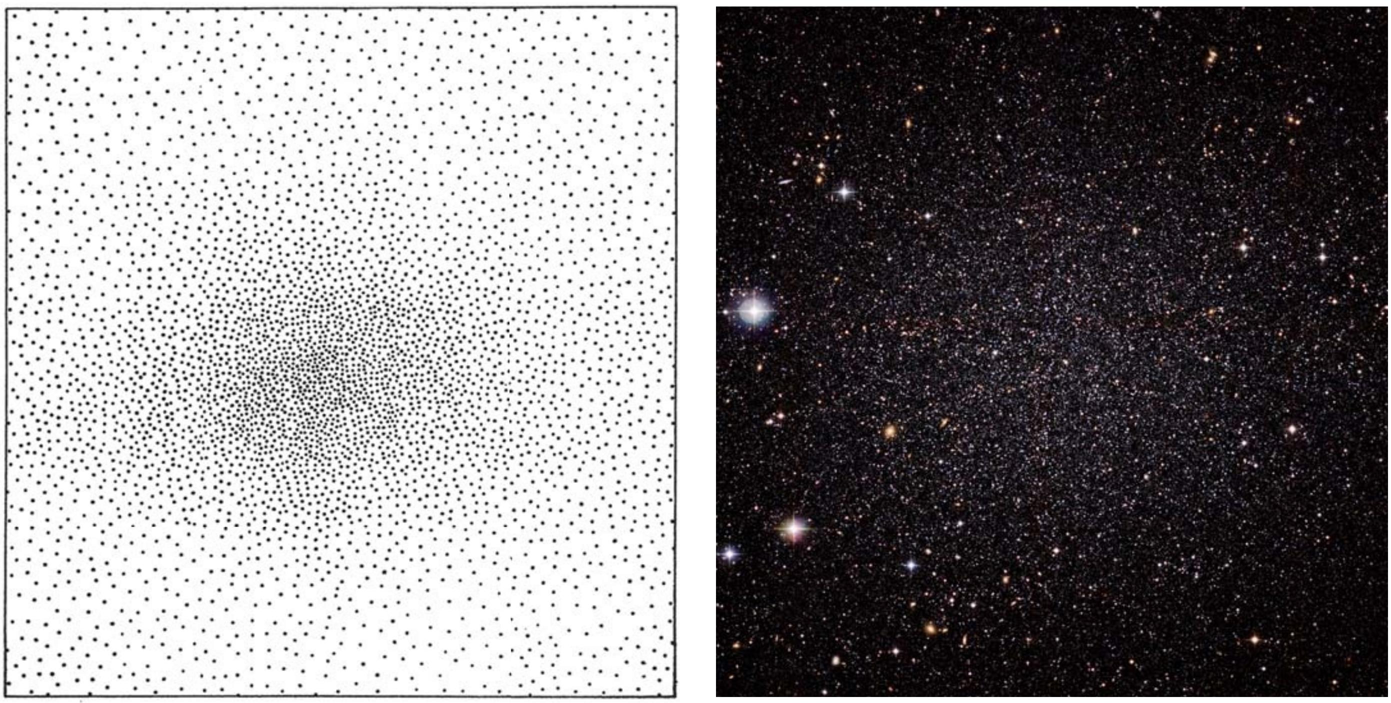
The close connection between galaxies and dark matter is one of the most active research topics in astrophysics. In fact, galaxies owe their very existence to dark matter.

Even if we don't know yet what dark matter *is* (see box on page 18), we know a lot about what it *does*. Dark matter and "normal" (baryonic) matter attract each other through the force of gravity, clumping together to form cosmic structures such as galaxies and clusters of galaxies. A galaxy's stars and gas are embedded in a dark matter cloud — or *halo* — that extends far beyond visible matter. Without this halo's gravitational pull, galaxies would have grown much more slowly, and the universe as a whole would look vastly different.

One challenge to understanding how galaxies form and evolve is that astronomers can only observe snapshots of individual galaxies, each one representing a single moment in history. By analogy, imagine an alien who visits Earth for only one day and sees humans of all ages but isn't able to watch a baby grow into a mature adult. What could the alien learn about the human species?

For this reason, computer simulations that follow galaxy assembly over billions of years are a vital tool, complementary to observations. Simulations also help us visualize invisible dark matter. To test our ideas of galaxy formation, we create mock universes with different laws of physics and compare their predictions to what we see in sky surveys.

Such comparisons between theory and data lead to several important conclusions. First, galaxies have grown in a hierarchical "bottom-up" process. Small protogalaxies of dark



▲ **SCULPTOR GALAXY** Harlow Shapley spotted Sculptor (along with its cousin Fornax, on the opposite page), using photographic plates taken at the Boyden Observatory in South Africa. What was initially presented as a star count diagram *(left)* is now seen as a full-fledged galaxy thanks to the Wide-Field Imager at the La Silla Observatory *(right)*. Fornax and Sculptor were the first of the Milky Way's companions to be found using telescopes.

DIAGRAM: SHAPLEY, HARLOW. *HARVARD COLLEGE OBSERVATORY BULLETIN* NO. 908, MARCH 1938.; IMAGE: ESO

What is Dark Matter?

About 85% of the matter in the universe is thought to be in an invisible form distinct from atoms and known elementary particles. This invisible stuff is five times as abundant as “normal” matter in the universe at large.

Evidence for dark matter comes from our observations of epochs ranging from the first minutes after the Big Bang to the present day, size scales ranging from dwarf galaxies to the whole observable universe, and from a diverse set of astronomical instruments and techniques.

However, all of these observations show only the effects of gravity — we know little about dark matter beyond its gravitational influence. Many extensions to the Standard Model of particle physics predict new particle species that might make up some or all of dark matter.

A better understanding of dark matter could support or refute radically different perspectives on the fundamental nature of matter, energy, and spacetime.

matter and gas appeared first, then merged with each other to form galaxies, galaxy groups and, eventually, galaxy clusters. So we expect, and observations have confirmed, that the smallest galaxies in the modern universe are also the oldest.

Second, simulations predict that dark matter gathered into small halos early on, and that many of these have survived into the present day without yet being absorbed into a larger halo. Hundreds of dark matter halos might surround the Milky Way, each large enough to host its own stellar population and be considered a (dwarf) galaxy in its own right.

The First Known Milky Way Companions

Like many new classes of astronomical objects, the nature of these systems was initially uncertain. When Harlow Shapley, director of the Harvard College Observatory, discovered the Sculptor and Fornax dwarfs in 1938, he described them as

> *unlike any known stellar organization. . . . The new objects have some properties in common with globular clusters, others with spheroidal galaxies, and still others (nearness and complete resolution into stars) with the Magellanic Clouds.*

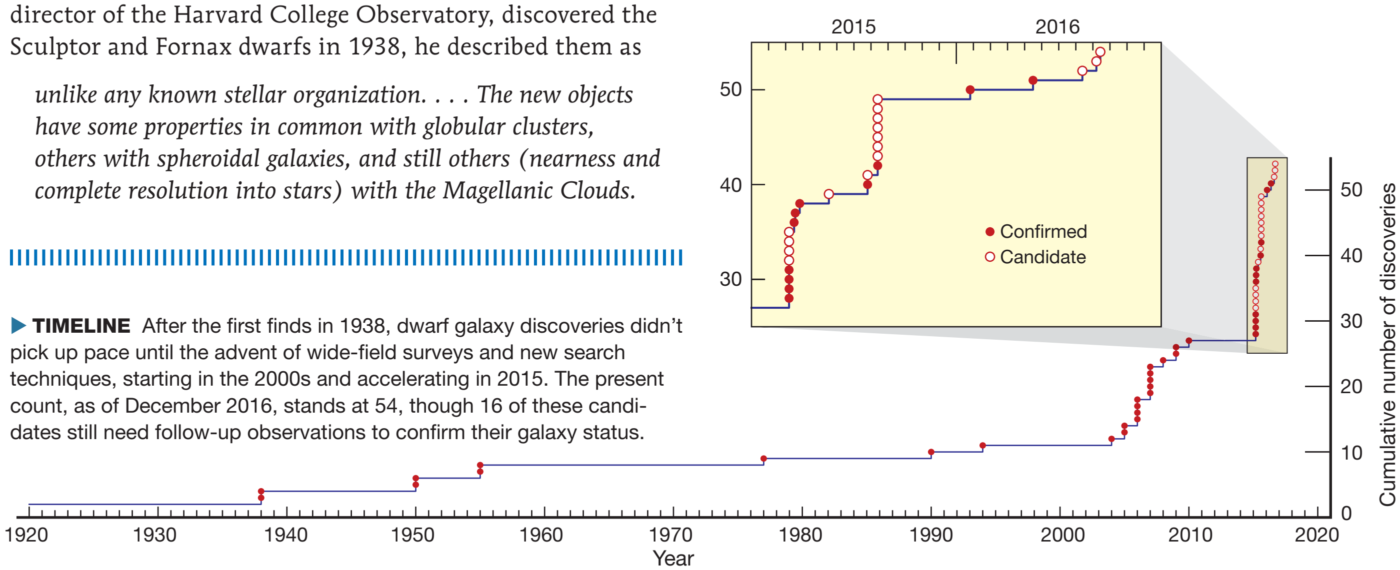
Shapley also anticipated that

> *There may be several others in the local group of galaxies; such objects may be of frequent occurrence in intergalactic space and of much significance both in the census and the genealogy of [galaxies].*

Indeed, by 2005 we knew of a dozen dwarfs orbiting the Milky Way. Yet, even though satellite galaxies of the Milky Way are close enough that we can resolve their light into individual stars, they’re still hard to find. With the exception of the LMC and SMC, the known satellites have no visible gas, dust, or other indications of ongoing star formation. Moreover, we have to sift through a dense foreground of Milky Way stars to find those few belonging to dwarfs, so in most cases we can recognize satellites only with the help of statistical search algorithms.

That’s why, starting in 2005, the Sloan Digital Sky Survey (SDSS) changed the field dramatically. Its digital maps and stellar catalogs eventually covered most of the Northern Hemisphere sky and transformed our knowledge of the Milky Way. Researchers developed algorithms to sift through this data and automatically identify places where more stars cluster together than usual. These searches led to the discovery of the first ultra-faint galaxies, some more than 100 times fainter than previous finds. Astronomers identified the smallest one based on only a few dozen possible member stars.

Echoing Shapley’s quandary, astronomers debated whether to classify these objects as tiny galaxies or very faint globular clusters. Eventually, dark matter became the deciding factor. Follow-up spectroscopy showed that the stars in ultra-faint galaxies move together as gravitationally bound groups. Yet the stars are moving too quickly relative to one another to *stay* bound unless some additional, unseen matter holds these systems together. By contrast, stellar motions within globular clusters can be explained solely by the stars’ own gravity.



▶ TIMELINE After the first finds in 1938, dwarf galaxy discoveries didn’t pick up pace until the advent of wide-field surveys and new search techniques, starting in the 2000s and accelerating in 2015. The present count, as of December 2016, stands at 54, though 16 of these candidates still need follow-up observations to confirm their galaxy status.

S&T: GREGG DINDERMAN, SOURCE: KEITH BECHTOL

Remarkably, the inferred dark matter mass in the central regions of ultra-faint galaxies is typically hundreds to thousands of times larger than the mass of the stars. Ultra-faint galaxies are essentially clouds of invisible dark matter with just enough stars to be detected.

A New Generation of Discovery

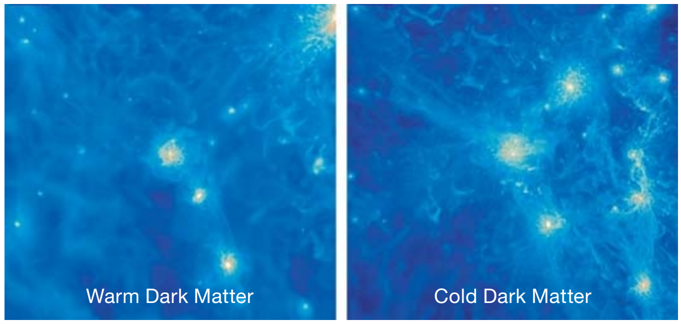
By 2010 the count of Milky Way satellites had grown to more than 25. But after the initial burst of discoveries from the SDSS, additional detections slowed to a standstill.

Then, during a six-month period in 2015, a combination of new wide-field, visible-light sky maps helped astronomers roughly double the number of Milky Way companions to 49 candidates. Five additional finds were reported by mid-2016. Spectroscopic observing campaigns have already confirmed seven of these new dwarfs by tracking the motions of their stars. Following tradition, our new galactic neighbors are named after their resident constellations.

Astronomers found these objects as part of larger efforts to map as much of the sky as possible. All of the new survey projects use advanced cameras with large fields of view — typically a couple of degrees across — that quickly scan the cosmos in pursuit of sources a million times fainter than the limit of human vision.

Many of the new satellites were found in images from the Dark Energy Survey (DES), a five-year project to map one-eighth of the celestial sphere. When finished, DES will record objects 10 times fainter than the SDSS. As the survey name suggests, its primary goal is to study dark energy, which causes the accelerating expansion of the universe. To this end, the survey will catalog thousands of supernovae and roughly 300 million galaxies beyond the Local Group. But DES images also contain millions of foreground stars in the Milky Way and its satellites, which is why it has proved such a successful tool for finding ultra-faint dwarfs.

The newfound stellar systems span a range of sizes and distances from Earth, and several have remarkable features.



▲ **DARK MATTER CLUES** These frames from a computer simulation known as Constrained Local Universe Simulations (CLUES) reveal how dark matter affects the formation of galaxy- and cluster-scale structures. Under a warm dark matter scenario *(left)*, dark matter doesn't clump easily. The cold dark matter scenario *(right)* predicts more clumps, potentially giving rise to many ultra-faint galaxies.

Tucana III appears to have a faint stellar stream, suggesting that the Milky Way's gravitational tug is pulling it apart. Crater II has a physical size comparable to the SMC but is about a thousand times fainter. The least luminous has only a few hundred stars. And while the nearest companions lie within 100,000 light-years of Earth, another galaxy named Eridanus II sits on the outskirts of the Milky Way, more than a million light-years away.

Cosmic Dark-Matter Laboratories

Finding our galaxy's faint companions enables us to explore dark matter's distribution in and around our galaxy. In the process, we might reveal dark matter's microscopic properties.

Under the standard theory of cosmology, "cold" dark matter particles move slowly compared to the speed of light, and they rarely collide with one another. In this cold dark matter scenario, the particles should coalesce into numerous tiny and dense halos, providing a multitude of places where dwarf galaxies can form.

That simple picture gets complicated in the real world, as dwarf galaxies are vulnerable to the gravitational tugs from

▲ **INSIDE MILKY WAY'S HALO** These frames, from a simulation known as Latte, map matter around a Milky Way-like galaxy. When only dark matter is simulated (*left*), many more dark matter clumps are predicted than when the physics of baryonic (non-dark) matter is incorporated (*center*). Only a small percentage of these clumps will go on to capture gas, form stars, and be detected as dwarf galaxies (*right*). Ultra-faint galaxies are thought to be associated with the largest of these clumps.

TOP: K. RIEBE / PMVIEWER; BOTTOM: A. WETZEL ET AL. *THE ASTROPHYSICAL JOURNAL LETTERS*, 827, 2016 AUGUST 2016

nearby galaxies. Feedback from their own stars might also halt dwarfs' growth. A comprehensive census of nearby satellites and increasingly realistic simulations of their growth will therefore help us test the cold dark matter framework.

We can also approach dwarf galaxies as particle physics laboratories. Some dark matter scenarios predict that the particles annihilate each other when they meet, or that they spontaneously decay on their own. Either process could produce gamma rays, electrons and positrons, or neutrinos.

This possibility has motivated hundreds of investigations into the origin of an unexpected gamma-ray glow radiating from the Milky Way's center. The signal might emanate from annihilating dark matter particles, or it may come from more conventional sources along the same line of sight, such as undiscovered pulsars. Because dark matter so heavily dominates ultra-faint galaxies, annihilation signals from these systems would be easier to interpret than those from our galaxy's core.

So far, though, no excess gamma-ray emission has been found in the direction of known Milky Way satellites. This non-detection has already allowed us to exclude several dark matter scenarios, and a direct test of dark matter explanations for the galactic center signal is close at hand.

Dwarf Galaxies and the First Stars

Ultra-faint galaxies can also teach us about the universe's first stars. From deep Hubble Space Telescope imaging of Milky Way satellites, we know that most of the stars in these dwarfs formed more than 10 billion years ago. They are galactic fossils, records of what the cosmos was like long ago.

Nearly all of the chemical elements heavier than helium that occur naturally in our universe are forged by nuclear fusion within stars or in explosive events at the end of the stellar life cycle. The chemically enriched gas from one generation of stars then becomes fuel for the next. This chemical evolution within galaxies makes possible the formation of planets and, ultimately, life.

Ultra-faint galaxies are reservoirs of some of the oldest and most chemically pristine stars in the universe. Any star serves as a time capsule, preserving a record of the conditions that existed when it was born. In ultra-faint galaxies, this record is largely unpolluted, thanks to meager stellar populations and fleeting periods of star formation. With high-resolution stellar spectroscopy, we can obtain each star's precise chemical "fingerprint." Thus the makeup of a dwarf's stars can record even a single major event that impacted an ultra-faint galaxy's history, such as a supernova.

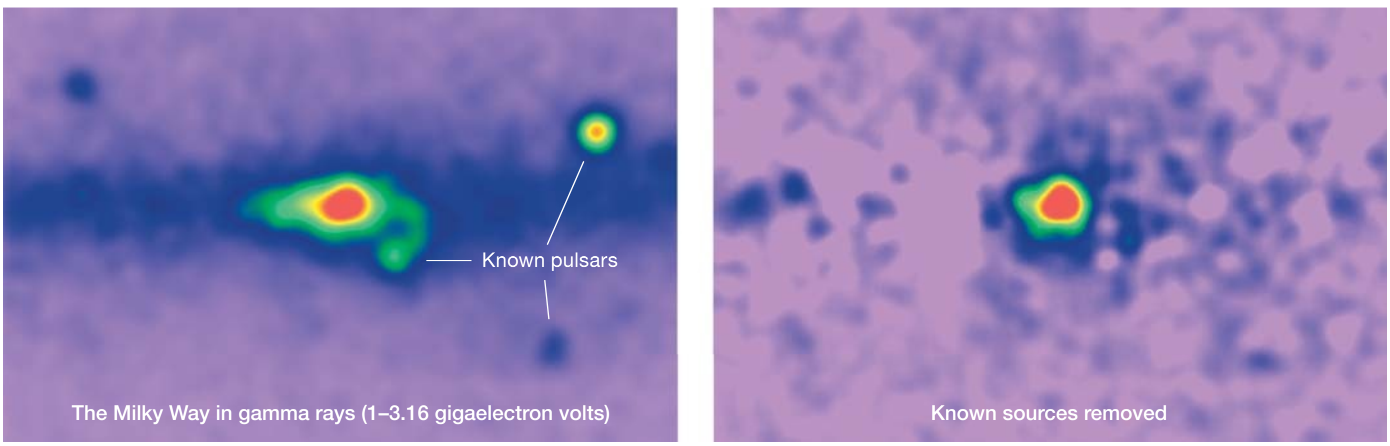
Astronomers may have recently discovered the imprint of just such an event in Reticulum II. Several of its stars have exceptionally high levels of certain heavy elements, known as *r-process elements*, which can only be made in cosmic explosions involving copious amounts of neutrons, such as when two neutron stars collide. We haven't found any other Milky Way satellites that share this chemical fingerprint, so such events are probably few and far between.

Satellites of Satellites

Intriguingly, the most recently discovered batch of satellites is concentrated in the direction of the Magellanic Clouds. Of the 17 dwarf galaxy candidates found in the DES, 15 of them are located in the southern half of the surveyed area, near the LMC and SMC. Since the DES is more sensitive than the SDSS, it will naturally detect more satellites; still, the detection of so many satellites in one small part of the sky caught astronomers' attention.

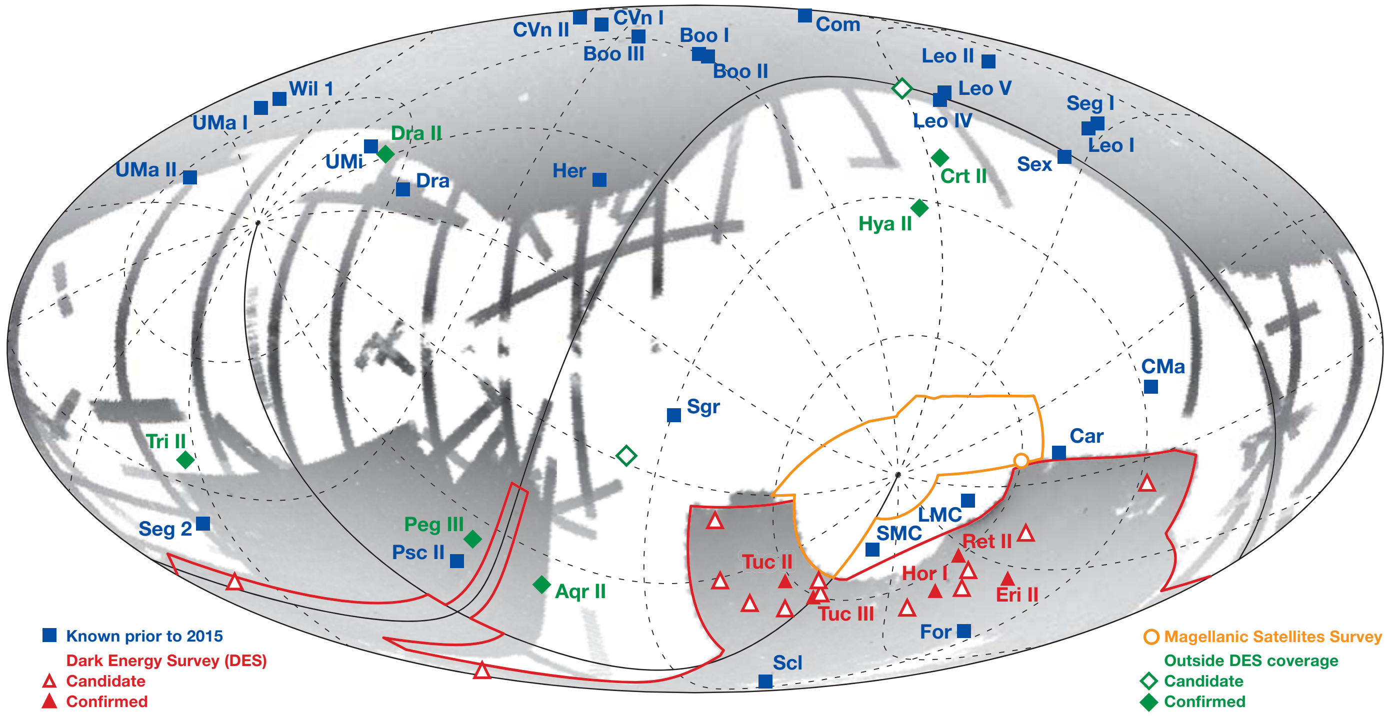
Perhaps some of these ultra-faint galaxies began as satellites of the Magellanic Clouds before arriving at the Milky Way. The notion that the LMC and SMC brought in their own galactic entourage is right in line with the bottom-up scenario of galaxy formation.

However, finding such satellite groups could have some important implications. For one, a compact cluster of satellites would support the idea that the Magellanic Clouds have only recently joined the Milky Way (*S&T:* Oct. 2012, p. 28).



▲ **GAMMA-RAY EXCESS** The Fermi Gamma-ray Space Telescope found that the center of the Milky Way produces gamma rays (*left*), even more than can be explained by known sources (*right*). It could be that there's an undiscovered population of pulsars in our galaxy's center. Or it could be that the signal comes from the mutual annihilation of dark matter particles. Ultra-faint galaxies make good laboratories to test the latter scenario.

T. LINDEN / UNIVERSITY OF CHICAGO



SOURCE: KEITH BECHTOL

Otherwise, our galaxy would have drawn the satellites away from the Clouds long ago and strewn them about the sky.

More generally, finding ultra-faint galaxies that grew in the vicinity of a larger dwarf might also shed light on how neighboring galaxies affect each other's growth. Ultra-faint galaxies may be viewed as astronomical "canaries in a coal mine," since they're particularly sensitive to their local setting.

We will soon be able to further explore the "satellites of satellites" hypothesis in a new project called the Magellanic Satellites Survey. That endeavor will investigate the sky on the other side of the Magellanic Clouds (where DES doesn't look) to see if we can find additional ultra-faint galaxies lurking there.

▲ **DWARFS: PAST, PRESENT & FUTURE** This map plots the locations of the Milky Way's dwarf galaxy companions. Those discovered before 2015 are marked as blue; ultra-faint galaxies revealed in the Dark Energy Survey (red outline) are marked as red; and dwarfs found in other recent surveys are marked as green. Open symbols represents candidates that need further observations to confirm their dwarf galaxy status, and the orange outline marks the just-started Magellanic Satellites Survey. The map is centered on the Milky Way, and the grayscale background indicates the number of stars per area of the sky, as calculated from the SDSS and DES sky surveys. The coordinate grid is equatorial; the black solid lines show the celestial equator and zero meridian.

The Search Continues

Now our story has come full circle: we have scoured the sky for Milky Way companions and found that some satellite galaxies might have their own, even smaller companions! Moreover, some forecasts envision several hundred more ultra-faint galaxies still at large in the Milky Way neighborhood. Each discovery offers a new perspective on galaxy formation. And a lack of discoveries might be telling, too, in deciding which dark matter framework is closest to reality.

One of the most exciting upcoming projects in this context is the Large Synoptic Survey Telescope (LSST), which will scan the full sky visible from Chile every few nights for 10 years, starting in 2022 (*S&T:* Sept. 2016, p. 14). A single 15-second exposure will rival five years of DES, and by combining repeated images of the same area of sky, LSST will bring out stars more than 10 times fainter.

LSST and other surveys will do more than spot dwarf galaxies around the Milky Way; they will give an even better look at their future, and their past. The fate of most satellite galaxies is to be subsumed into the Milky Way over the next few billion years — those that venture too close to our galaxy's core experience tidal gravitational forces that stretch them into stellar streams. For instance, the stellar stream of the Sagittarius dwarf now wraps around our galaxy several times. Such stellar debris holds clues to the past. In the not too distant future, we hope to reconstruct the Milky Way's history by identifying the remains of its past companions.

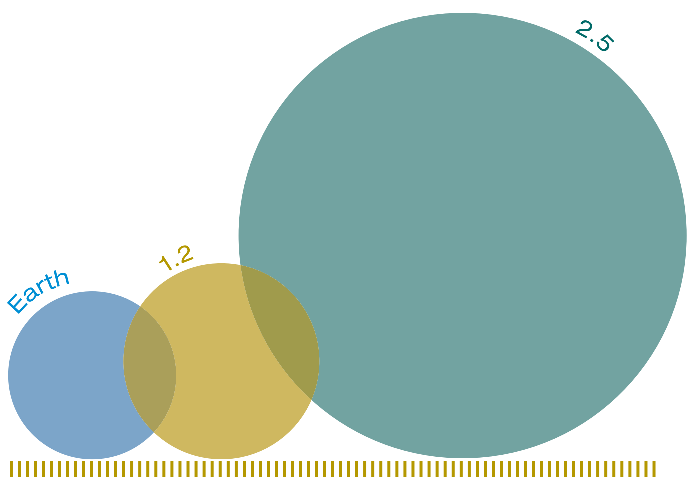
And that gives one much to ponder while admiring the night sky over Chile.

• Visit **https://is.gd/ultrafaintgalaxies** to find an image gallery of ultra-faint dwarf galaxies.

■ **KEITH BECHTOL** is an associate scientist working with the Large Synoptic Survey Telescope construction project and an active member of the Dark Energy Survey and Fermi LAT collaborations. He wrote most of this article as a John Bahcall postdoctoral fellow at the University of Wisconsin-Madison.

The Secrets of SUPER-EARTHS

The galaxy is teeming with planets that have no parallel in our solar system & were once thought impossible.



WHAT IS A SUPER-EARTH?

Astronomers don't all use the same criteria, but a super-Earth is generally no more than 5 to 10 times more massive than Earth or between 1.2 and 2.5 Earth radii. (The Kepler team draws the line between super-Earth and mini-Neptune at 2 Earth radii.) Mini-Neptunes are less than about 3 Earth radii.

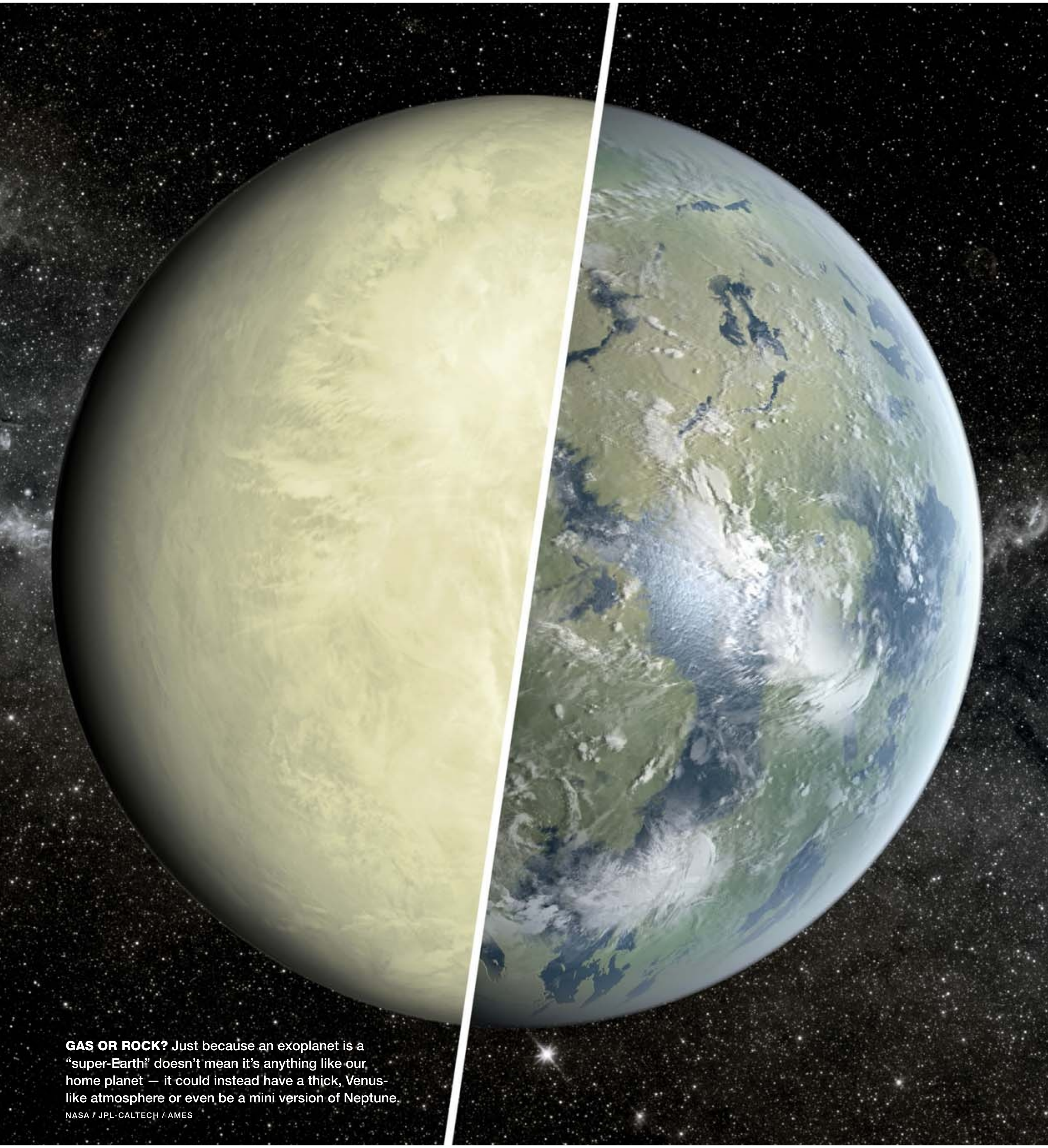
The first exoplanets discovered were truly alien. To begin with, the two planets don't orbit a star, but a millisecond pulsar dubbed PSR 1257+12 — a tiny, corpse-like remnant of a once mighty star that rotates more than a hundred times each second. The pulsar blasts them with a stream of particles, which likely causes permanent auroras that dance across both planets' dark skies and polishes their surfaces until they glisten.

But these oddities pale in comparison to the mass of the two planets: at three to four times the mass of Earth, these worlds have no parallel in the solar system.

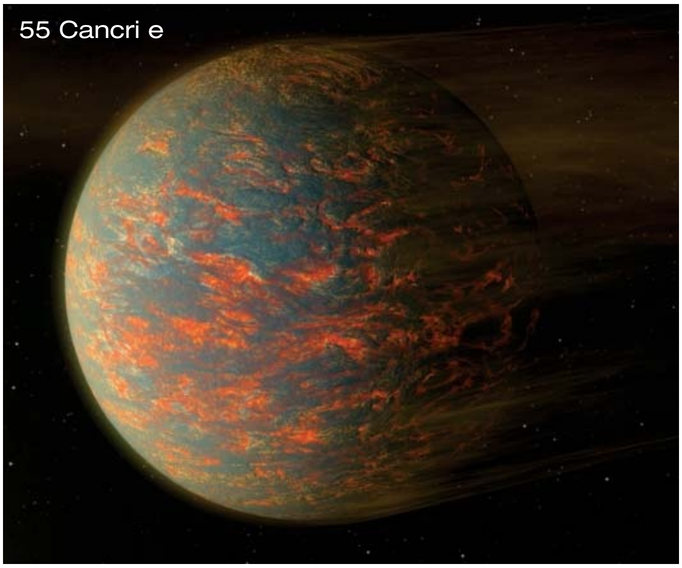
After Earth, the next widest planet in our system is gaseous Neptune, which is nearly four times larger than Earth and weighs 17 times more. (Uranus is a little wider but less massive, at 14.5 Earths.) Astronomers had thought any planets between Earth and Neptune were strictly forbidden. Instead, they had concluded, bodies a little heavier than Earth would rapidly pull in a thick envelope of hydrogen and helium gas as they formed, puffing up into giants like Neptune. There was simply no in-between.

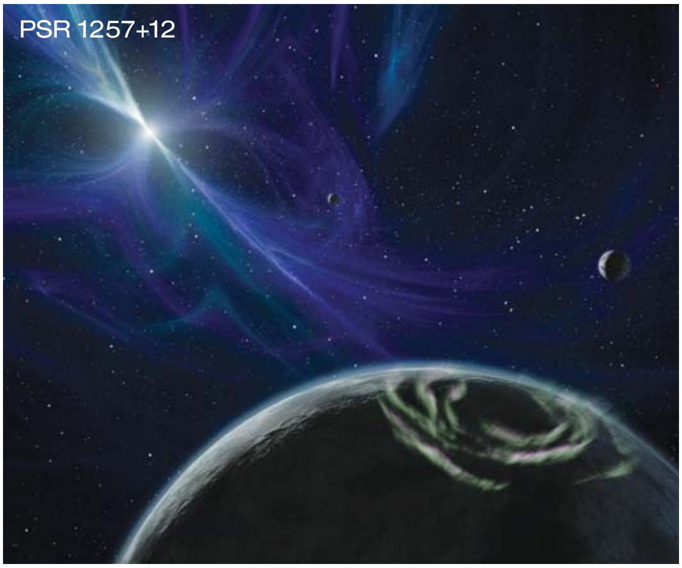
The first exoplanets proved otherwise. "Looking back on that system, it's pretty clear that it was a preview of what we're finding today," says Aleksander Wolszczan (Penn State University), one of the two astronomers responsible for the discovery.

And today's exoplanets are just as odd as those first worlds. Take GJ 1214b, a mini-Neptune cloaked in a dark fog of superheated gases, as an example. Or 55 Cancri e, a super-Earth possibly coated in flowing lava. Perhaps no two worlds better walk us through the challenges and surprises of these unexpected planets than these two.



GAS OR ROCK? Just because an exoplanet is a "super-Earth" doesn't mean it's anything like our home planet — it could instead have a thick, Venus-like atmosphere or even be a mini version of Neptune.
NASA / JPL-CALTECH / AMES





But they are only manifestations of a greater story. Now, over two decades after the first discovery, astronomers have spotted thousands of exoplanets. They know that there are more planets in the universe than there are grains of sand on all the beaches in the world — and most of those planets appear to fall into this regime between Earth and Neptune. The galaxy is overrun with these "forbidden" worlds.

A World Soaked in Water?

After Wolszczan's discovery, exoplanets around typical stars trickled in slowly. The first few were discovered via the *radial velocity technique*. An orbiting planet will tug ever so slightly on its parent star, causing that star to wobble — an effect that can be seen in the star's spectrum of light. Because more massive planets will pull harder than less massive planets, this technique reveals the mass of the orbiting bodies.

Perhaps optimistically, astronomers first called any exoplanet that was less massive than Neptune, but more massive than Earth, a super-Earth. "What we didn't know — because you can't get it just from these wobble measurements — was whether these were true super-Earths, scaled-up versions of the Earth, or whether they were mini-Neptunes," scaled-down versions of Neptune, says David Charbonneau (Harvard-Smithsonian Center for Astrophysics).

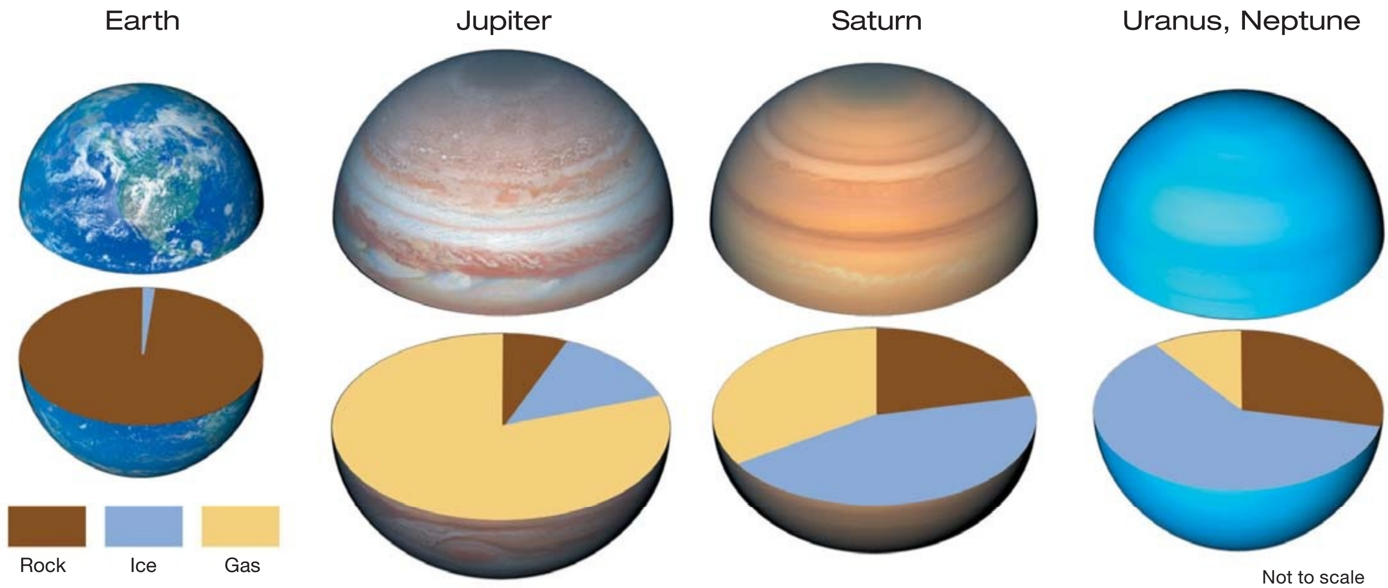
To actually determine whether a planet is rocky or gaseous, astronomers also need to know its size. This, combined with its mass, gives astronomers the planet's average density — and a rough guess at the planet's composition. If a newly discovered planet crosses in front of its host star as seen from Earth, it will block some of the starlight and cause it to dim ever so slightly. Because larger planets block more of their star's light, and because we can estimate a star's size based on its spectral type, this technique reveals the size of the orbiting bodies.

Still, a planet's density is deceptive. And no world demonstrates that better than GJ 1214b.

When Charbonneau and his colleagues first spotted the planet in 2009, they saw a world that was 6.6 times heavier than Earth and 2.7 times wider. Although they called it a super-Earth, the density, which is consistent with a water-heavy makeup, didn't divulge the planet's secrets. "The problem is that you can actually mimic a water-rich world by taking a ball of rock and putting hydrogen and helium on top," says Heather Knutson (California Institute of Technology).

The density alone would have left astronomers at a roadblock, but they hadn't used all their wiles just yet. By observing the spectrum of the planet backlit by its host star, astronomers can peer into its atmosphere, finding yet another clue about the planet's composition. In this case, a thick layer of clouds revealed that the term super-Earth is likely a mis-

◀ **SYMPHONY OF "SUPER-EARTHS"** These illustrations depict four super-Earths/mini-Neptunes: 55 Cancri e (*top*, 8 Earth masses), the two around PSR 1257+12 (*center*, 3.9 and 4.3 Earth masses; the third world is about Mercury's mass), and GJ 1214b (*bottom*, 6.3 Earth masses). Although separated by only 4 Earth masses from least to greatest, these four worlds are all distinct — and have no counterpart in the solar system.



▲ **SOLAR SYSTEM PLANETS** Our system's outer planets have compositions distinct from Earth and from one another. The proportion of ice (blue) goes up, and that of hydrogen and helium (yellow) goes down, farther from the Sun. Astronomers are now struggling to understand where super-Earths fit in this picture — which likely changes from super-Earth to super-Earth.

nomer: GJ 1214b appears to have a puffy atmosphere. It isn't a water world but a gaseous world, more akin to Neptune, Charbonneau says.

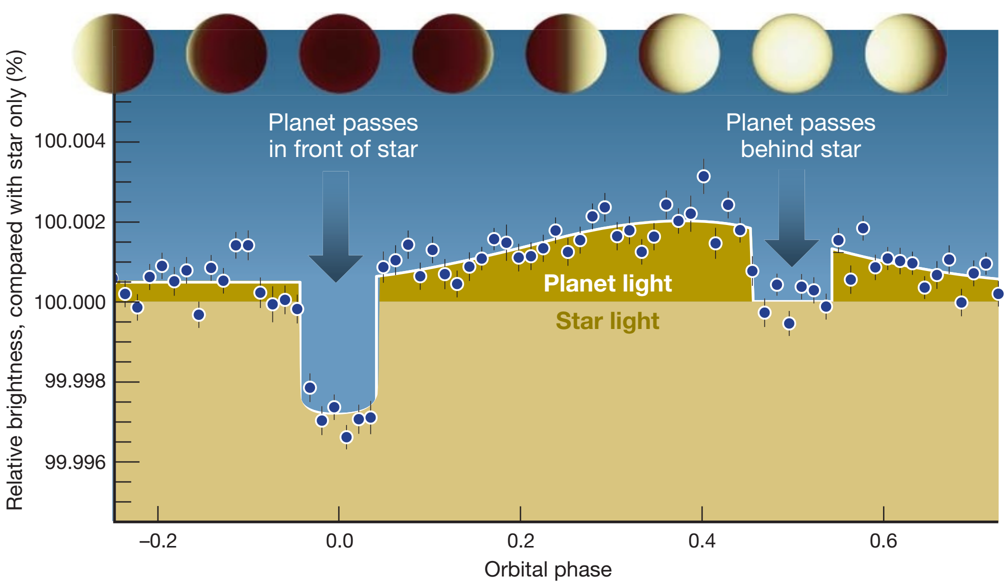
In an attempt to not repeat that mistake, astronomers searched for a dividing line between mini-Neptunes and super-Earths. They did so by measuring the average density for dozens of these small worlds, then figuring out the most likely composition based on those densities. So far, it looks like planets up to 1.5 to 2 Earth radii are truly super-Earths. These worlds have relatively thin atmospheres, and in this regime the larger the planet, the denser it is — a telltale sign that the bodies are rocky.

But beyond twice Earth's size, planets become increasingly fluffy. That means that they're mostly massive atmospheres of hydrogen and helium. These are the mini-Neptunes.

Unfortunately, that line blurs around the edges. Knutson's favorite exoplanet, for example, is Kepler-138b. Although it's less massive than Earth, its radius is 50% larger, making it a "tiny puffball," she says. "It's actually another great example of a planet that defies conventional wisdom."

A World Coated in Lava

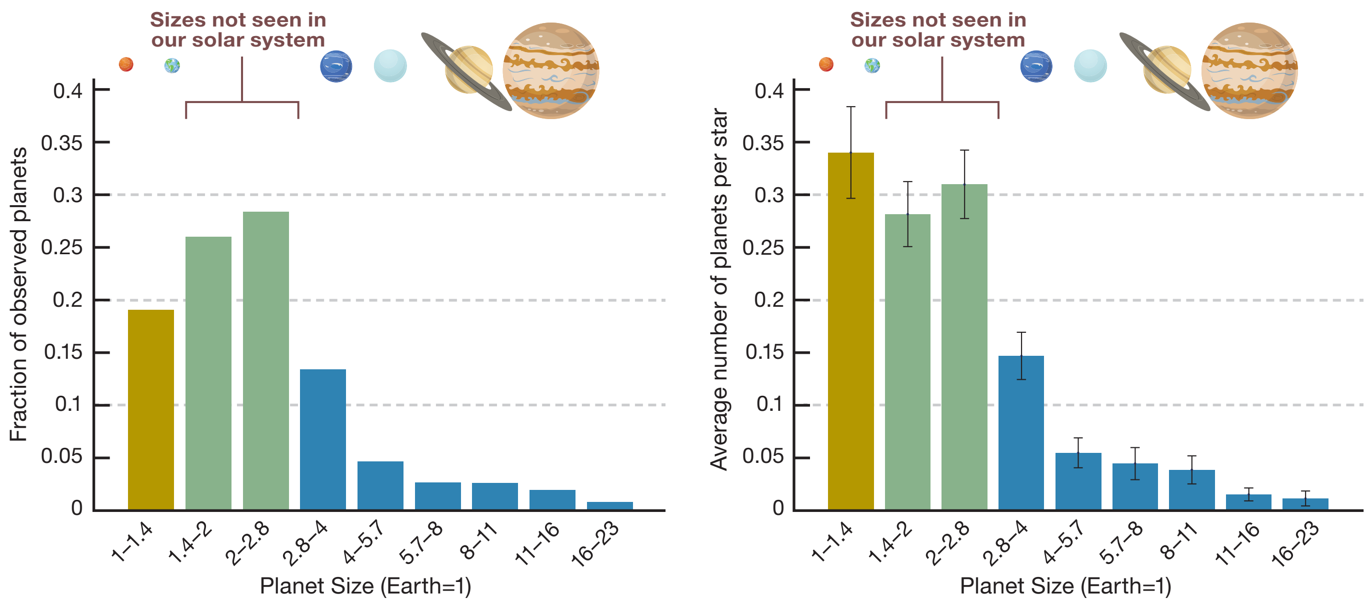
In a few rare instances, astronomers have struck solid ground. In 2004, they discovered 55 Cancri e orbiting a star only 40 light-years away. At twice Earth's size, the planet straddles the hazy boundary between rocky worlds and gas giants. But it



Phases of a Super-Earth

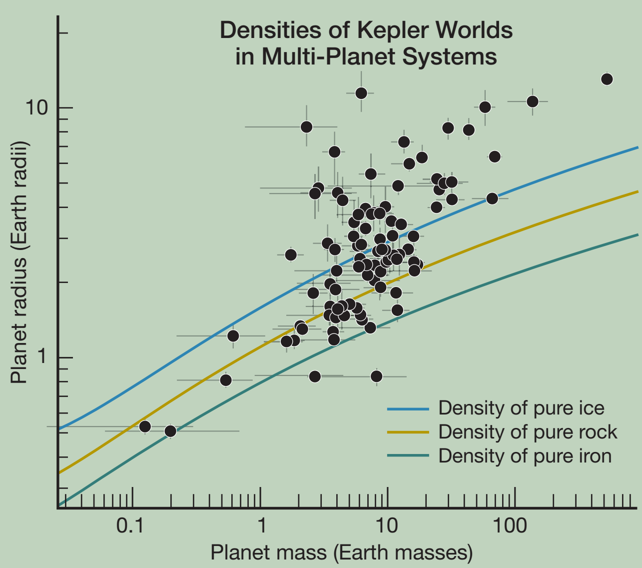
◖ This light curve tracks the varying infrared brightness of the system 55 Cancri as its planet "e" passes in front of (big dip) and behind (little dip) the star. The depth of the dips reveals not only how much light comes from just the planet (dark yellow) but also how the temperature of the planet's dayside compares with that of its nightside.

TOP: DON DAVIS & DAVID HUGHES; BOTTOM: *S&T* LEAH TISCIONE, SOURCE: NASA / JPL-CALTECH / UNIV. OF CAMBRIDGE



▲ **WHAT KEPLER SAW** In its primary mission, Kepler discovered thousands of potential exoplanets orbiting within 1 astronomical unit of their host stars. On the left is a graph of the confirmed worlds, divvied up by size. The *y*-axis is the fraction of planets that fall into each size category. On the right is an extrapolation from that discovery population: astronomers' estimate for the average number of planets from each category per star, based on various assumptions and data corrections. (Black, bracketed bars indicate uncertainty ranges.)

Density Matters



◖ Astronomers can surmise a planet's potential composition if they know both its radius and mass. Plotted here are a few dozen worlds in multi-planet systems discovered by Kepler for which that's true (with reasonable uncertainties). The contour lines designate densities for pure ice, rock, and iron. Planets above the ice line are less dense than ice, suggesting that they have thick gas envelopes. These worlds are all within a few tenths of an astronomical unit of their host stars.

wasn't until 2016 when Brice-Olivier Demory (University of Bern, Switzerland) and his colleagues created the first heat-map that they realized what an oddity this world is.

Using 75 hours of observing time on NASA's infrared Spitzer Space Telescope, the team mapped 55 Cancri e's thermal "phase curve." Because the planet is tidally locked to its host star, like the Moon is to Earth, one hemisphere is eternally bathed in sunlight while the other is eternally dark. But the same side isn't always pointed at *Earth*: seen from a distance, astronomers observe the planet pass through phases, from new through crescent to full and back through crescent to new again, just as we see with Venus. They can thus image both hemispheres as the planet circles the star and search for any temperature differences between the day- and nightsides.

Demory's team suspected that strong winds would carry heat from the dayside to the nightside, meaning that they would both radiate at similar temperatures. But instead, it looks like 55 Cancri e's dayside is twice as scalding as its nightside. "We were surprised to see a contrast similar to the Moon, suggesting that there was no significant atmosphere surrounding it," Demory says.

But there was a contradiction in the team's measurements. While there was clearly no atmosphere, the planet's hottest point, which should reside directly beneath the star overhead, had shifted — an effect that astronomers usually attribute to heavy winds. Without an atmosphere, Demory and his colleagues think the movement is instead due to lava. A patch of molten rock at the surface could circulate the heat away from the planet's hottest point.

Although not all astronomers are convinced that 55 Cancri e is a lava world, it's pretty clear that the planet is far from

S&T: LEAH TISCIONE, TOP SOURCE: NATALIE BATALHA / NASA AMES, PLANET ICONS: MEOWU / ISTOCK; BOTTOM SOURCE: S. HADDEN AND Y. LITHWICK habitable. That's the story with most super-Earths spotted so far. Astronomers have also discovered a world that rains glass and others that are so hot, iron would melt on their surfaces. And don't forget the two circling that deadly pulsar. It's now clear that some super-Earths, despite their name, are the antithesis of Earth.

Still, astronomers have made progress in their hunt for planets that do resemble Earth — arguably the Holy Grail of exoplanet research. In 2015, Courtney Dressing (Caltech) and others calculated the density of 10 small exoplanets and found that the five with radii smaller than 1.6 Earth radii fall in the same density range as Venus and Earth. This suggests that these five worlds have roughly the same chemical makeup as our home planet: a mix of silicon, iron, oxygen, magnesium, and trace amounts of other metals.

Stitching Together a Planet's Saga

What causes such a wide array of diverse super-Earths? In the case of 55 Cancri e, it might be the planet's backstory. Astronomers used to consider planetary systems reasonably ordered and well-behaved — even from the get-go. As such, the traditional model of planet formation (which dates back to the 18th century) said that planets remain roughly where they form. As they coalesce out of the swirling disk of gas and dust, the inner part of the disk is too warm for planets forming there to grow much bigger than Earth, whereas the outer part of the disk contains so much icy material that these planets could easily reach Jupiter-like proportions.

But the discovery of 55 Cancri e, which hugs its star tighter than it "should," and other super-Earths like it turned this theory on its head. "It's like saying if you have a dice and you only roll it once, that you know everything about the dice," Knutson says. "You don't know anything until you roll it a bunch of times, and then you understand that there are six different possible numbers that you can get, and the probability is the same for each. So in a way that's what we're trying to do with exoplanets as well. We're trying to roll the dice a bunch of times [and] see all the possible outcomes, so that we can understand which things are more likely and less likely, and then develop stories to explain the different routes that you can go down in forming planets."

The sheer existence of these hot exoplanets upset conventional models of planetary evolution. Some astronomers are investigating whether the planets could have somehow formed in situ, while other astronomers suggest that they likely formed in the outer disk and then migrated inward via gravitational interactions.

But just how this migration occurs is unknown. Planets are either launched inward by interactions with the disk of primordial gas that they formed in, or they're later propelled there by encounters with their planetary siblings. The first mechanism has to happen before the disk dissipates, so it occurs within a couple million years. The second mechanism can take more than 100 million years.

Given that most discovered exoplanets circle middle-aged stars, astronomers couldn't decipher which mechanism is at play. That is until last year, when the Kepler Space Telescope detected a hot Neptune that orbits a stellar infant. In a system that's only 10 million years old, the planet must have migrated via interactions with its gravitational disk. Other research, too, has hinted that disk migration might have the upper hand.

Yet planets around Neptune's size might not last long so near their suns. Kepler Mission Scientist Natalie Batalha (NASA Ames Research Center) has discovered a dearth of hot mini-Neptunes — unlike all other planet types, worlds of this size aren't found baking in their star's light. Because there's no reason why these planets alone wouldn't migrate inward, Batalha thinks that they shape-shift into super-Earths.

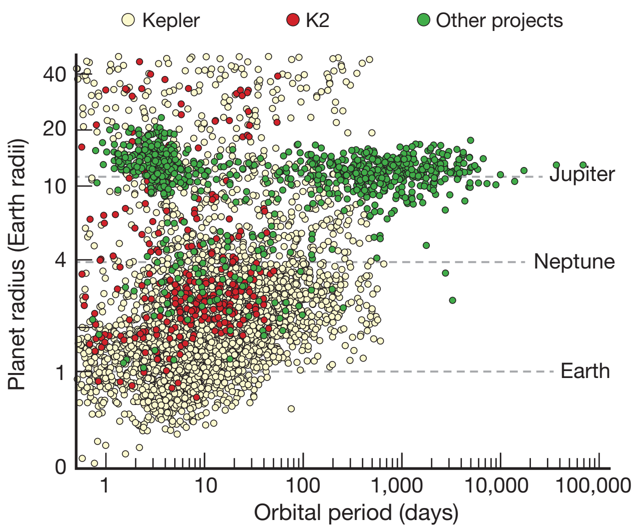
In theory, she explains, these planets begin life as mini-Neptunes in the cold outer reaches of their planetary systems. Then after they migrate inward, the star's intense radiation blows away their atmospheres, leaving a steaming core that looks like a super-Earth. So it might just be that some super-Earths are the skeletal remnants of their puffier cousins.

HOW COMMON?

Approximately one-third of all systems discovered by Kepler have a super-Earth or mini-Neptune. Conversely, only one out of every 200 has a hot Jupiter.

Where is the Solar System's Super-Earth?

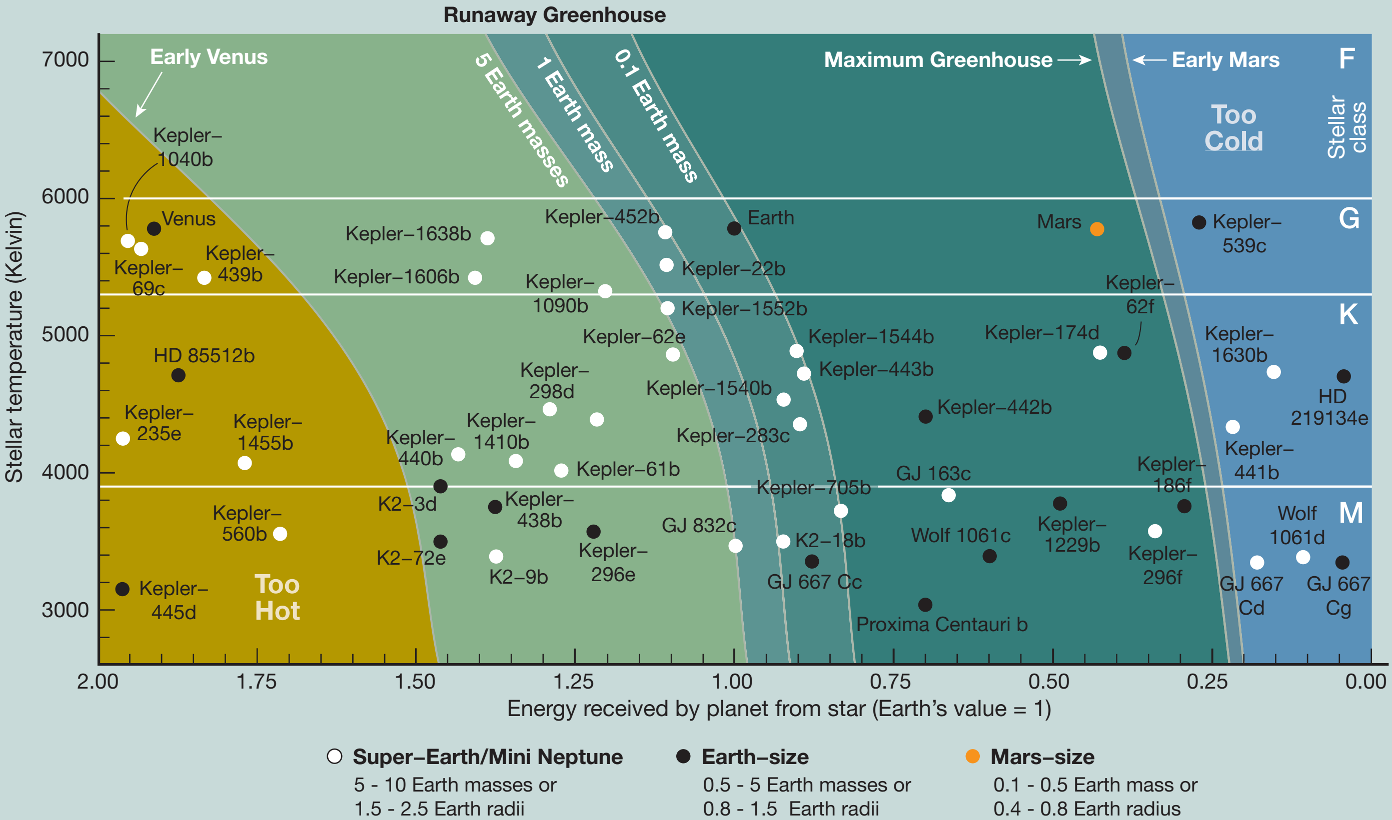
It was the launch of the Kepler space telescope in 2009 that transformed the trickle of exoplanet discoveries into a cas-



▲ **THE HOT MINI-NEPTUNE DESERT** Thanks to Kepler, astronomers have found hundreds of small exoplanets huddled up against their stars. But strangely, there's a gap in the data: planets between 2 and 10 Earth radii don't seem to have periods of less than 4 days. Perhaps such worlds are stripped down to super-Earth sizes.

JUPITER: ISTOCKPHOTOS.COM / MEOWU; DIAGRAM: S&T LEAH TISCIONE, SOURCE: NATALIE BATALHA / NASA AMES

Small Habitable-Zone Planets



Shown here are confirmed, potentially rocky exoplanets that fall in their stars' habitable zones (HZs), as compiled by the Planetary Habitability Laboratory at the University of Puerto Rico, Arecibo. The "optimistic" HZ (all green regions) is set by observations of Venus and Mars: based on the last time Venus and Mars could have had liquid surface water, and how bright the Sun was at that epoch, astronomers draw the inner and outer habitability boundaries for how much stellar radiation a planet needs to receive in order to be habitable. The "conservative" HZ is darker green and based on simplified climate models for an Earth-like atmosphere, which includes the greenhouse effect of water and carbon dioxide. Smaller planets are more vulnerable to greenhouse-gas runaway than larger ones, so the inner edge of the conservative HZ depends on a planet's mass. One important caveat: exoplanet research is still an imprecise science, so no two habitability catalogs agree — a planet shown here might not appear in the Kepler's team habitable-zone list, or vice versa. Learn more about this chart at **https://is.gd/hzsaga**.

cade. Roughly one in every three planetary systems discovered by the observatory has a super-Earth or a mini-Neptune in tow (in comparison, one in every 50 planetary systems has a Saturn- or Jupiter-like planet). This translates to roughly 700 super-Earths and 900 mini-Neptunes discovered thus far.

The result was absolutely shocking, says Jacob Bean (University of Chicago). "That's the thing in astronomy — if you go look, you're going to find something unexpected," he says. "The universe and nature are a little more creative than we are."

With so many planetary systems observed, theorists are playing catch up. They're coming up with scenarios for growing forbidden planets and envisioning how planets can form in chaotic environments that allow them to migrate inward. But these theories are also forcing astronomers to turn the telescope back around and ask the question: Why is the solar system different? Why doesn't it contain the one kind of planet most common around other stars?

One explanation is the "grand tack" scenario, in which Jupiter migrated into and then back out of the inner solar system. "So Jupiter comes charging in and throws a bunch of stuff around the inner solar system, which causes those super-Earths to accrete onto the Sun and then Jupiter moves back out again and leaves behind the depleted disk of material, which then forms the terrestrial planets," Knutson says. "That's pretty speculative. I don't know if we have any clear evidence that that happened, but it's at least one story that we can tell."

Another story suggests that there is a super-Earth in the solar system today. In 2014, it became clear that *some-*

S&T: LEAH TISCIONE, SOURCE: PLANETARY HABITABILITY LABORATORY / UNIVERSITY OF PUERTO RICO, ARECIBO *thing* might be stirring up the icy bodies of the Kuiper Belt. Although such a planet, which is perhaps 10 times as massive as Earth and two to four times its size, has avoided detection, the lines of evidence (albeit indirect) in favor of its existence are multiplying. And astronomers are on the hunt.

The sheer possibility of our own super-Earth raises hope for astronomers that the solar system might not be so alien after all. "If it turns out that we do have one, that would make me feel better because it would mean that we're more normal," says John Armstrong (Weber State University). "I'm concerned about us being normal because if we're not normal and there's something really special about the solar system, then life is probably rare. But if we're just a garden variety solar system, then that gives me hope that life is not rare."

Beyond the Mirror

Although the solar system appears alien compared to most planetary systems discovered so far, astronomers have not yet seen those planetary systems in their entirety. Kepler observations probe systems out to one astronomical unit — the distance from the Sun to Earth. This is only 2% of the solar system's radius. As future missions probe more distant orbits, we may come to find that Earth-like planets are common (as early results from Kepler suggest) or we may stumble upon more surprises.

"In order to answer all these questions we have to leave the Kepler survey behind and look for these kinds of planets around closer and brighter stars, and also preferably around small stars, because those are the ones that are easiest to follow up and really characterize," Knutson says. Astronomers were able to study GJ 1214b's atmosphere and probe 55 Cancri e's surface because their stars are close to us and therefore bright.

With this in mind, NASA will launch the Transiting Exoplanet Survey Satellite (TESS) in December 2017 (at the earliest). Like Kepler, TESS will look for dips in a star's light due to a transiting exoplanet. But unlike the primary Kepler mission, which focused on a patch of stars in one part of the sky, TESS will sweep across nearly the entire sky and focus on nearby stars. Then, in order to scrutinize these worlds in detail, astronomers will turn to the James Webb Space Telescope, a telescope with a mirror roughly three times as wide as Hubble's that will launch in late 2018.

"James Webb will be the star of the show," Knutson says. It will shed light on super-Earths and mini-Neptunes, allowing astronomers to better understand how these worlds formed and whether any might be habitable — which will help astronomers better understand how the solar system itself formed as well as the circumstances that led to life.

"As the Greek philosophers said in the past, it's always by looking far away and then coming back that we understand things," Demory says. "It's not just by looking at ourselves."

As a freelance science journalist, **SHANNON HALL** spends her days pondering the wonders of the universe from a local coffee shop.

Could Super-Earths Be Super-Habitable?

NIVIX / WIKIMEDIA COMMONS / GFDL 1.2

ISLAND OASES Exoplanets with widespread shallow seas and islands, reminiscent of this one in Norway, might be life havens.

With the search for life at the forefront of most astronomers' minds, John Armstrong (Weber State University) and René Heller (Max Planck Institute for Solar System Research, Germany) set out to answer the question: could there be planets where life is more likely to arise than it did on Earth? Together, they theorized that super-Earths might just be those planets.

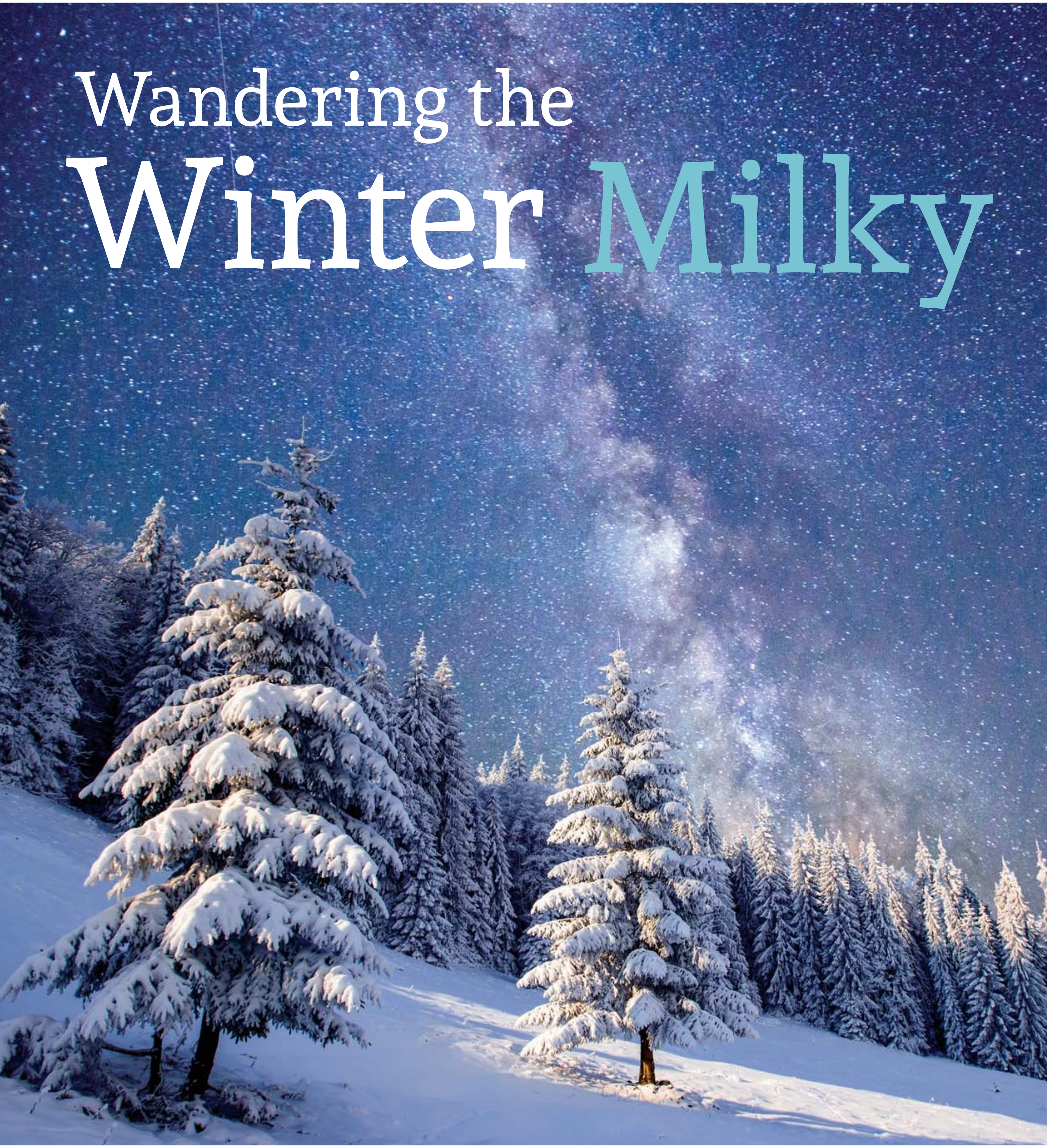
To begin, super-Earths have a higher surface gravity than Earth-size worlds, which could cause them to hang on to thicker atmospheres. This would allow them to retain heat at farther distances from their star, extending the habitable zone. But it would also yield a smoother planet, which would cause water to pool in shallow seas dotted with island chains rather than in deep oceans separated by large continents. Heller and Armstrong argue that this is more conducive to life because islands and shallow waters are among the most biologically dense spots on the planet.

The idea excited Ravi Kopparapu (Penn State University), because life in shallow waters is more likely to influence its atmosphere — a signature that astronomers could observe. But the good news doesn't end there. If life is more likely to arise on super-Earths, their heavy masses will make them much easier to detect and characterize than Earth-size planets.

Finally, a planet more massive than Earth would retain significantly more heat within its interior from its initial formation. Not only would this heat reservoir create a spinning molten core — producing a powerful, global magnetic field that could protect the atmosphere from harmful space radiation — but it would also prolong volcanism and plate tectonics, which together could help regulate the planet's temperature.

To use Armstrong's phrase, super-Earths might be *super-habitable*.

Wandering the Winter Milky



Way

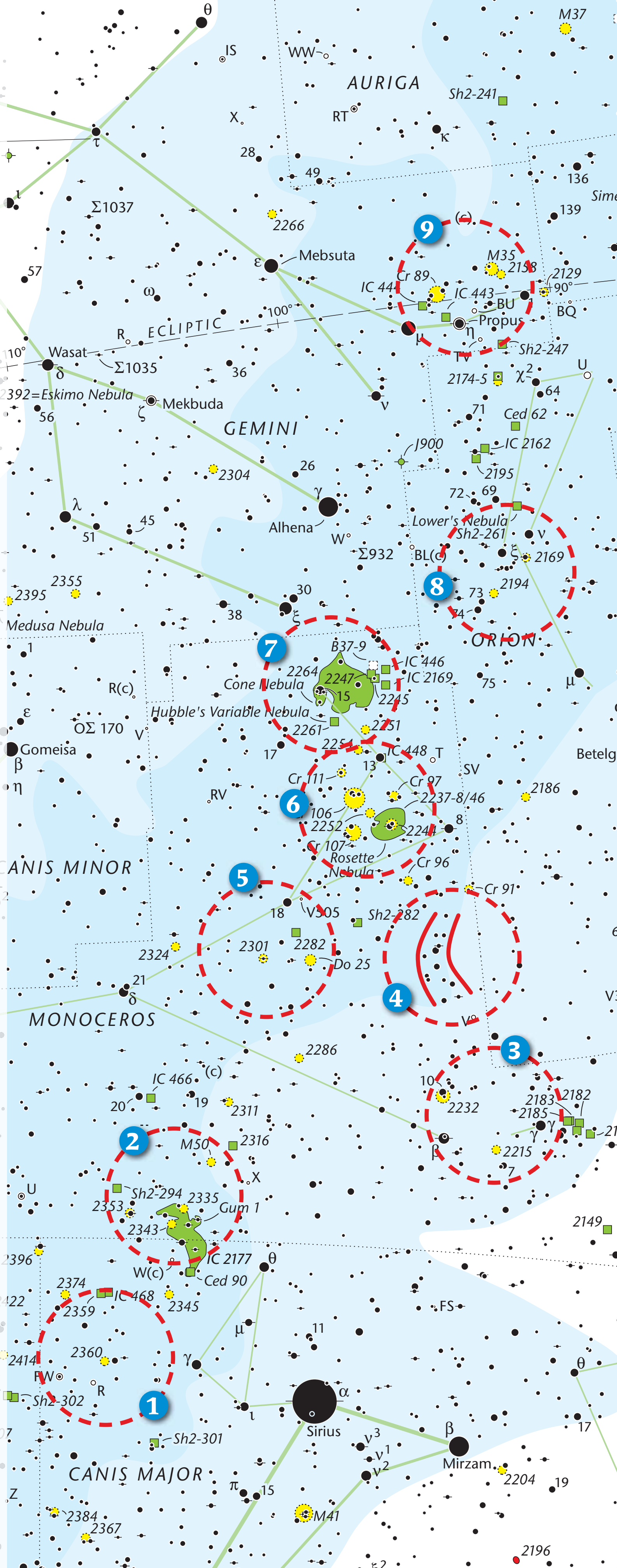
Grab your binoculars and head outdoors for this seasonal sky tour.

Is there a more enchanting time of year than this for stargazing? In all honesty . . . maybe. It's still cold out most evenings, and even though late-season snow isn't a problem where I live in southern California, we're often clouded out. But when the clouds part, the winter Milky Way arches high overhead, spangled with bright stars, clusters, asterisms, and associations beyond counting.

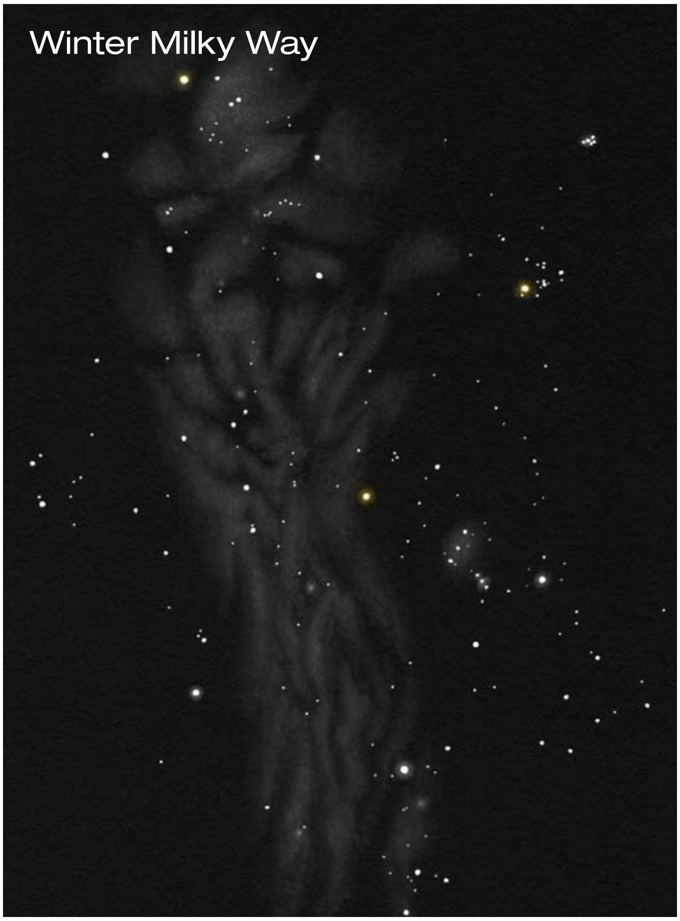
At other times of year, different spectacles draw our attention — galaxies in spring, and the clusters and star clouds of the galactic center in summer. But when we survey the winter Milky Way, we're looking away from the center of our galaxy. We see the nearby spiral arms without the distractions of any farther backdrop, and the fine-scale fabric of the galaxy is revealed.

In this tour of the nearby Milky Way, we'll explore stars, clusters, and nebulae ranged along the axis of the galaxy from Canis Major, the Big Dog, through Monoceros, the Unicorn, to Orion, the Hunter, and the Twins of Gemini. I made these observations with 15×70 binoculars with a 4.4° field of view. Most of the objects will also be visible in smaller binoculars, and even more rewarding in rich-field telescopes. Dark skies will help, but most of the clusters and double stars look good even in suburban skies. To better appreciate the differences among the open clusters, try sketching them. You may be surprised at how much more you'll see.

In my last binocular tour of the Milky Way (*S&T:* Dec. 2015, p. 32) I started at Sirius, the brightest star of winter, and looped around to M46 and M47 in Puppis, the Poop Deck, before going on to M48 in Hydra, the Water Snake. In



▶ **ROAD MAP** A well-used atlas acts as a diary, reminding you where you've been and where you want to go. The author used charts from the *Sky & Telescope Pocket Sky Atlas* to map his route.



▲ When we look at the Milky Way during the Northern Hemisphere's winter months, we're looking away from the center of our galaxy, so it appears fainter than it does in the summer in similarly dark conditions. Even so, it still holds some spectacular deep-sky objects.

1 Caroline Herschel discovered open cluster NGC 2360 in 1783 with her "comet sweeper," a small telescope with 14½× magnification with a 3° 10′ field of view.

doing so, I skipped over NGC 2360 (Caldwell 58), which sits 3.5° east of Gamma (γ) Canis Majoris. It's time to fix that oversight, so I'm giving NGC 2360 pride of place this time.

NGC 2360 is also known as Caroline's Cluster, named in honor of Caroline Herschel, who discovered it on February 26, 1783. Like many open clusters, Caroline's has as many descriptions as there are observers. I see a spray of bright stars like a sheaf of grain, and in *Deep-Sky Companions: The Caldwell Objects*, Stephen James O'Meara compares it to a butterfly's chrysalis. Have a look and see what you think.

From NGC 2360, sweep north-northwest 5.5° to find a nice pair of open clusters, **NGC 2343** and **NGC 2353**, sitting just over the border in the constellation Monoceros. Both are embedded in a vaguely bat-shaped asterism of a half dozen fifth- and sixth-magnitude stars. Those bright foreground stars are *O*, *B*, and *K* giants, ranged from 400 to 1,900 light-years distant — practically next door in galactic terms. NGC 2343 and NGC 2353 are much farther out, at 3,400 light-years, where our own Orion Spur points toward the Perseus Arm of the Milky Way. NGC 2343 has a distinctive shape like a miniature Hyades cluster, with the part of Aldebaran played by the red giant star HD 54387.

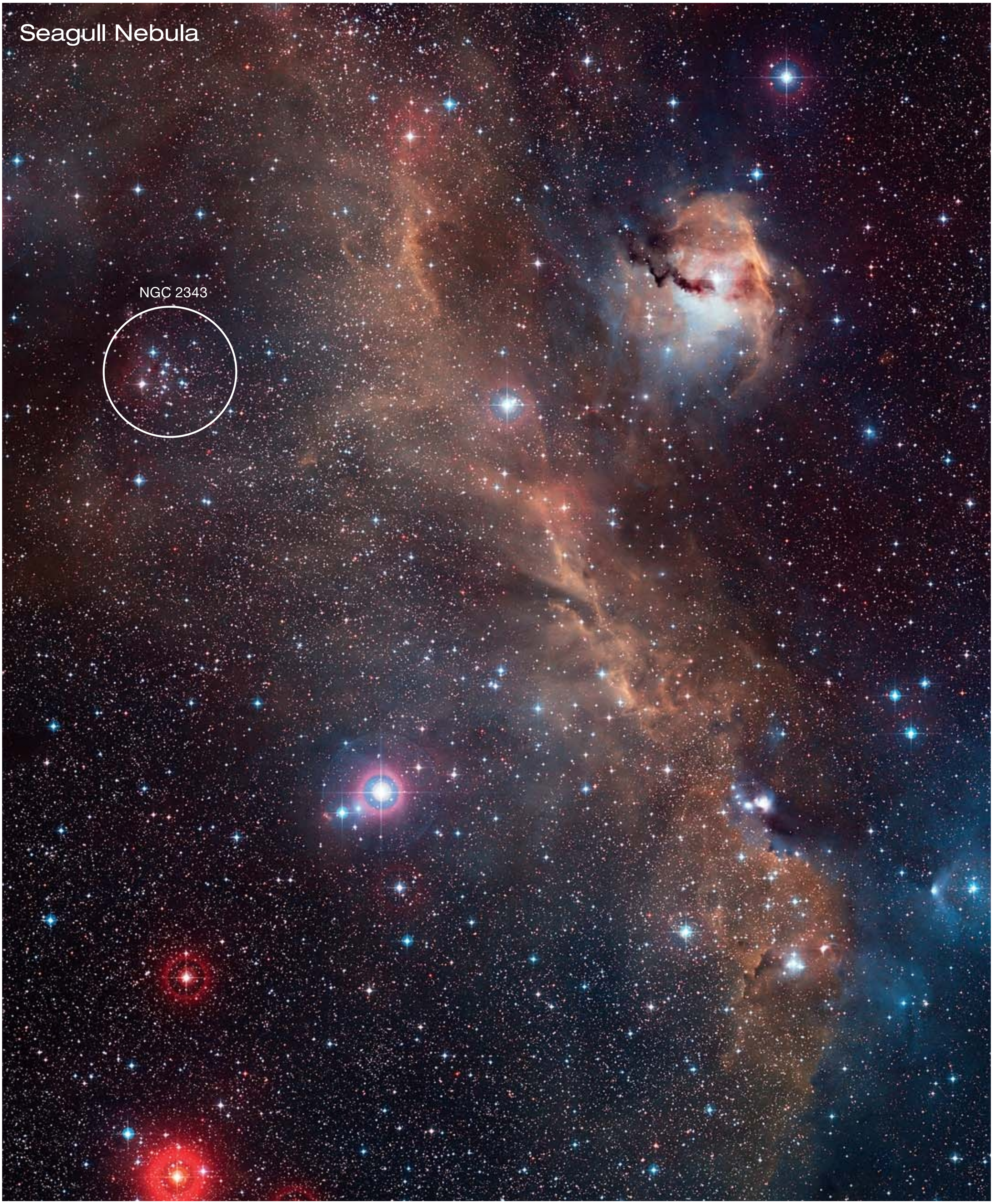
Another 3° north-northwest of NGC 2343 lies **M50**. Considered on its own, M50 is one of the lesser Messiers, unlikely to make anyone's list of favorites. But you really have to work to consider M50 on its own, because this field is so rich. Any 50–70-mm binocular will show M50 in the same field with NGC 2343 and 2353, against a starfield so dense that it's hard to tell where the clusters end. The question of which stars do and do not belong to these clusters is a real problem for professional astronomers, but for amateur stargazers it's no problem at all. We only need to look and enjoy.

Sweep about 10° west of M50 and you'll find a triangle of bright stars — Beta (β), Gamma (γ), and 7 Monocerotis. Beta Monocerotis is a famous triple star, and well worth revisiting at higher magnification, but it also forms a nice binocular double with HD 45709, which lies 4′ to the northwest. At the southern point of the triangle, 7 Monocerotis and HD 44178 make an even easier split, with a separation of 6.4′.

Nestled within this triangle you'll find **NGC 2215**. This cluster is probably the toughest catch so far on the tour. I've spotted it in a 9×50 finder, but only under very dark skies. Any instrument of 70 mm or larger should reel it in, though, revealing between a dozen and 20 equally bright members. Checking my logbook, I see that at different times I've compared the curving star chains of NGC 2215 to a fleur-de-lis and, well, a pumpkin. The flower is a much more elegant and seasonally appropriate metaphor, so let's go with that.

Two degrees north of Beta Monocerotis lies **NGC 2232**. This cluster is one of my favorites. Anchored on 10 Monocerotis and with three lobes of bright stars spanning almost 1°, it's big and bright enough to have easily been a Messier object, if only Messier had spotted it. The cluster's prominence is a function of its proximity — at only 1,300 light-years, it's slightly closer to us than the Orion Nebula.

WINTER MILKY WAY: JEREMY PEREZ; NGC 2360: JIM THOMMES



ESO / DIGITIZED SKY SURVEY 2 / DAVIDE DE MARTIN

2 The small but bright open cluster NGC 2343 is tucked under the trailing edge of the wing of the Seagull Nebula (IC 2177). Look for the red giant star HD 54387 on the cluster's eastern edge.

2 NGC 2353 lies about 3,400 light-years away. The open cluster appears a bit bottom heavy, with the brightest stars in its lower half. Look for 7th-magnitude HD 55879 near the cluster's southern edge.

2 Charles Messier discovered open cluster M50 in 1772, but it was probably detected in 1711 by Giovanni Domenico Cassini. M50 looks like a patch of fog in small binoculars, an appearance that caused many 18th-century observers to (erroneously) conclude that the cluster was surrounded with nebulosity.

Objects in the Winter Milky Way

Object	Mag(v)	Size	RA	Dec.
NGC 2360	7.2	14.0′	$07^h 17.7^m$	−15° 39′
NGC 2343	6.7	5.0′	$07^h 08.1^m$	−10° 37′
NGC 2353	7.1	18.0′	$07^h 14.5^m$	−10° 16′
M50	5.9	15.0′	$07^h 02.8^m$	−08° 23′
NGC 2215	8.4	11.0′	$06^h 20.8^m$	−07° 17′
NGC 2232	4.2	45.0′	$06^h 28.0^m$	−04° 51′
Fertile Crescent	—	3.0°	$06^h 28.0^m$	+00° 00′
NGC 2301	6.0	15.0′	$06^h 51.8^m$	+00° 28′
NGC 2244	4.8	30.0′	$06^h 32.3^m$	+04° 51′
Rosette Nebula	9.0	1.3°	$06^h 31.4^m$	+04° 58′
Cr 97	5.4	25.0′	$06^h 31.0^m$	+05° 50′
Cr 106	4.6	35.0′	$06^h 37.1^m$	+05° 58′
Cr 107	5.1	30.0′	$06^h 37.7^m$	+04° 45′
NGC 2264	4.1	40.0′	$06^h 41.0^m$	+09° 54′
NGC 2169	8.7	5.0′	$06^h 08.4^m$	+13° 58′
Cr 89	5.7	60.0′	$06^h 18.0^m$	+23° 38′
M35	5.1	25.0′	$06^h 09.0^m$	+24° 21′
NGC 2158	8.6	5.0′	$06^h 07.4^m$	+24° 06′

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.

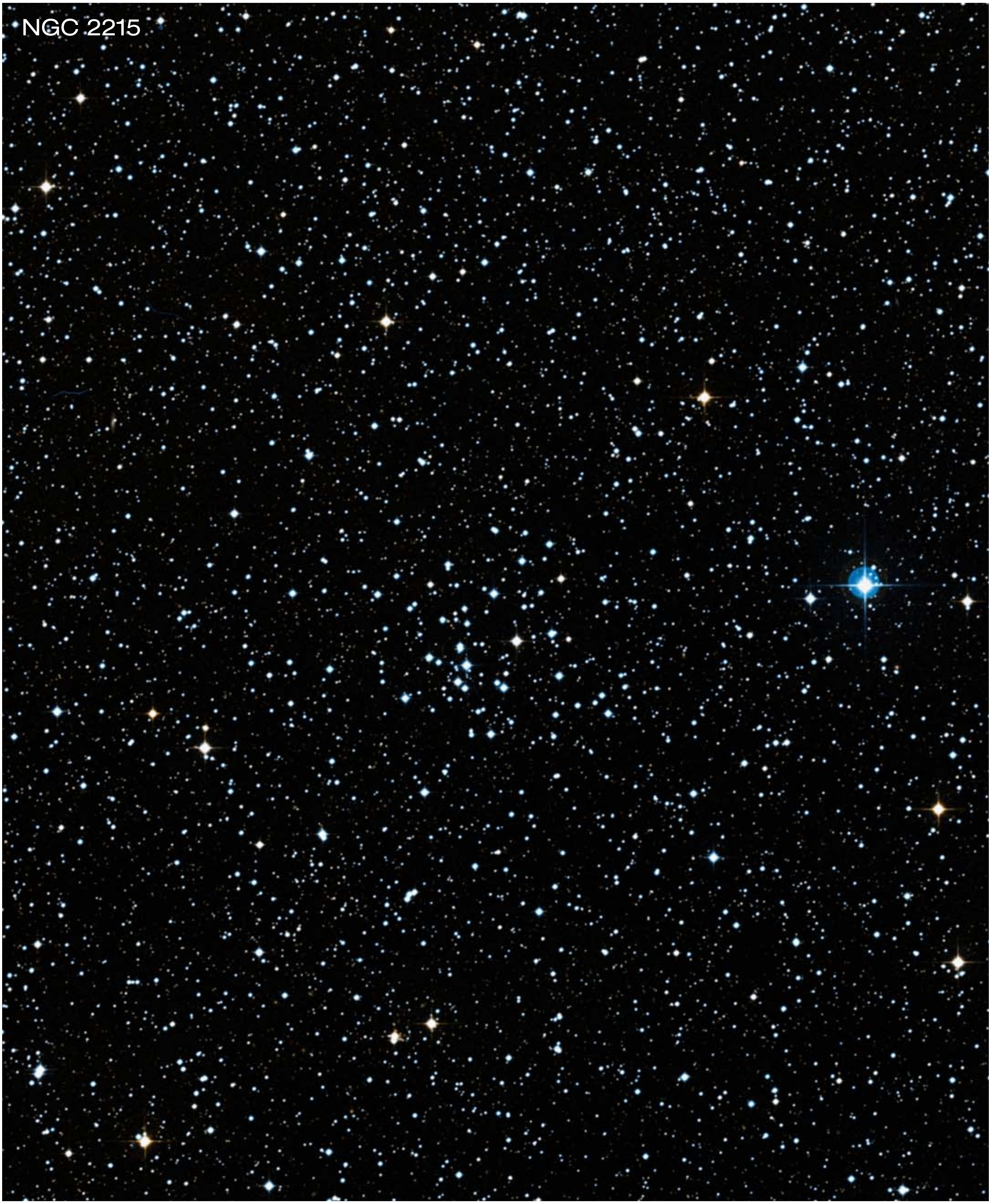
Our next "object" has no name, but it may be the best view in the entire tour. Five degrees north of NGC 2232, you'll find an arc of bright stars straddling the celestial equator. This group spans just over 3°, from declination +1° north to –2° south, at $06^h 28^m$ RA, and forms an arc that opens to the west. If this lovely asterism has a name, I haven't found it yet, so I've taken to calling it the "**Fertile Crescent**". It's a perfect match for 70-mm binoculars, filling half the field with a sea of *F* main sequence stars and *K* giants.

Scan 6° east of the Fertile Crescent to pick up **NGC 2301**. If I hold my 15×70s very still, I can make out half a dozen stars in a ragged north-south line. A line of three equally bright stars 1° west of NGC 2301 adds to the charm of this field. You'll definitely want to revisit this one with a telescope, as more magnification will reveal a dense swarm of stars with three arms sticking out like a letter T. While you're in the neighborhood, go on 4° east to pick up the pretty pairing of Delta (δ) and 21 Mon, a visual double with a separation of 13′.

Now zig back another 6° to the northwest of NGC 2301 to find a cluster of clusters, including **NGC 2244** (Caldwell 50). NGC 2244 is full of bright young stars, so it looks smashing even across the intervening 5,200 light-years. The cluster is outlined by six bright stars in two bent lines, in the shape of an open book. The brightest stars in NGC 2244 are HD 46223 and HD 46150, both O giants more than 50 times more massive than our Sun, and over 400,000 times brighter.

I'd be remiss if I didn't mention that NGC 2244 is the cluster embedded in the **Rosette Nebula**. From the remote Sonoran Desert I have seen the Rosette Nebula enclose the cluster like the petals of a rose. Be warned, though, this faint flower only blooms under dark skies, and it doesn't take much light pollution to kill it. If you can see the nebula, great, but if not, don't fret — the field offers plenty of wonders besides.

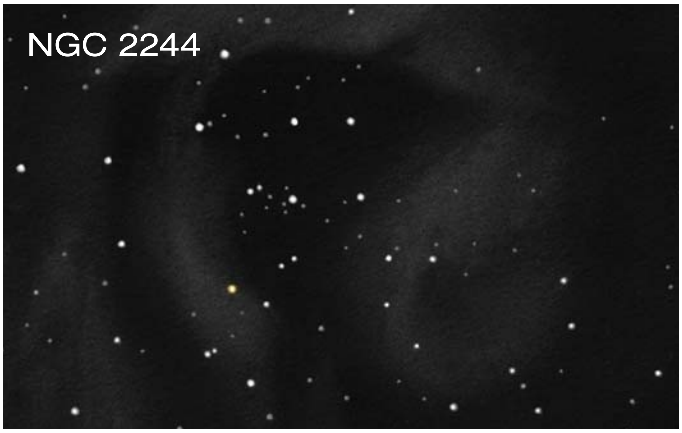
NGC 2353: JIM THOMMES; M50: JOHN BLUM



POSS II / CALTECH / STSCI / PALOMAR OBSERVATORY

3 NGC 2215 in Monoceros looks like a granular hazy patch when viewed in small binoculars. Moving up to 70-mm binoculars will reveal two arcs of stars. Use averted vision to pull them from the murky background.

5 Set your larger binos up on a tripod for NGC 2301. In 8×50s, the cluster is little more than a smudge, but when viewed in stabilized 15×70s, stars will begin to pop. The brightest star in the cluster, 8th-magnitude *G*8 subgiant TYC 148-2862-1, may be a foreground star, not true member of the cluster.



6 The brilliant open cluster NGC 2244 dwells at the center of the Rosette Nebula, and clouds of dust and gas surround its bright stars. You'll need dark skies to tease out the nebulosity, but even if light pollution interferes with your view of the Rosette, the hot, young cluster never disappoints.

7 The brighter stars of open cluster NGC 2264 outline the rough form of a traditional Christmas tree. This cluster is a star-forming region, so its component stars burn blue and hot, energizing the clouds of nebulosity surrounding them.

NGC 2244 is the southwest corner of a 1.5° square whose other corners are marked by Collinder clusters: **Cr 97** to the northwest, and **Cr 106** and **Cr 107** to the northeast and southeast. With keen eyes and dark skies, you may also spot a fifth cluster, NGC 2252, in the middle of the square.

Just over 5° north-northeast of NGC 2244 lies **NGC 2264**, the Christmas Tree Cluster. The cluster really does look like a Christmas tree, about ½° tall, with the tip pointing south. The base is marked by 15 Monocerotis, another O giant. Spectroscopically, 15 Mon is about as blue as it's possible for a star to be, but the perception of star colors varies enormously among observers, so have a look for yourself. Like NGC 2244, NGC 2264 is bound up in a vast field of subtle nebulosity, but you'll need crystalline skies and fanatical dark adaptation to spot any of it in binoculars or small telescopes.

Three degrees northwest of NGC 2264 is a nice little Y-shaped asterism, and about 6° further on the same track you'll find Xi (ξ) and Nu (ν) Orionis, either the right hand or elbow of the Hunter, depending on how the stick figure is drawn. If you imagine Xi and Nu Orionis as eyes, you'll find a pretty, boxy little group of stars forming a freckled nose below and between them. This is **NGC 2169**, the 37 Cluster, so named because it seems to spell out the number 37 when seen through a telescope. The "print" here is too fine to read through binoculars, so instead look for a symmetrical chain of six stars arching a degree to the east of the cluster.

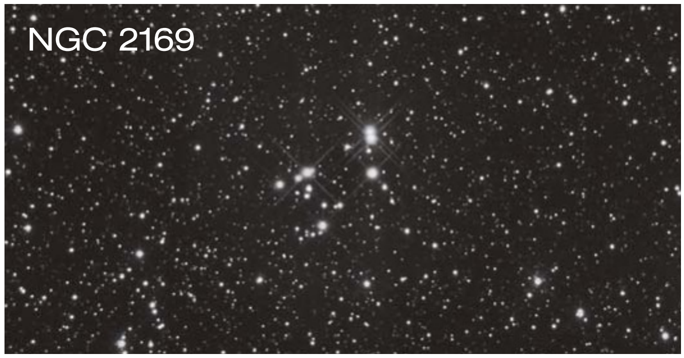
After you've had a good look at the cluster and the star chain, scan just over 2° southeast for the wide binocular pair of 73 and 74 Orionis. This pair of stars is one of my favorite cosmic odd couples — pairs of objects that show up well in the same field of view, despite lying at wildly different distances. The southeastern member of the pair is 74 Orionis, an *F*-type yellow-white subgiant. It's only slightly larger than our own Sun, and lies only 63 light-years away (hello, 1954!). The other star, 73 Orionis, is another story entirely. It's a blue-white *B* giant, seven times the diameter of our sun and almost 700 times as luminous, lying 1,200 light-years away (hello, Dark Ages!).

For our last stops we're going 10° north, to Gemini and the western foot of the western twin. You've probably been here countless times to look at M35, but don't skip to that famous cluster just yet. Instead, take a minute and check in on **Cr 89**, a beautiful and often-neglected open cluster. It's 2° east-southeast of M35, anchored between the foreground stars 9 and 12 Geminorum. Cr 89 is a little bigger than M35, a little more spread out, and a little less bright, but it's an easy catch and a rewarding view, and most binoculars will show it in the same field as its Messier neighbor.

And that brings us to our last stop, **M35** and **NGC 2158,** another cosmic odd couple. M35 is big and bright, naked-eye visible under good conditions, and a stunning object in binoculars or telescopes of all sizes. That's because it's close, only 2,600 light-years away. Close is a relative term here, since the light we see now left M35 around 600 BC, before the founding of the Roman Republic. NGC 2158 is a tougher catch, much smaller and dimmer than M35. That's because it's way out there, 11,000 light-years distant, on the far edge of the Perseus Arm, and it takes us back to the end of the last Ice Age. It's a heady view — in the span of a single degree, light from the two clusters encompasses a huge swath of human history, from the twilight of cave bears and woolly rhinos to the rise of Athens and Sparta.

This isn't really the end. We've covered 45° of sky, an eighth of the Milky Way, but we've only picked out a handful of the brightest baubles, a few shells glittering on the cosmic beach. And just like an earthly beach, I find new treasures to marvel over on every visit. Good hunting!

■ **MATT WEDEL** is lost in the Milky Way. We should probably send someone to check on him.



8 The "37" asterism embedded in NGC 2169 is too tight to read through binoculars, so you may want to re-visit this cluster with a telescope. In the meantime, look for the chain of six stars (the downward stroke of the "7") to the west of the main body of the cluster.

9 M35 and NGC 2158 form an odd couple. If your skies are dark enough, you may be able to see M35 without optical aid; even small binoculars will pick this out one for you. NGC 2158 is more of a challenge. It lies 8,400 light-years beyond M35 and consequently appears smaller and dimmer.

NGC 2169: MARTIN GERMANO; M35 & NGC 2158: JIM BLUM

TINY FEATHER TOUCH ▶

Starlight Instruments announces two 1¼-inch Feather Touch focusers. The FTF1575BCR ($249) brings the uncompromising quality of the Feather Touch custom Crayford-style focusers with brake system to telescopes with limited field of views. The unit has a ¾-inch draw tube and a load capacity of 8 pounds. Its 1¼-inch eyepiece port includes a brass compression ring and T-threads to directly attach cameras and other accessories. A dual-speed model (FTF1575BCR-DS) is also available for $429.

Starlight Instruments
2380 E. Cardinal Dr.,
Columbia City, IN 46725
260-244-0020; starlightinstruments.com

SOLAR LENS CONVERTER ▶

Turn your SLR lens into a solar telescope with DayStar Filters Camera Quark ($1,095). This compact solar hydrogen-alpha filter is designed to connect to Canon or Nikon manual-focus lenses. The Camera Quark unit is a powered Fabry-Pérot etalon that is placed between your lens and DSLR camera using the included Canon or Nikon adapter. It allows you to directly couple your DSLR with the unit to capture stunning images of the Sun's dynamic chromosphere. Or enjoy the views with the included 1¼-inch eyepiece adapter. The Camera Quark comes with a plastic case, camera lens adapter, two focus-extension tubes, a Quark-to-1¼-inch eyepiece adapter, and an AC power supply with international plug adapters.

DayStar Filters
149 Northwest OO Hwy., Warrensburg, MO 64093
660-747-2100; daystarfilters.com

POWERED HUBS ▶

Deep Space Products produces a series of USB hubs for astrophotographers, the Deep Space Dock. These powered, backwards-compatible USB 3.0 hubs permit the use of many imaging accessories powered through a USB connection, including filter wheels, focusers, CCD cameras, and dew prevention devices. Available in 4- ($55), 7- ($75), and 10-port models ($95), each can be mounted on your telescope and include a 12-volt, 2.5-amp power supply, 3.3-foot USB 3.0 cable, USB port dust covers, and a 6-foot bare-end customizable power cable.

Deep Space Products
deepspaceproducts.com

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

OBSERVING
March 2017

1 **EVENING:** The waxing crescent Moon shines in the west. As twilight deepens, Mars will appear 5° right of the Moon. Brilliant Venus, which sets mid-evening, blazes white about 15° lower right of the pair. Uranus, 6th magnitude, is 2.1° below Mars.

4 **NIGHT:** The Moon is in the Hyades and occults Aldebaran for the contiguous United States, Mexico, and Central America; see page 51.

10 **NIGHT:** The waxing gibbous Moon hangs 2–4° below or lower left of Regulus, the brightest star in Leo.

12 **DAYLIGHT-SAVING TIME STARTS** at 2 a.m. for most of the United States and Canada.

14 **NIGHT:** Jupiter, Spica, and the waning gibbous Moon form a triangle after rising in the east around 9 or 10 p.m.

NIGHT: Algol shines at minimum brightness for roughly two hours centered at 9:24 p.m. PST (12:24 a.m. EDT March 15th); see page 50.

17 **NIGHT:** Algol shines at minimum brightness for roughly two hours centered at 9:14 p.m. EDT.

20 **MORNING:** Approximately 3° separate the last-quarter Moon and Saturn. The pair will be highest at dawn.

SPRING BEGINS in the Northern Hemisphere at the Equinox, 6:29 a.m. EDT (3:29 a.m. PDT).

29 **DUSK:** As twilight deepens, the thin waxing crescent Moon sinks low in the west. About 30–45 minutes after sunset, look for 1.5-magnitude Mars about 10° above it.

30 **DUSK:** The Moon is about 8° left or upper left of Mars.

The Seagull Nebula (IC 2177) flies along the border of Monoceros and Canis Major. A number of deep-sky objects nestle in its wings, including open cluster NGC 2343.

◖ See more on page 30.

ESO / DIGITIZED SKY SURVEY 2 / DAVIDE DE MARTIN

MARCH 2017 OBSERVING

Lunar Almanac

Northern Hemisphere Sky Chart

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

NASA / LRO

MOON PHASES

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

FIRST QUARTER
March 5
11:32 UT

FULL MOON
March 12
14:54 UT

LAST QUARTER
March 20
15:58 UT

NEW MOON
March 28
02:57 UT

DISTANCES

Perigee 369,063 km — March 3, 08^h UT, Diameter 32′ 23″

Apogee 404,649 km — March 18, 17^h UT, Diameter 29′ 32″

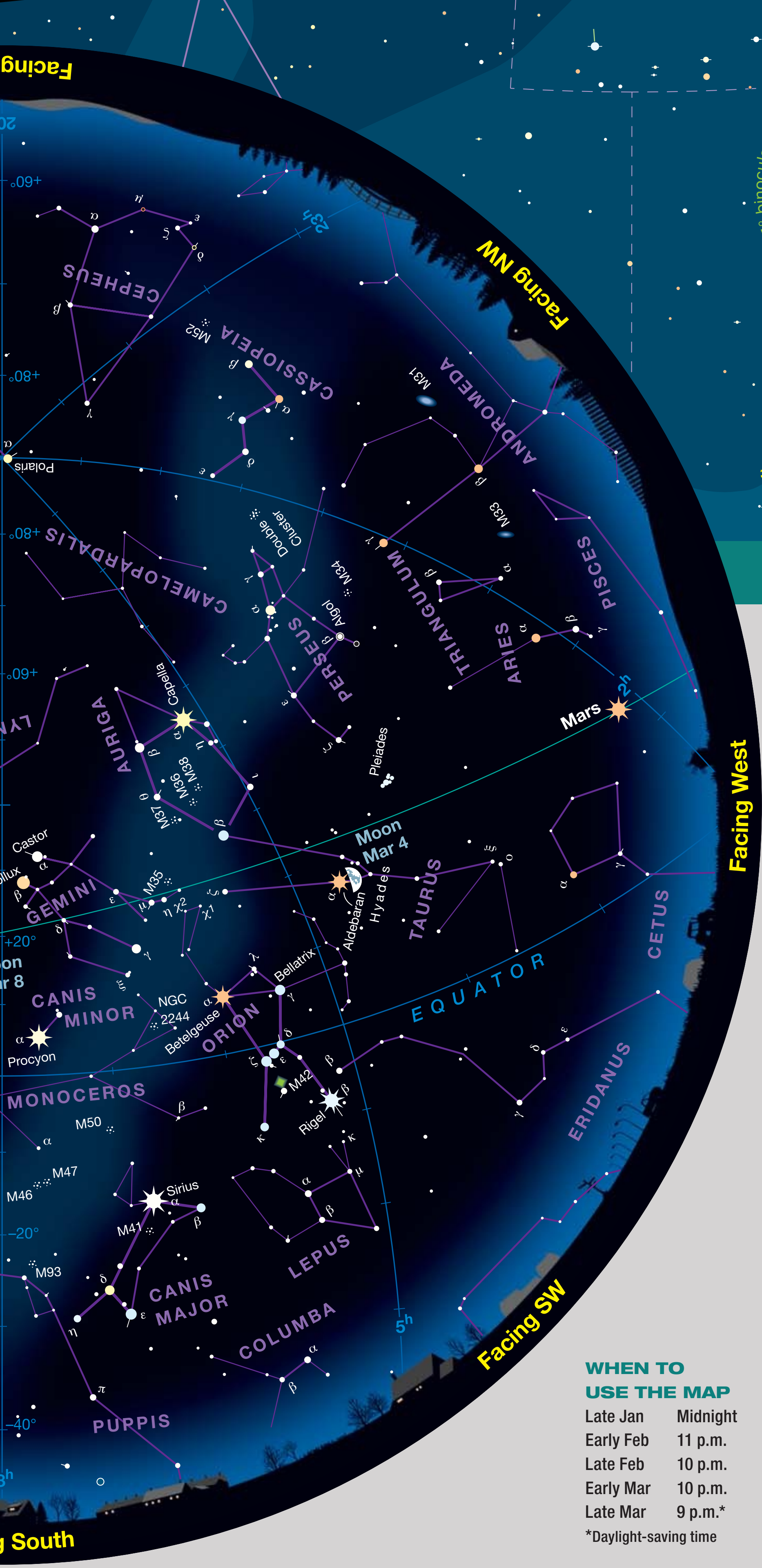
Perigee 363,854 km — March 30, 13^h UT, Diameter 32′ 50″

FAVORABLE LIBRATIONS

- Mare Humboldtianum — March 6
- Gauss (crater) — March 9
- Lyot (crater) — March 13
- Montes Cordillera — March 24

Planet location shown for mid-month

USING THE NORTHERN HEMISPHERE MAP
Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing.



WHEN TO USE THE MAP

Late Jan	Midnight
Early Feb	11 p.m.
Late Feb	10 p.m.
Early Mar	10 p.m.
Late Mar	9 p.m.*

*Daylight-saving time

Binocular Highlight by Mathew Wedel

Easy and Hard

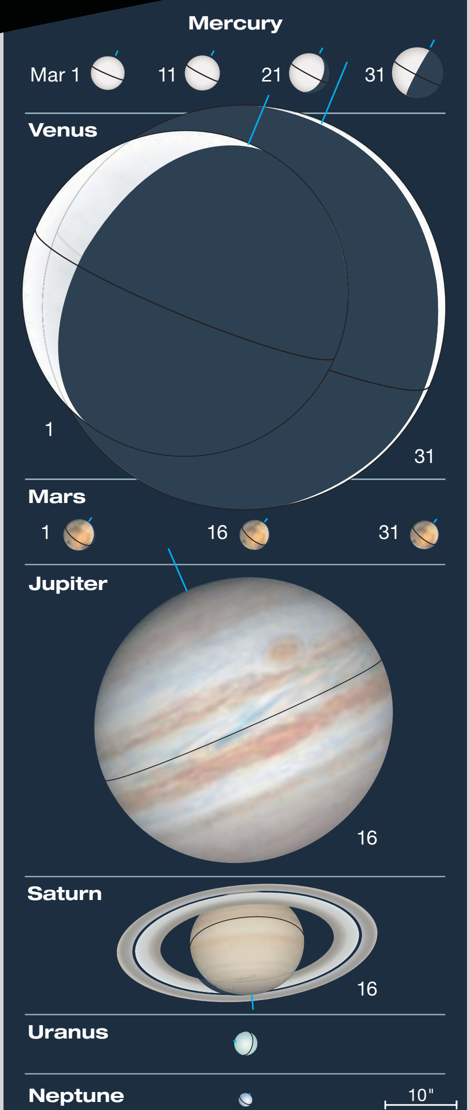
Here's a fun field with which to push your observing abilities. Starting at Alpha (α) Persei (Mirfak), the brightest star in the constellation Perseus, follow the J-shaped chain of stars east to Mu (μ) and Lambda (λ) Persei. Mu and Lambda form an equilateral triangle with a wide binocular double star, which consists of 4th-magnitude b Persei and 5th-magnitude HD 27084. Almost exactly 1° northwest of b Persei you'll find the open cluster **NGC 1528**.

I mean, you *will* find it — it's bright and concentrated, and doesn't have anything in its way. Using 10×50 binos I see a fan-like spray of light, which starts to resolve into a dense swarm of stars in my 15×70s. At 3,600 light-years out, NGC 1528 is one of the host of open clusters that define our galaxy's spiral arms.

Now it's time to dig in. Making a right triangle with b Persei and HD 27084 is a yellow, 7th-magnitude star. That yellow star is actually two foreground main sequence stars, but they're too close to split with handheld binoculars. With 10×50 binoculars, that's all I see. But with the 15×70s I can start to make out a faint scattering of stars lurking around the yellow double (which is still not split). That dim swarm is **NGC 1545**, another open cluster. Depending on which source you check, NGC 1545 is about as bright as NGC 1528. But its light is concentrated into a few bright stars near the center of the cluster, and it tends to be overwhelmed by the foreground stars.

So there's your challenge this month: see if you can spot NGC 1545. And if you do happen to catch NGC 1545, compare it to NGC 1528 – can you hold both in direct vision at once?

■ **MATT WEDEL** likes to kick back with his binoculars on a driveway in Claremont, California.



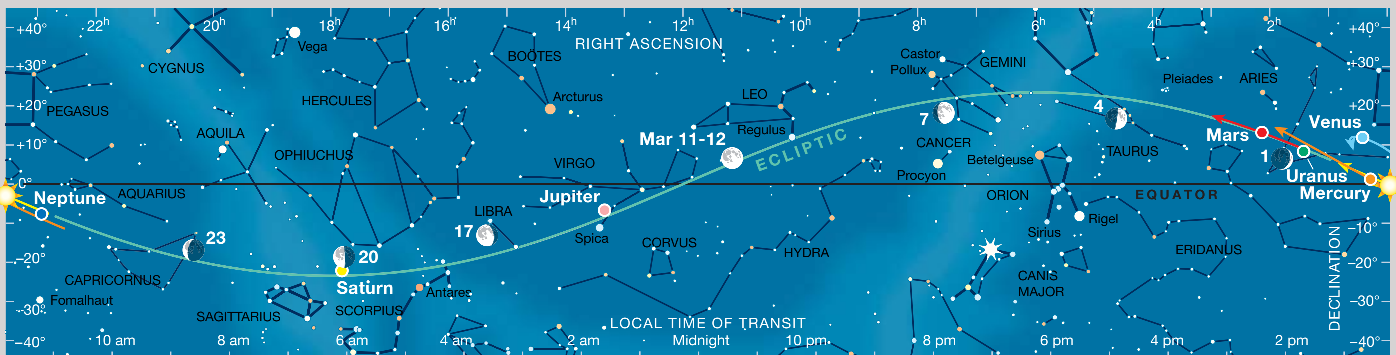
PLANET DISKS have south up, to match the view in many telescopes. Blue ticks indicate the pole currently tilted toward Earth.

PLANET VISIBILITY: Mercury: March 16 – April 9, dusk, low west to WNW • **Venus:** To March 22, dusk, west to low WNW; after March 22, dawn, low ENE • **Mars:** All month, dusk and after, west • **Jupiter:** All month, late evening to dawn, east to WSW • **Saturn:** All month, early morning, SE.

March Sun & Planets

	Date	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$22^h\ 47.5^m$	–7° 41′	—	–26.8	32′ 17″	—	0.991
	31	$0^h\ 37.6^m$	+4° 03′	—	–26.8	32′ 01″	—	0.999
Mercury	1	$22^h\ 31.1^m$	–11° 31′	6° Mo	–1.3	4.9″	99%	1.381
	11	$23^h\ 40.3^m$	–3° 30′	4° Ev	–1.8	5.0″	99%	1.334
	21	$0^h\ 49.3^m$	+5° 44′	13° Ev	–1.2	5.7″	84%	1.179
	31	$1^h\ 44.3^m$	+13° 19′	19° Ev	–0.4	7.3″	47%	0.925
Venus	1	$0^h\ 36.6^m$	+10° 53′	33° Ev	–4.8	46.9″	17%	0.356
	11	$0^h\ 31.6^m$	+12° 00′	23° Ev	–4.6	54.0″	8%	0.309
	21	$0^h\ 13.8^m$	+10° 45′	11° Ev	–4.1	58.8″	2%	0.284
	31	$23^h\ 52.7^m$	+7° 32′	12° Mo	–4.1	58.3″	2%	0.286
Mars	1	$1^h\ 25.9^m$	+9° 03′	43° Ev	+1.3	4.6″	94%	2.036
	16	$2^h\ 07.0^m$	+13° 04′	39° Ev	+1.4	4.4″	95%	2.132
	31	$2^h\ 48.7^m$	+16° 37′	35° Ev	+1.5	4.2″	96%	2.225
Jupiter	1	$13^h\ 24.0^m$	–7° 12′	138° Mo	–2.3	42.1″	100%	4.677
	31	$13^h\ 12.6^m$	–5° 59′	171° Mo	–2.5	44.1″	100%	4.467
Saturn	1	$17^h\ 44.9^m$	–22° 05′	74° Mo	+0.5	16.2″	100%	10.282
	31	$17^h\ 49.3^m$	–22° 05′	103° Mo	+0.4	17.0″	100%	9.787
Uranus	16	$1^h\ 24.5^m$	+8° 16′	27° Ev	+5.9	3.4″	100%	20.812
Neptune	16	$22^h\ 54.9^m$	–7° 51′	13° Mo	+8.0	2.2″	100%	30.917

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



The Sun and planets are positioned for mid-March; 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.

Mythical Beast

Take a moment — or more — to meander through Monoceros, the Unicorn, this month.

It's fun to give your telescope's computer a rest and develop your ability to find deep-sky objects manually. But it's not just fun: learning to "star-hop" brings a much deeper knowledge of the heavens and turns up fascinating sights as you explore unknown territory.

Even so, you might appreciate those deep-sky objects that are conveniently located near bright stars or asterisms, and so are easier to locate. Let's consider some of these in the March sky.

The magic horn of the unicorn. In last month's column, I noted that the superb star cluster M50 lies about one-third of the way between Sirius and Procyon, and the splendid triple star Beta (β) Monocerotis a little more than one-third of the way between Sirius and Betelgeuse. But I also said the third side of the Winter Triangle has a key object one-third of the way along it, between Betelgeuse and Procyon.

That object is 13 Monocerotis, the middle star of what I like to think of as the horn of Monoceros, the Unicorn, though many star atlases picture it as the long head of the mythical beast.

Doesn't ring a bell? The star centers a short northeast-to-southwest diagonal line of three 4.5-magnitude stars — a line that I regard as the magical horn. The northeast star in the line, the point of my imagined horn, is 15 Monocerotis, which also goes by the designation S Monocerotis as a variable star. It's the brightest member of NGC 2264, the Christmas Tree Cluster, and not far from it are the spooky dark Cone Nebula and the intriguing Hind's Variable Nebula.

The cluster NGC 2244 forms a right triangle with the bottom two stars of the horn, 13 and 8 Monocerotis. This relatively bright, 4.8-magnitude open cluster appears slightly fuzzy to the naked eye compared to the similarly bright stars of the horn. Surrounding NGC 2244 is a dusty cloud of glow more than a degree wide that's elusive (but beautifully so) in telescopes and absolutely stunning in photographs: the Rosette Nebula.

X-RAY: NASA / CXC / SAO / J. WANG ET AL. OPTICAL: DSS & NOAO / AURA / NSF / KPNO 0.9-M / T. RECTOR ET AL

The heavy pair of the horn. A final strange attraction near the horn — just 1½° southeast of 13 Monocerotis and about 2° from the Rosette — is one of the most massive pairs of stars known, the hefty suns that make up Plaskett's Star. The two components are too close together to split in telescopes and so appear only as a single 6.1-magnitude point of light. But the estimated mass is 43 Suns for the brighter component and 51 for the dimmer.

If Plaskett's Star is 6,600 light-years away (there's still some uncertainty on this issue), then each of its components shine with a luminosity more than a half-million times greater than the Sun's. Both components of Plaskett's Star are certain to go supernova, and the first to blast may send the other component flying off as a runaway star. Or the second star may hold on so the system eventually becomes, as star expert Jim Kaler predicts, "a binary neutron star, a double black hole, or some combination of the two."

Easily located treasures. The southern feet of Gemini, the Twins, featuring 2nd-magnitude Alhena (also known as Almeisan), stand just north of my Unicorn horn. But it's in Gemini's northern feet that we find the big and bright M35, an easy naked-eye target in any reasonably dark sky. M67 is a second fairly easy-to-find star cluster that can be glimpsed with the unaided eye. This very old but still rich open cluster shines just 1.8° west of Alpha (α) Cancri (Acubens), the southern claw of the Crab.

■ Contributing Editor FRED SCHAAF has been writing about the skies above us for more than 40 years.

An Evening-Morning Star

Vivid Venus shines in evening twilight — and then again at dawn.

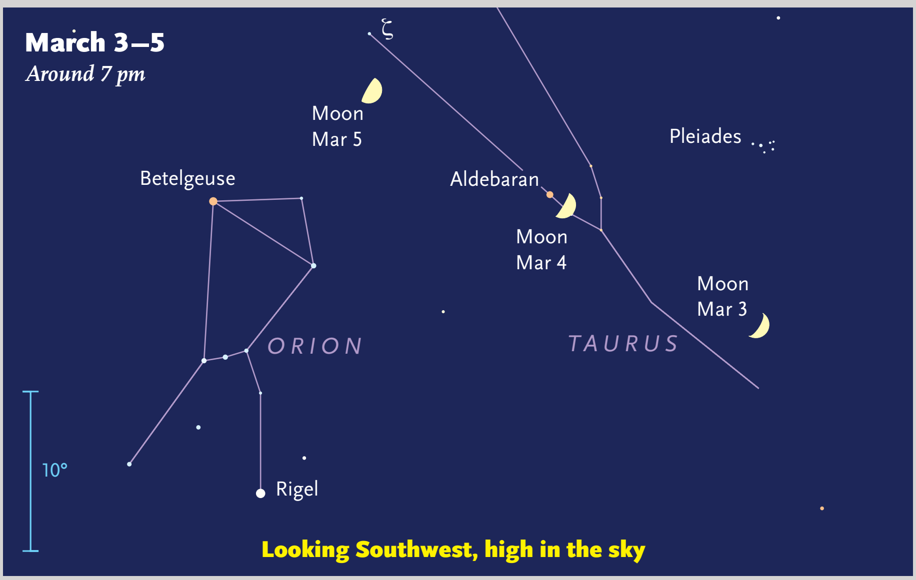
This is an extraordinary month for observing the planets. Venus makes its rare "most-watchable" passage from the evening to morning sky for observers at mid-northern latitudes. Mercury passes Venus on its way up to its highest evening appearance of the year, with Mars glowing above it. Jupiter dazzles at nearly its brightest and biggest for the year, rising in early evening. And Saturn reaches its highest altitude this month in the south at dawn.

DUSK TO EVENING

Venus passes as much as 8° north of the Sun only once in its 8-year cycle of recurring appearances. That happens this March 25th, when Venus goes through inferior conjunction. Around that date it offers some rare and amazing observing opportunities.

Let's start with Venus's rapid drop from the evening sky. For viewers around latitude 40° north, the planet moves from a sunset altitude of about 32° to 0° in less than 4 weeks, with its magnitude fading from a blazing –4.8 to –4.2 and its telescopic aspect thinning to a hairline crescent. The current northerliness of Venus places it higher at each stage of this descent than it would be at any other apparition, so we have the best views that are possible in the weeks before and during a Venusian inferior conjunction.

Look for Venus in the west-northwest in bright twilight. As March begins, it's still very high but already a striking crescent in a telescope: 48″ wide and 16% lit. Venus becomes even more remarkable as it descends closer to our line of sight with the Sun. It enlarges and thins to 55″ wide and 7% lit on March 11th, 59″ wide and 2% lit on March 19th, and finally 59″ wide and 1% lit on the evening of March 24th, less than 12 hours (as seen from the Americas) before inferior conjunction. On these dates, for observers at latitude 40° north, Venus sets 163 minutes, 112 minutes, 62 minutes, and 14 minutes after the Sun, respectively.



Venus is far enough north of the Sun to start rising before sunup on March 15th — 10 days *before* inferior conjunction! On March 22nd Venus sets 30 minutes after the Sun, but the following morning rises 33 minutes before the Sun. Can you, as I once did, see Venus with the naked eye on both ends of a single night? Or as the "Morning Star" before sunrise and the "Evening Star" after sunset — on the same day?

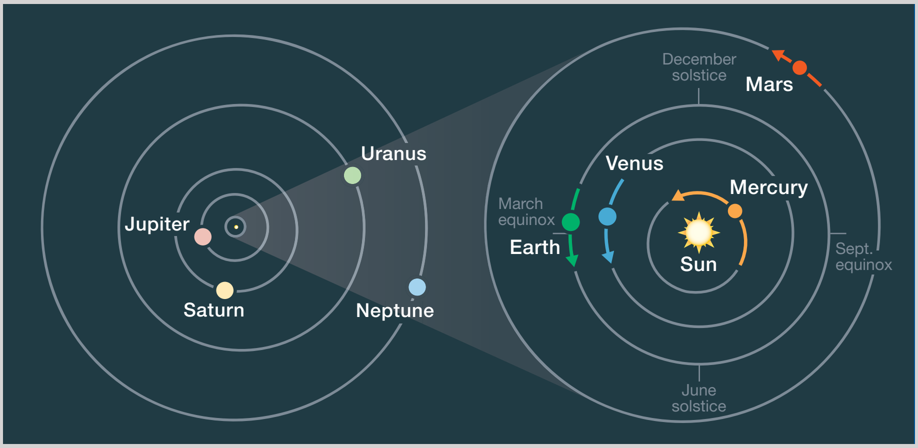
Can you spot Venus after it rises about 40 minutes before sunrise on March 25th? From eastern North America, you'll be seeing it almost at the hour of inferior conjunction: 10^h UT (6 a.m. EDT). Venus will be 8° 18′ north of the Sun at the time. Optical aid will help.

A week or two before inferior conjunction comes the rare opportunity to try to view the crescent of Venus without magnification. I've succeeded by centering a small, clean, round pinhole in cardboard in front of my eye. This reduces the blurring and spikiness of Venus caused by imperfections in the outer part of your eye's lens and cornea. Experiment with holes of different sizes.

On the final day of March Venus rises about an hour before the Sun and is still almost 59″ wide and only 2% lit.

Mercury, meanwhile, put on its own show; it has its best apparition of the year for mid-northern viewers this month. After passing through superior conjunction on March 7th, –1.4-magnitude Mercury climbs into view around March 15th, just above the west horizon in bright twilight. Venus heading down,

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



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

and Mercury coming up, never come closer than 8.5° from each other this month. They're at their closest together on March 18th, at similar altitudes: about 5° above the western horizon about 30 minutes after sunset.

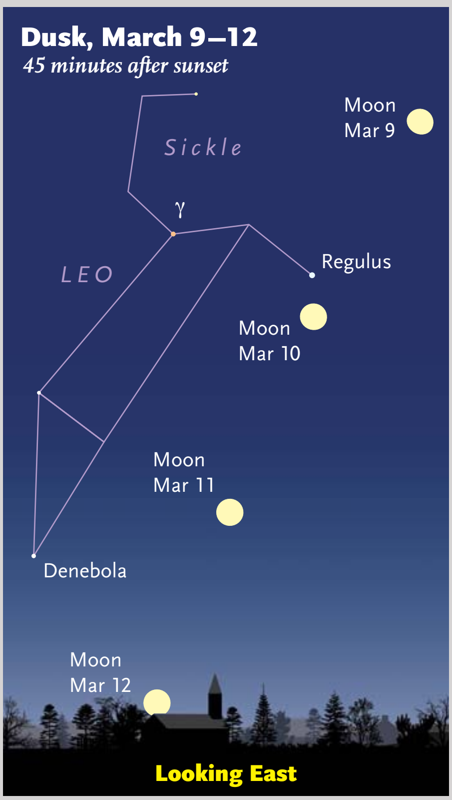
Dim **Uranus**, magnitude +5.9, is 2.2° left of Mercury on March 25th. Use high magnification to distinguish it from a star.

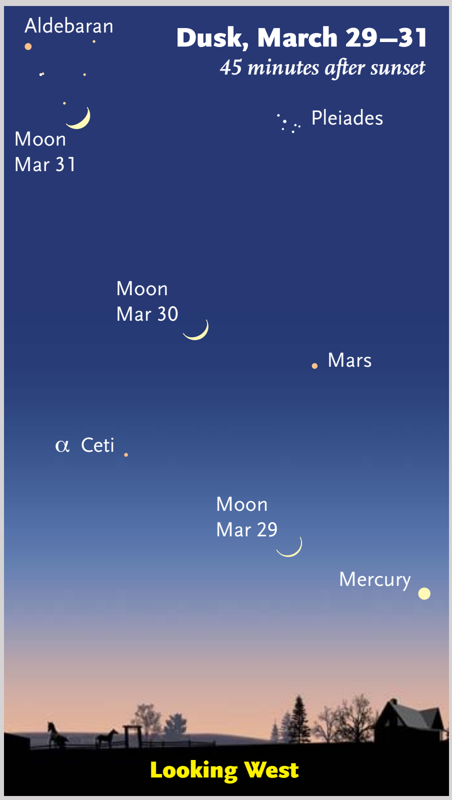
Mars remains in view in the west during twilight and into late evening, setting about 3 hours after the Sun. The Red Planet floats far upper left of Mercury and Venus at mid-month, about 30° high 30 minutes after sunset, around the time its +1.4-magnitude light becomes visible to the naked eye.

The ice giant **Neptune** is in conjunction with the Sun on March 2nd, so is not visible this month.

EVENING TO DAWN
Jupiter is on its way to an April 7th opposition. It rises in Virgo well after dark early in March, then in twilight after the turn of spring. It brightens from magnitude –2.3 to –2.5, and in telescopes its globe grows from 42″ to 44″ wide. It's highest after midnight all month. The retrograding giant moves a little farther away from Spica during the month but stays within 4° to 6° of the fainter star.

PRE-DAWN & DAWN
Saturn, in western Sagittarius, rises well after midnight — around the time Jupiter reaches the meridian — and shines highest as dawn starts to brighten. Saturn hits western quadrature (90° west of the Sun) on March 17th, so the shadows of its globe and wide-open rings are prominent all month. Over the course of the month, Saturn brightens a little bit, going from magnitude +0.5 to +0.4.





S&T: LEAH TISCIONE

SUN & MOON
The **Sun** arrives at the March equinox at 6:29 a.m. EDT (3:29 a.m. PDT) on March 20th, starting spring in the Northern Hemisphere and autumn in the Southern Hemisphere.

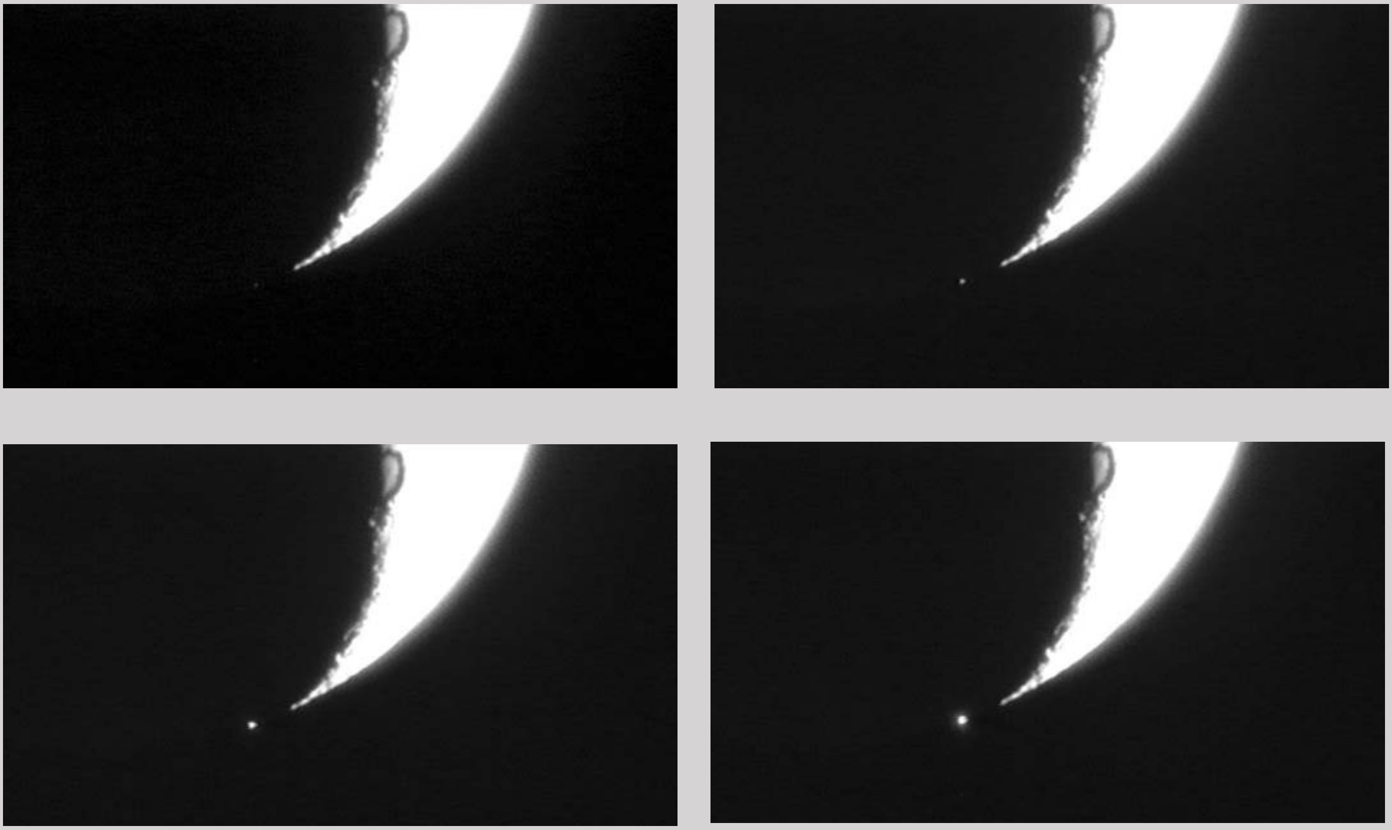
The crescent **Moon** slices the western twilight about 5° left of Mars on March 1st. The dark limb of the first-quarter Moon occults Aldebaran for many American viewers on the evening of March 4th, a naked-eye event; see page 51. The Moon is a couple degrees below Regulus at nightfall on March 10th.

The waning gibbous Moon, Jupiter, and Spica form a triangle the evening of March 14th. The last-quarter Moon beams some 3° above Saturn in the early morning hours of March 20th. At dusk on March 29th the waxing lunar crescent stands well below Mars and upper left of Mercury. On the next evening, the Moon shines left or upper left of Mars. And on March 31st, it hangs below the Hyades and Aldebaran.

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

The Best Occultation of 2017

On the night of March 4th, watch the Moon occult Aldebaran naked-eye. Better yet, place yourself on the graze line.



During last July's Aldebaran graze, Bob Sandy videorecorded several disappearances and reappearances using a Supercircuits PC23C camera on a 5-inch f/5 refractor. The events were gradual, due to Aldebaran's angular size. These frames of a reappearance are 0.1 second apart.

BOB SANDY / IOTA

It can't get much better than this: an occultation of the brightest star the Moon ever crosses, visible across most of the U.S. on a Saturday evening, with the Moon barely first-quarter (46% sunlit), and the star's dark-side disappearance visible without optical aid.

Moreover, a spectacular grazing occultation will take place along a narrow path skirting Vancouver and crossing the upper Midwest, then the Toronto area and the U.S. Northeast. Especially in the populous eastern part of the path, the graze will be nearly as good as last July's well-observed Aldebaran graze in the southern plains (*S&T:* July 2016, p. 50). This one provides another chance to detect the angular size of a star other than the Sun. But the Moon will be brighter, with the graze events occurring closer to the northern cusp, so binoculars are recommended to see the gradual and partial occultation events that will reveal the star's angular size.

The occultation will also be visible at night throughout Mexico, most of Central America, the western Caribbean Sea, and Bermuda. The occultation will occur in daylight in Hawai'i (disappearance at 3:33 p.m. HST in Honolulu).

A telescope will be needed to see or videorecord the star's *reappearance* even at night, because this event will occur on the Moon's glary sunlit limb.

Here are some times:

Los Angeles, *disappearance* at 7:08 p.m. PST, *reappearance* at 8:27 p.m. PST; **Seattle,** *d.* 7:21 p.m., *r.* 7:50 p.m. PST; **Denver,** *d.* 8:33 p.m., *r.* 9:33 p.m. MST; **Chicago,** *d.* 9:57 p.m., *r.* 10:33 p.m. CST; **Austin,** *d.* 9:44 p.m., *r.* 10:52 p.m. CST; **Atlanta,** *d.* 10:56 p.m., *r.* 11:52 p.m. EST; **Miami,** *d.* 11:03 p.m., *r.* 12:02 a.m. EST; **Pittsburgh,** *d.* 11:03 p.m., *r.* 11:36 p.m. EST; **Washington, DC,** *d.* 11:04 p.m., *r.* 11:39 p.m. EST; **New York,** *d*: 11:10 p.m. EST, *r.* 11:31 p.m. EST.

More precise times, and additional details including the altitudes of the Sun and the Moon, are listed for over 1,000 cities and towns in the predictions link at the end of this article.

The Graze

The most interesting views will be from a strip of land only a few hundred yards wide along the occultation's northern limit. You can scout the precise graze path to street-level accuracy using the interactive Google Maps links in the special page that the International Occultation Timing Association (IOTA) has set up for this event, also given at the end of this article.

Viewed from this narrow zone, the giant star is likely to disappear and reappear multiple times as hills and valleys along the Moon's northern limb skim eastward, covering and exposing it. Most of these events will appear non-instantaneous, even taking up to a full second, due to Aldebaran's large angular diameter: 20 milliarcseconds, which is equivalent to 40 meters at the Moon's distance.

We can predict these narrow zones very accurately now; laser altimeters on recent lunar-orbiting spacecraft have mapped all of the Moon's topography to high accuracy. So you can choose your viewing location to within a few tens of meters in order to maximize the number of contact events you can see or videorecord. Zoom in on the Google Maps in the predictions link at the end of this article.

The Moon will be high in the western sky for the western and central states. In the East it will be lower: about 15° above the west horizon where the graze crosses southern New England.

The position and angle of "central graze" both change along the path, causing the lunar limb profile to change also. West of Montana the star skims sunlit land. East of North Dakota the graze happens on the Moon's dark limb, though the high mountaintops just after central graze will likely be sunlit.

Occultation timings are not as compelling scientifically as they used to be. However, video recordings of grazes are so precise that small corrections to spacecraft lunar-profile data, and to positions of stars, are still being found. They are also still occasionally useful in discovering and resolving very close double stars. However, we know that Aldebaran lacks any close companion.

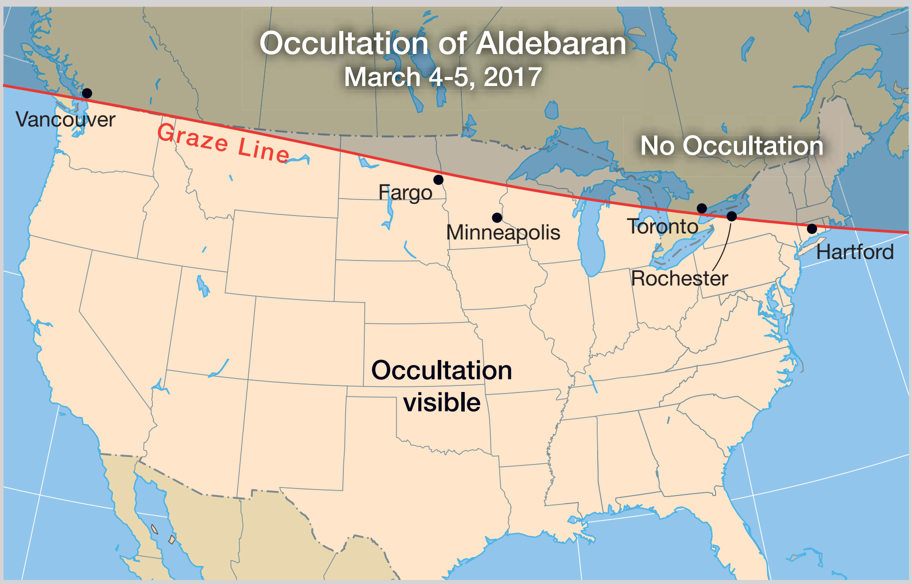
JOIN US!

◖ IOTA observers are planning expeditions to the graze line. Come along! See details at occultations.org/aldebaran/2017march. And stay in touch; plans are likely to change in the final days due to weather.

Results from July's Graze

For the July 2016 Aldebaran graze, IOTA observers set up at 23 stations in Texas and Oklahoma, recording video at most of them. The results show what we might expect in March. Details are given on IOTA's results page for the event (**is.gd/aldeb_july_2016_results**), including links to most of the videos. Four frames from one of the recordings are shown at left, but you should watch some of the videos to appreciate the gradual and partial events that might be seen again on March 4th.

Joan Dunham and I recorded the graze from seven locations at once along a lonely north-south road near Carey, Texas. For the five remote stations, we used Scotty Degenhardt's "mighty mini" binocular-based video systems (**scottysmightymini.com**) on small tripods. We pre-pointed them to Aldebaran's predicted altitude and azimuth, using handy star charts by



▲ The first-quarter Moon will occult Aldebaran on the night of March 4th for most of the U.S., Central America, and the Caribbean. Along the graze line the Moon's northern limb will barely skim the star — likely producing several gradual disappearances and reappearances. Graze maps with street-level precision are on the website listed at the end of the article.

S&T: LEAH TISCIONE; DATA: IOTA

Ernie Iverson. The Moon's edge at the observed occultation points was systematically south of the Lunar Reconnaissance Orbiter profile, by 0.04″ ±0.02″, showing that Aldebaran's proper motion in declination needs a correction. A similar result was found from analysis of October 19th's Aldebaran graze observed in California and Wisconsin.

Hyades Stars

Four hours before Aldebaran disappears behind the Moon's dark limb, the 5.0-magnitude Hyades star 75 Tauri will do the same for Atlantic States south of southern Pennsylvania.

Two hours before Aldebaran, the Moon will occult some brighter Hyades stars, including 4.8-magnitude ZC 677 and the pair Theta^1 and Theta^2 Tauri, magnitudes 3.8 and 3.4, respectively. Detailed predictions for them are in the predictions link below.

For More Information

• We at IOTA have set up a special web page for the Aldebaran graze on March 4–5 (i.e. March 5th UT), with interactive Google Maps and much other information, at **occultations.org/aldebaran/2017march**. Keep checking there for new information as the time draws near.

• Detailed predictions for the total occultations of Aldebaran and Hyades stars are listed for more than 1,000 locations at **lunar-occultations.com/iota/bstar/bstar.htm**. Note that the page for each star displays three long tables with less-than-obvious divides: for the disappearance, the reappearance, and the locations of cities.

■ **DAVID DUNHAM,** a founder of IOTA, has led the coordination of occultation timings since 1962. You can write him at **dunham@starpower.net**.

Minima of Algol

Feb.	UT	Mar.	UT
3	0:54	2	17:45
5	21:43	3	17:07
8	18:32	6	13:56
11	15:22	9	10:46
14	12:11	12	7:35
17	9:00	15	4:24
20	5:50	18	1:14
23	2:39	20	22:03
25	23:28	23	18:52
28	20:18	26	15:41
		29	12:31

Algol remains near minimum for about two hours, at magnitude 3.4 instead of its usual 2.1. It takes several more hours to fade and rebrighten. These geocentric predictions are from the heliocentric elements Min. = JD 2445641.554+ 2.867324*E*, where *E* is any integer. For a comparison-star chart: skyandtelescope.com/algol.

Action at Jupiter

THE SOLAR SYSTEM'S dominant planet, far outweighing all the rest combined, shines fairly high in the southeast by late evening in March. It's still not in its highest, sharpest view until well after midnight. Jupiter is nearing its April 7th opposition, expanding in March from 42″ to 44″ across its equator.

Any telescope shows Jupiter's four big Galilean moons. Binoculars usually show at least two or three. Identify them at any date and time using the diagram at far right.

The interactions in February between Jupiter and its satellites and their shadows are tabulated on the facing page. Find events timed for when Jupiter will be in good view for you.

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

February 1, 8:33, 18:29; **2,** 4:24, 14:20; **3,** 0:16, 10:11, 20:07; **4,** 6:03, 15:58; **5,** 1:54, 11:49, 21:45; **6,** 7:41, 17:36; **7,** 3:32, 13:28, 23:23; **8,** 9:19, 19:14; **9,** 5:10, 15:06; **10,** 1:01, 10:57, 20:53; **11,** 6:48, 16:44; **12,** 2:39, 12:35, 22:31; **13,** 8:26, 18:22; **14,** 4:17, 14:13; **15,** 0:09, 10:04, 20:00; **16,** 5:56, 15:51; **17,** 1:47, 11:42, 21:38; **18,** 7:34, 17:29; **19,** 3:25, 13:20, 23:16; **20,** 9:12, 19:07; **21,** 5:03, 14:58; **22,** 0:54, 10:50, 20:45; **23,** 6:41, 16:36; **24,** 2:32, 12:28, 22:23; **25,** 8:19, 18:14; **26,** 4:10, 14:06; **27,** 0:01, 9:57, 19:52; **28** 5:48, 15:44.

March 1, 1:39, 11:35, 21:30; **2,** 7:26, 17:22; **3,** 3:17, 13:13, 23:08; **4,** 9:04, 18:59; **5,** 4:55, 14:51; **6,** 0:46, 10:42, 20:37; **7,** 6:33, 16:29; **8,** 2:24, 12:20, 22:15; **9,** 8:11, 18:07; **10,** 4:02, 13:58, 23:53; **11,** 9:49, 19:44; **12,** 5:40, 15:36; **13,** 1:31, 11:27, 21:22; **14,** 7:18, 17:13; **15,** 3:09, 13:05, 23:00; **16,** 8:56, 18:51; **17,** 4:47, 14:43; **18,** 0:38, 10:34, 20:29; **19,** 6:25, 16:20; **20,** 2:16, 12:12, 22:07; **21,** 8:03, 17:58; **22,** 3:54, 13:50, 23:45; **23,** 9:41, 19:36; **24,** 5:32, 15:27; **25,** 1:23, 11:19, 21:14; **26,** 7:10, 17:05; **27,** 3:01, 12:56, 22:52; **28,** 8:48, 18:43; **29,** 4:39, 14:34; **30,** 0:30, 10:26, 20:21; **31,** 6:17, 16:12.

These times assume that the spot will be centered at System II longitude 264°. If the Red Spot has moved elsewhere, it will transit 1{2/3} minutes earlier for each degree less than 264° and 1{2/3} minutes later for each degree more than 264°.

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 helps the contrast and visibility of Jupiter's markings.

Asteroid Occults a Bright Star

The second-brightest asteroid occultation that's predicted to happen for North America this year comes late on the night of March 10–11. A 6.3-magnitude star in Leo's snout, just in front of the Sickle of Leo, should snap out of sight for up to 3 seconds for observers along a very narrow track running from the Georgia coast to just north of San Francisco. The culprit is the 15th-magnitude asteroid 1343 Nicole, only about 26 km (16 miles) in diameter.

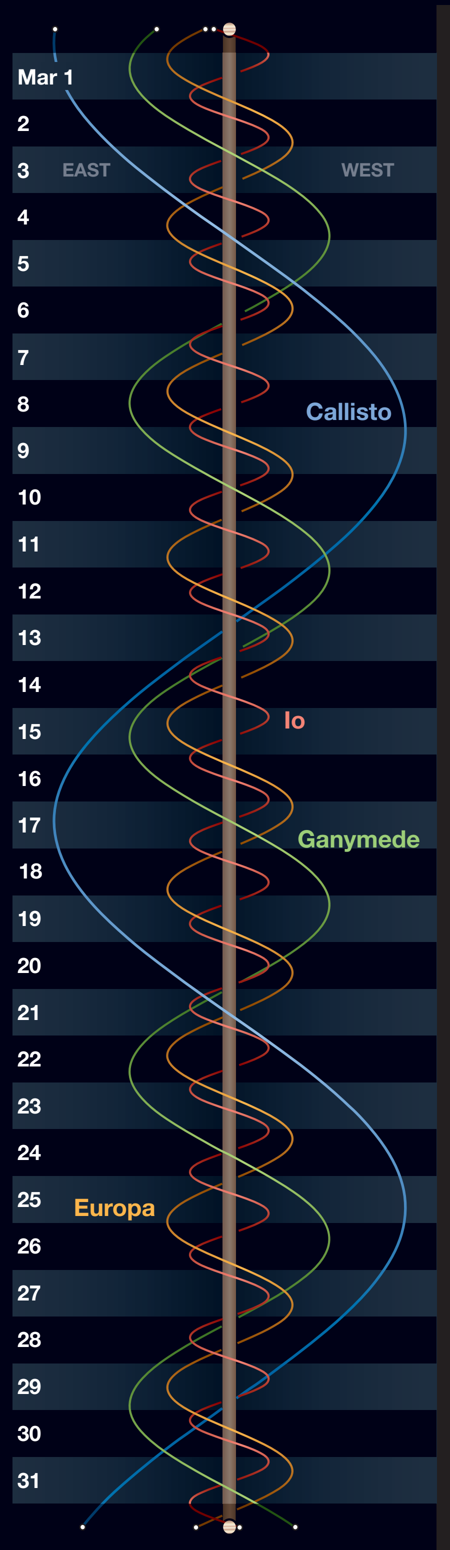
Leo will be very high in the southwest or south. For a detailed map, finder chart for the star (easily spotted less than 1° northeast of Lambda Leonis), and other information, see Steve Preston's comprehensive asteroid-occultation prediction site at **asteroidoccultation.com/IndexAll.htm**.

Phenomena of Jupiter's Moons, March 2017

Mar. 1	9:40	I.Ec.D
	12:40	I.Oc.R
	21:38	II.Sh.I
	23:19	II.Tr.I
Mar. 2	0:07	II.Sh.E
	1:39	II.Tr.E
	7:01	I.Sh.I
	7:49	I.Tr.I
	9:13	I.Sh.E
	9:59	I.Tr.E
	22:41	III.Sh.I
Mar. 3	1:11	III.Sh.E
	2:06	III.Tr.I
	4:03	III.Tr.E
	4:08	I.Ec.D
	7:07	I.Oc.R
	16:45	II.Ec.D
	20:43	II.Oc.R
Mar. 4	1:29	I.Sh.I
	2:16	I.Tr.I
	3:41	I.Sh.E
	4:25	I.Tr.E
	22:36	I.Ec.D
Mar. 5	1:33	I.Oc.R
	10:55	II.Sh.I
	12:28	II.Tr.I
	13:24	II.Sh.E
	14:48	II.Tr.E
	19:58	I.Sh.I
	20:42	I.Tr.I
	22:10	I.Sh.E
	22:52	I.Tr.E
Mar. 6	12:46	III.Ec.D
	15:17	III.Ec.R
	15:57	III.Oc.D
	17:05	I.Ec.D
	17:55	III.Oc.R
	20:00	I.Oc.R
Mar. 7	6:02	II.Ec.D
	9:52	II.Oc.R
	14:26	I.Sh.I
	15:09	I.Tr.I
	16:38	I.Sh.E
	17:18	I.Tr.E
Mar. 8	11:33	I.Ec.D
	14:26	I.Oc.R
Mar. 9	0:13	II.Sh.I
	1:38	II.Tr.I
	2:42	II.Sh.E
	3:58	II.Tr.E
	8:54	I.Sh.I
	9:35	I.Tr.I
	11:06	I.Sh.E
	11:44	I.Tr.E
Mar. 10	2:38	III.Sh.I
	5:08	III.Sh.E
	5:31	III.Tr.I
	6:02	I.Ec.D
	7:28	III.Tr.E
	8:52	I.Oc.R
	19:20	II.Ec.D
	23:00	II.Oc.R
Mar. 11	3:23	I.Sh.I
	4:01	I.Tr.I
	5:35	I.Sh.E
	6:11	I.Tr.E
Mar. 12	0:30	I.Ec.D
	3:19	I.Oc.R
	13:30	II.Sh.I
	14:47	II.Tr.I
	15:59	II.Sh.E
	17:07	II.Tr.E
	21:51	I.Sh.I
	22:27	I.Tr.I
Mar. 13	0:03	I.Sh.E
	0:37	I.Tr.E
	16:44	III.Ec.D
	18:58	I.Ec.D
	19:14	III.Ec.R
	19:20	III.Oc.D
	21:18	III.Oc.R
	21:45	I.Oc.R
Mar. 14	8:37	II.Ec.D
	12:09	II.Oc.R
	16:19	I.Sh.I
	16:53	I.Tr.I
	18:31	I.Sh.E
	19:03	I.Tr.E
Mar. 15	13:27	I.Ec.D
	16:11	I.Oc.R
Mar. 16	2:48	II.Sh.I
	3:55	II.Tr.I
	5:17	II.Sh.E
	6:16	II.Tr.E
	10:48	I.Sh.I
	11:19	I.Tr.I
	13:00	I.Sh.E
	13:29	I.Tr.E
Mar. 17	6:37	III.Sh.I
	7:55	I.Ec.D
	8:53	III.Tr.I
	9:06	III.Sh.E
	10:37	I.Oc.R
	10:50	III.Tr.E
	21:54	II.Ec.D
Mar. 18	1:17	II.Oc.R
	5:16	I.Sh.I
	5:46	I.Tr.I
	7:28	I.Sh.E
	7:55	I.Tr.E
Mar. 19	2:24	I.Ec.D
	5:03	I.Oc.R
	16:05	II.Sh.I
	17:03	II.Tr.I
	18:34	II.Sh.E
	19:24	II.Tr.E
	23:44	I.Sh.I
Mar. 20	0:12	I.Tr.I
	1:56	I.Sh.E
	2:21	I.Tr.E
	20:41	III.Ec.D
	20:52	I.Ec.D
	23:29	I.Oc.R
Mar. 21	0:38	III.Oc.R
	11:11	II.Ec.D
	14:24	II.Oc.R
	18:13	I.Sh.I
	18:38	I.Tr.I
	20:25	I.Sh.E
	20:47	I.Tr.E
Mar. 22	15:21	I.Ec.D
	17:55	I.Oc.R
Mar. 23	5:23	II.Sh.I
	6:12	II.Tr.I
	7:52	II.Sh.E
	8:32	II.Tr.E
	12:41	I.Sh.I
	13:04	I.Tr.I
	14:53	I.Sh.E
	15:13	I.Tr.E
Mar. 24	9:49	I.Ec.D
	10:35	III.Sh.I
	12:11	III.Tr.I
	12:22	I.Oc.R
	13:03	III.Sh.E
	14:10	III.Tr.E
Mar. 25	0:28	II.Ec.D
	3:32	II.Oc.R
	7:10	I.Sh.I
	7:30	I.Tr.I
	9:21	I.Sh.E
	9:39	I.Tr.E
Mar. 26	4:18	I.Ec.D
	6:48	I.Oc.R
	18:41	II.Sh.I
	19:19	II.Tr.I
	21:09	II.Sh.E
	21:40	II.Tr.E
Mar. 27	1:38	I.Sh.I
	1:55	I.Tr.I
	3:50	I.Sh.E
	4:05	I.Tr.E
	22:46	I.Ec.D
Mar. 28	0:39	III.Ec.D
	1:14	I.Oc.R
	3:56	III.Oc.R
	13:45	II.Ec.D
	16:39	II.Oc.R
	20:06	I.Sh.I
	20:21	I.Tr.I
	22:18	I.Sh.E
	22:31	I.Tr.E
Mar. 29	17:15	I.Ec.D
	19:40	I.Oc.R
Mar. 30	7:59	II.Sh.I
	8:27	II.Tr.I
	10:28	II.Sh.E
	10:48	II.Tr.E
	14:35	I.Sh.I
	14:47	I.Tr.I
	16:47	I.Sh.E
	16:57	I.Tr.E
Mar. 31	11:43	I.Ec.D
	14:06	I.Oc.R
	14:33	III.Sh.I
	15:28	III.Tr.I
	17:00	III.Sh.E
	17:28	III.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; 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

Jupiter's Moons



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

The Twilight Zone of Venus

Watch for interesting atmospheric wisps when our neighbor world passes between Earth and the Sun this month.

Circling the Sun almost 30% closer than Earth does, on average, Venus has a shorter orbital period and "laps" our planet at regular intervals, passing between Earth and the Sun in events known as *inferior conjunctions*. Over an interval of 8 years, Venus orbits the Sun almost exactly 13 times and swings through inferior conjunction five times. So the planet's *synodic period*, the interval between two inferior conjunctions, is 1.6 years.

If the two planets had identical orbital planes, we'd witness a transit of Venus across the face of the Sun every 1.6 years. However, Venus' orbital plane is inclined by 3.4° with respect to Earth's, and the two planets' orbital periods are not in perfect resonance. Consequently, transits of Venus are very rare and eagerly anticipated events. Instead, we usually see its disk pass north or south of the Sun during its inferior conjunctions at elongations that can approach 9° — a bit less than the width of your clenched fist held at arm's length.

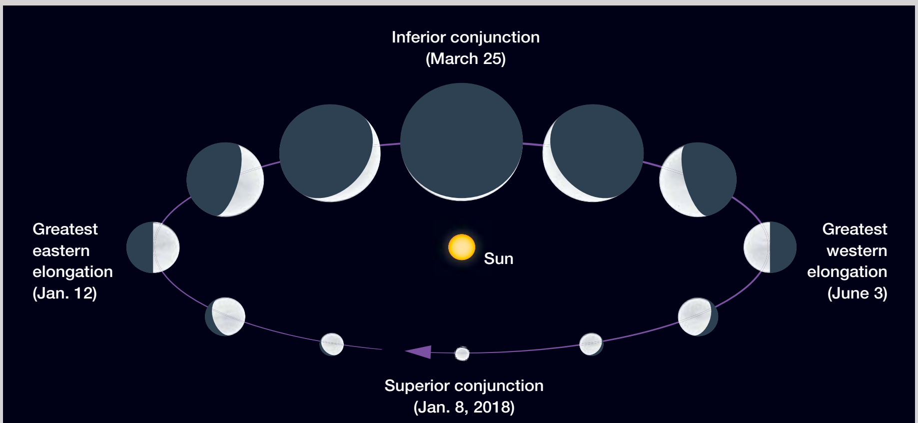
Venus is now a dominant fixture in the evening sky. This beacon achieves its greatest apparent brightness on February 18th, shining as a brilliant –4.6-magnitude "evening star" and setting nearly 3½ hours after the Sun. On this date, even the most humble telescope will reveal a 28%-illuminated crescent with an apparent diameter of 40 arcseconds.

During the following weeks, the illuminated crescent becomes increasingly slender as Venus swings closer to Earth. It swells to almost 60 arcseconds (1/30 the apparent diameter of the Moon) at inferior conjunction on March 25th. On this date Venus passes more than 8° north of the Sun, and for several days before or afterward those of us at mid-northern latitudes can glimpse the spectacle of a razor-thin crescent both shortly after sunset and before sunrise.

Twilight Time

Whenever Venus approaches within 15° of the Sun, faint bluish-white wisps of light begin to extend from the needle-sharp cusps (tips) of the crescent. When Venus and the Sun close to less than 3.7° apart — which won't be the case this year — these *cusp extensions* coalesce into a ring of light that completely encircles the dark rim of the planet. This delicate halo has been evocatively called the "silken thread."

First described in 1790 by Johann Hieronymus Schröter, the cusp extensions frequently appear unequal in length and often contain irregularities in the form of brighter spots and arc segments or dark interruptions. (William Sheehan details Schröter's careful study of Venus on page 52 of the Janu-



Because its orbital plane is tipped slightly with respect to Earth's, Venus usually passes several degrees north or south of the Sun whenever it reaches conjunction. This illustration is not to scale.

This combination of color and infrared-filtered images, taken 4 days after Venus transited the Sun in June 2012, gives a sense of the delicate crescent and cusp extensions that appear when Venus is near inferior conjunction.

DIAGRAM: S&T / LEAH TISCIONE; PHOTO: JOHN BOUDREAU

▲ Here's how Venus looked on August 8, 2015, a week before inferior conjunction. Note the disk's delicate cusp extensions. The sky looks black because the image was taken through a 900-nm infrared filter.

▶ Viewing Venus near the Sun in daylight is one thing, but imaging it can be a challenge. Damian Peach used this setup in the days prior to the planet's June 2012 transit of the Sun.

DAMIAN PEACH (2)

ary issue.) These anomalous appearances are caused by transient changes in the circulation of Venus' atmosphere that are still poorly understood.

In 1899 Princeton astronomer Henry Norris Russell correctly attributed cusp extensions to sunlight scattered by exceedingly fine particles suspended in a transparent layer of atmosphere just above the planet's opaque canopy of clouds. In recent decades space probes have identified a tenuous layer of aerosol haze about 3 kilometers thick that is responsible for the scattering.

Unlike the cusp extensions, the brilliant aureole that outlines the disk of Venus at ingress or egress during its rare transits (*S&T:* Oct. 2012, p. 20) is produced by refracted (not scattered) sunlight. Both of these "twilight zone" phenomena appear when Venus is backlit by the Sun.

In an extensive series of observations conducted during the 1930s and '40s, Lowell Observatory astronomers Earl Slipher and James Edson took thousands of photographs of the cusp extensions through monochromatic filters. They reported that these features appeared generally similar in red, yellow, and blue light, though they usually differed in length and brightness and often contained prominent reddish spots.

Observing the Wispy Cusps

A large telescope isn't required to see these delicate cusp extensions. (For example, Slipher and Edson used instruments only 6 inches in aperture for their groundbreaking studies.) But to get a clear telescopic view of Venus near inferior conjunction, you'll need to view the planet in broad daylight. Despite its extreme thinness, the delicate crescent stands out boldly in a clear sky and actually is fairly easy to spot if the sky is free of haze or cirrus clouds.

Be extremely careful not to aim your telescope directly at the Sun. The danger it poses to your eyes and equipment is serious and real. Don't forget to cover the lens of your finderscope.

If you've got a computerized Go To mount or an accurately aligned equatorial mount equipped with setting circles, you'll locate Venus without much difficulty. If instead you must sweep the sky to find the planet, consider setting up your telescope in the shadow of a building or tree to minimize the hazard posed by the nearby Sun. The planet will be moving rapidly relative to the Sun, so use your favorite planetarium software to find Venus' precise offset and position angle from the Sun for a given date from your location.

Daytime atmospheric seeing tends to be steadiest an hour or two before sunset. Around midday the convection produced by solar heating usually makes for "boiling" images, so you'll want to strike a balance between the steadiness of the atmosphere and the planet's altitude above the horizon. Avoid setting up on or near expanses of asphalt or concrete. A grass-covered lawn provides a much better thermal environment, and viewing from an elevated balcony or over a nearby body of water is truly optimal for avoiding "ground seeing."

Your telescope's optics should be scrupulously clean to eliminate veiling glare caused by any scattered sunlight that enters its tube. If you're using a refractor or a catadioptric telescope, you can fashion a tube extension from a rolled-up newspaper or cardboard to prevent sunlight from falling directly onto the objective lens or corrector. (A Newtonian reflector's tube is already a very effective glare shield.) If you own a large reflector, consider installing an off-axis aperture stop to further reduce stray light and improve definition.

Regardless of your telescope's optical configuration, try using a light-red (Wratten 23A) or orange (Wratten 21) filter to selectively block blue light and improve contrast by reducing the brightness of the sky background. These filters will also eliminate the smear of spurious colors produced by atmospheric dispersion that appear when viewing the planet close to the horizon.

Edson wrote that Venus' "best-kept secrets are reserved for the bold few who will gaze into the very eye of the Sun to find her at inferior conjunction, where her outer and diaphanous draperies gleam in the through-shining sunlight . . . the twilit sky upon that distant world." Don't miss this year's rare opportunity to witness that spectacle.

■ Contributing Editor **TOM DOBBINS** expects to be eyeballing Venus through his 7-inch refractor on March 25th.

Little Lion

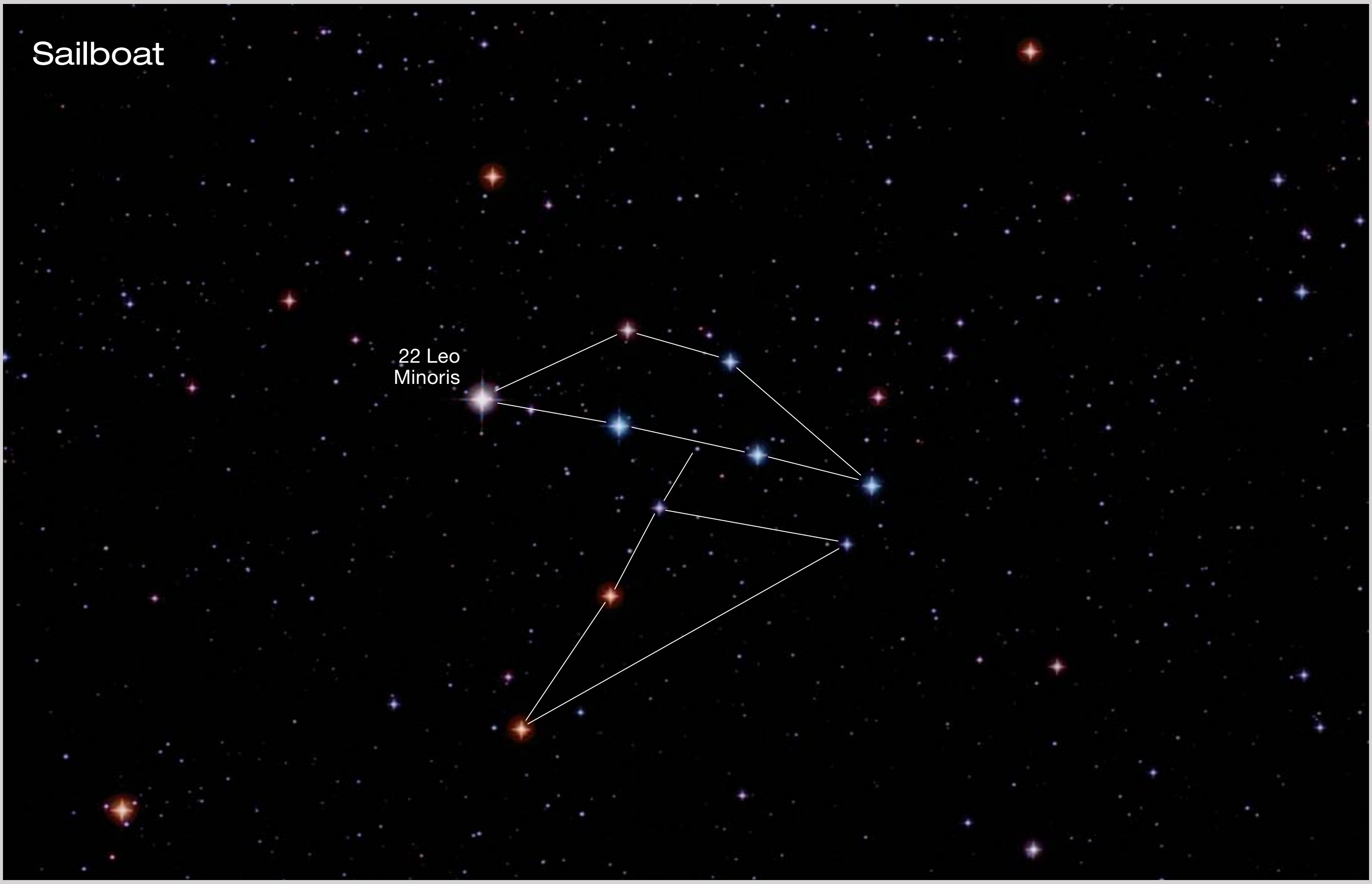
This celestial cat may be small, but it contains an impressive number of deep-sky sights.

Pussyfooting its way across the evening sky, the constellation Leo Minor, the Little Lion, can be faintly spotted between the back feet of Ursa Major, the Big Bear, and Leo, the Lion. The name seems quite apt when you compare the stature of Leo Minor to these much larger neighbors. Our smaller celestial cat was introduced by the Polish astronomer Johannes Hevelius in his charming and innovative atlas *Firmamentum Sobiescianum* (1687).

Hevelius didn't assign letters to the stars in *Firmamentum Sobiescianum*, as Johann Bayer had in his earlier atlas. But in the 1845 *Catalogue of Stars of the British Association*, Francis Baily assigned Greek letters to the brighter stars in constellations devised by Hevelius. Oddly, Leo Minor's second-brightest star is designated Beta (β), but its brightest star is not lettered. Usually a constellation's brightest star is given the letter Alpha (α). In his book *Lost Stars*, Morton Wagman points out that Baily died before he had a chance to check the galley proofs for this constellation and perhaps rectify the omission.

With a lack of Bayer stars to guide us, we'll turn to those that bear Flamsteed numbers, starting with the 6th-magnitude star 22 Leo Minoris. This

▼ When viewed through binoculars, the Sailboat asterism cruises through Leo Minor upside down. Look aft for 6th-magnitude 22 Leo Minoris. Two red stars form the top half of the boat's mast.



DAVID RATLEDGE; SKETCH: SUE FRENCH

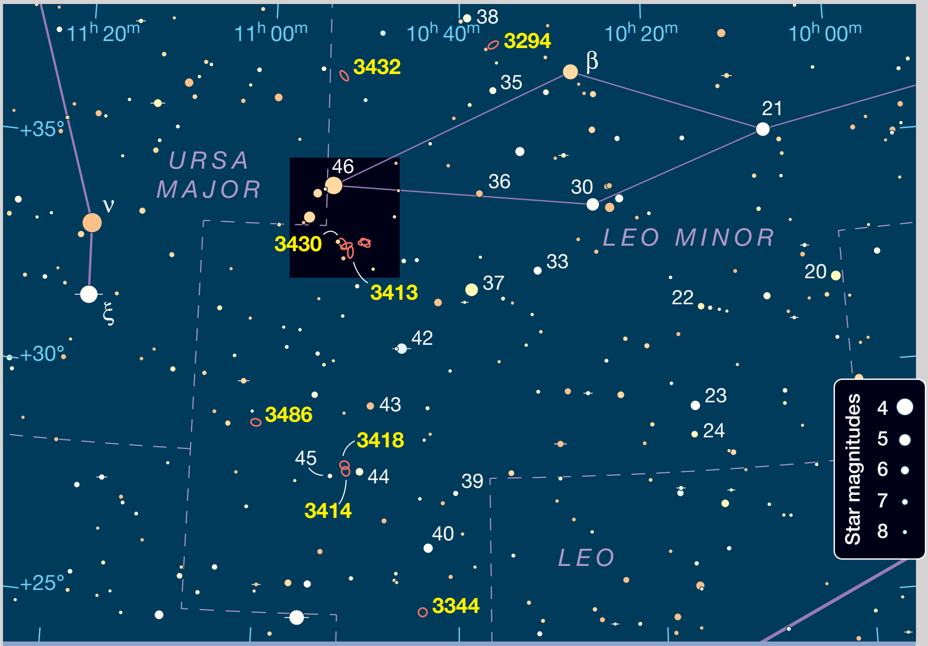
star is the luminary of the **Sailboat**, an asterism brought to the attention of the amateur community in the Summer 1988 issue of the now-defunct magazine *Deep Sky*. Through my 18×50 image-stabilized binoculars, 22 LMi shines deep yellow and marks one end of the boat, while five more stars complete its hull. The sailboat's mast is composed of three stars in a row sticking out to the south-southeast. A star near the western end of the hull could be imagined to make a sail with the mast. Otherwise, you might imagine the sail furled or connected to the ends of the hull. The sketch at left is my interpretation of the Sailboat.

Our next navigational star is 40 LMi, with the face-on spiral galaxy **NGC 3344** dangling 1.4° to its south. Seen through my 130-mm refractor at 48×, the galaxy brightens considerably toward the center. It stands out well despite the superimposed, 10th-magnitude star east of the galaxy's center. At 91× a fainter star, more deeply ensconced in the galaxy, blooms west-northwest of the first. The galaxy itself presents a roundish face about 3½′ across. My 10-inch reflector at 213× adds a faint star southeast of the small, bright nucleus. Spiral structure has been detected in NGC 3344 with scopes as small as 14.5 inches in aperture.

The peculiar lenticular galaxy **NGC 3414** is handily placed between 44 and 45 LMi. The 130-mm scope at 23× shows a moderately faint, small, round glow. At 91× the galaxy becomes slightly elongated and canted north-northeast. It's brighter along the long axis, and it bulges out at the sides. At 117× the bulge holds a small, bright core. In the 10-inch scope at 115×, NGC 3414 shares the field with **NGC 3418**, 8′ to its north-northeast. This smaller galaxy is a faint, oval spot with nearly uniform surface brightness, except for a tiny, bright nucleus.

In images, NGC 3414 resembles a barred lenticular galaxy or an edge-on disk with a prominent bulge. In *The de Vaucouleurs Atlas of Galaxies* (Buta, Corwin, and Odewahn, 2007), the authors point out that the apparent bar may actually be a polar ring — a gas-rich ring perpendicular to the plane of a galaxy, generally thought to be created by galaxy-galaxy interactions. They also indicate that the galaxy's center doesn't show the absorption features that would be expected if the bar-like structure was an edge-on disk.

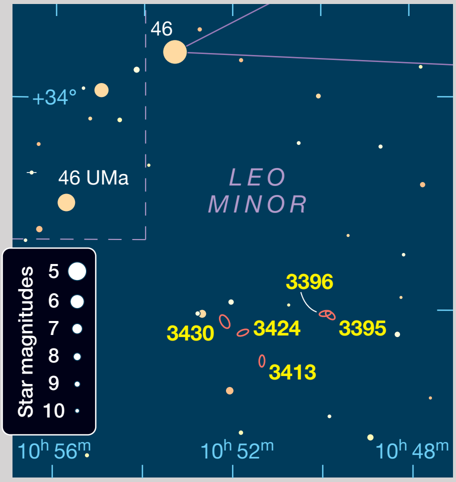
NGC 3486 is a 2° climb northeastward from 45 LMi. This galaxy is easily spotted in my 130-mm scope at 23× as a small, roundish disk. At 91× it reveals a relatively large, brighter interior with a small core and a faint halo. Through the 10-inch scope at 115×, the halo appears slightly oval and roughly 3½′ long. It enfolds a fairly large, vaguely round, somewhat brighter shell that encompasses the bright interior. At 187× the core clasps a nearly stellar nucleus.



Deep-Sky Objects in the Little Lion's Lair

Object	Surface Brightness	Mag(v)	Size	RA	Dec.
Sailboat	—	5.6	40′	10^h 14.0^m	+31° 15′
NGC 3344	14.2	9.9	7.1′ × 6.5′	10^h 43.5^m	+24° 55′
NGC 3414	13.2	11.0	3.5′ × 2.6′	10^h 51.3^m	+27° 59′
NGC 3418	13.7	13.2	1.3′ × 0.9′	10^h 51.4^m	+28° 07′
NGC 3486	14.0	10.5	7.1′ × 5.2′	11^h 00.4^m	+28° 58′
NGC 3430	13.8	11.6	4.0′ × 2.2′	10^h 52.2^m	+32° 57′
NGC 3424	13.3	12.4	2.8′ × 0.8′	10^h 51.8^m	+32° 54′
NGC 3413	12.8	12.2	1.7′ × 0.9′	10^h 51.3^m	+32° 46′
NGC 3395	12.9	12.1	2.1′ × 1.2′	10^h 49.8^m	+32° 59′
NGC 3396	13.4	12.1	2.5′ × 0.8′	10^h 49.9^m	+32° 59′
NGC 3432	13.7	11.3	6.8′ × 1.5′	10^h 52.5^m	+36° 37′
NGC 3294	13.0	11.8	2.3′ × 1.4′	10^h 36.3^m	+37° 20′

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.



The halo and much of the interior look mottled, but I can't pick out any structure that indicates the winding of the galaxy's spiral arms.

Fairly bright and easy to find, spiral galaxy **NGC 3430** hangs 1.3° south of 46 LMi, Leo Minor's brightest star at magnitude 3.8. If you drop southward from 46 LMi, the first modestly bright star you'll come to is a deep-yellow, 7.5-magnitude gem accompanied by a 9.4-magnitude neighbor. A yellow, 8.7-magnitude star lies 9′ to their west-northwest. The galaxy sits about halfway between this star and the pair, and it's a bit south of an imaginary line connecting them. Through the 130-mm scope at 48× I see a 2′ × 1′ oval of light, tipped north-northeast. At 91×, it softly brightens toward the center. When I boost the magnification to 117×, two more galaxies materialize in the field of view southwest of NGC 3430. The closer one is **NGC 3424**, a faint, 1½′ slash escorted by a 2½′ wedge of four 13th-magnitude stars south of the galaxy's east-southeastern tip. **NGC 3413** is a gossamer, north-south smudge, but it can be held steadily in view with averted vision.

At a magnification of 48× NGC 3430 also shares the field with the colliding galaxies **NGC 3395** and **NGC 3396**. Their combined glow appears a little smaller and fainter than the lone galaxy. At 117× these entangled galaxies each harbor a brighter center, with NGC 3395 boasting the more obvious one. NGC 3396 is elongated approximately east-west, with NGC 3395 south of its western end, where their halos blend together. Seen through my 10-inch scope at 166×, NGC 3396 hosts an elongated core with a starlike nucleus.

NGC 3395 and NGC 3396 have undergone at least one close encounter in the past and are now thought to be in the early stages of a merger, a show we're watching from a distance of 85 million light-years.

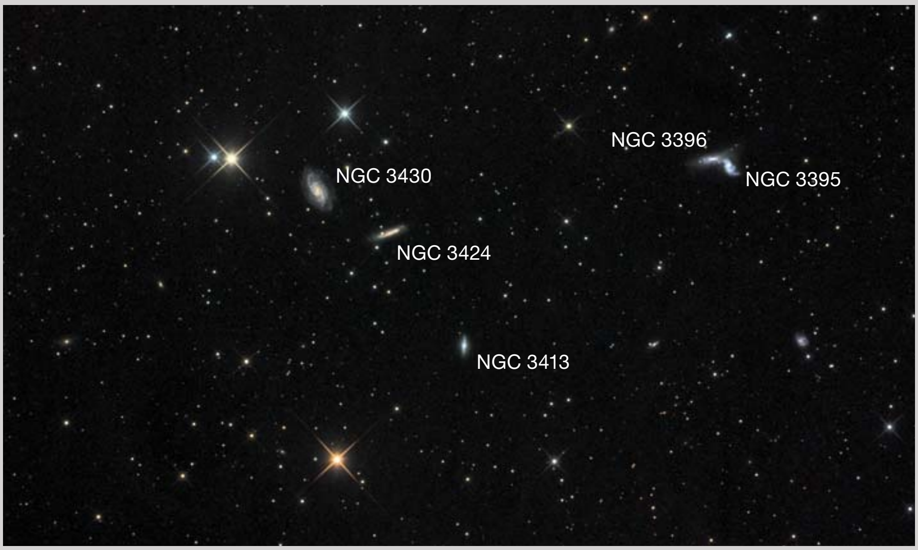
Rising 2.4° north from 46 LMi brings us to **NGC 3432**, a striking, edge-on, barred Magellanic spiral. In my 130-mm refractor at 23×, the galaxy is a moderately faint, slender glow. It looks very nice at 91×. The brightness is a little lumpy, and three stars attend the galaxy. NGC 3432 pierces the space between two 13th-magnitude stars that nuzzle the galaxy's flanks. The western star has a 14th-magnitude companion farther away from the galaxy. At 117× NGC 3432 stretches 4½′ northeast-southwest and is roughly ¾′ wide.

Images show two dim objects near NGC 3432. UGCA 5983 is a dwarf galaxy just west of NGC 3432's southern tip. It's been viewed with 18-inch and larger scopes. The two galaxies form an interacting pair about 40 million light-years away from us. The other object is a large H II (hydrogen emission) region dwelling in the very faint, northern end of NGC 3432. Astronomy author Stephen James O'Meara detected this with his 127-mm refractor at 94× as "an extremely small enhancement of faint light," yet I saw no trace of it with mine.

Our final galaxy, **NGC 3294** rests 49′ southwest of 38 LMi. In the 130-mm scope at 37×, its oval profile tips east-southeast within the northern extremes of a 26′ circlet of several stars, magnitudes 8 to 12. At 63× it covers about 2½′ × 1′ and grows gently brighter toward the center. The galaxy's countenance becomes slightly patchy at 102×. Deep images display a lovely spiral galaxy with tightly wound arms.

As the 64th-largest constellation, the Little Lion doesn't prowl a very imposing swath of sky, but its wealth of galaxies proves its worth as a hunting ground for deep-sky enthusiasts — even for those packing small-bore telescopes.

■ **SUE FRENCH** welcomes your comments at **scfrench@nycap.rr.com**.



▲ Use this LRGB image, captured with a 10-inch f/3.8 astrograph, to guide your galaxy hop. Spiral galaxy NGC 3430 hovers below and between a pair of bright stars (the eastern star has a dimmer neighbor). From NGC 3430, move to the almost edge-on NGC 3424 and down to the dim NGC 3413. Or, from NGC 3430, move 24′ almost due west to find the interacting pair NGC 3395 and NGC 3396.

GREGG RUPPEL

A Flotilla of Edge-On Galaxies

Turn your scope toward this quintet of faint fuzzies floating in Ursa Major.

When I was working through the H400 list of William Herschel's discoveries with my 8-inch f/6 Newtonian two decades ago, I documented a great many unexciting galaxies with descriptions in my logbook that went something like "small, round, with a gradually brighter core." So it was always a thrill when my star-hop revealed something much more interesting, especially an edge-on galaxy. What could be better than an edge-on? Why, the whole flotilla of edge-ons I first captured with my 8-inch on March 17, 1998!

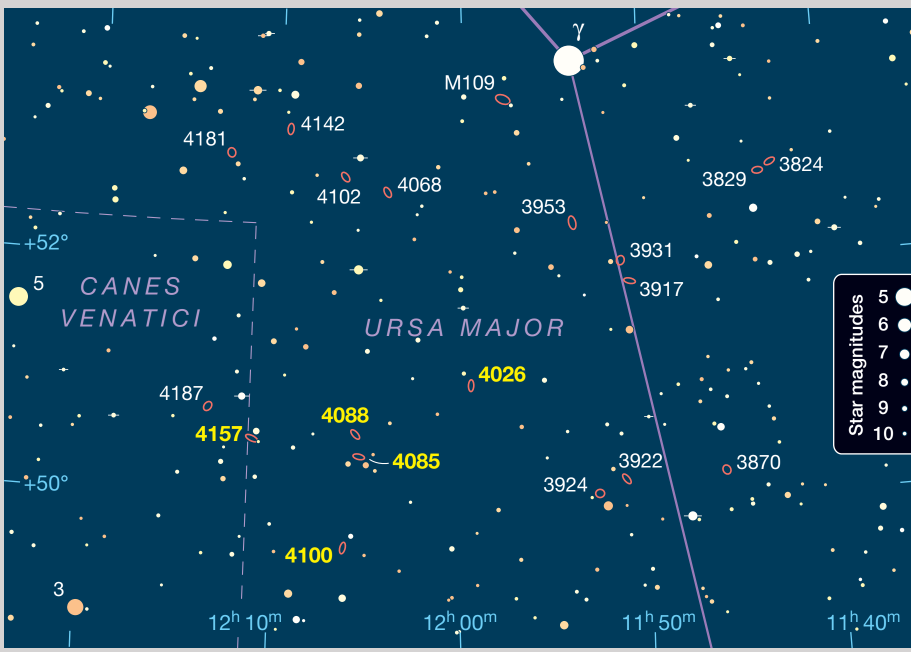
Bright NGC 4088 anchors a splendid group of five edge-on galaxies that spans about 2° in Ursa Major. You'll find the pentad just south-southeast of Gamma (γ) Ursae Majoris and the oval barred spiral M109. All five edge-ons are members of the M109 Galaxy Group, located about 55 million light-years away.

Although only three of the five are on the Herschel 400 list, I always attempted to find all of the adjacent galaxies plotted on Tirion's *Sky Atlas 2000.0*, which was my best atlas way back then. Because of this habit, I was fortunate to see the two non-H400 edge-on galaxies in the group, NGC 4100 and NGC 4157, as well. The Astronomical League's Herschel 400 list seems rather erratic: it includes many mere yawners simply because they have bright cores while leaving out easy and memorable objects like these two.

I made memorable observations of the flotilla with my observatory's 16-inch, equatorially mounted f/4.5 Newtonian on May 26–29, 2005. Over those three nights the transparency was excellent, and the seeing ranged from very good to superb because the winds aloft were light in a broad upper ridge. The seeing on the best night allowed me to resolve a 0.5-arcsecond double star in morning twilight. The night was so fine that I was able to use powers up to 1098× without the double star image suffering, the only night when I have ever been able to use such a high power.

The ratios of length to width given below are my eyepiece-impressions of faint outer halos whose tips fade away to nothingness, not the ratios of the published dimensions in catalogues. Some other observers report smaller ratios. I also give Steve Gottlieb's elongation ratios, as observed with his 17.5-inch Newtonian, in square brackets following mine.

▲ Lenticular galaxies fall between elliptical and true spirals on galaxy morphology diagrams: they have disks, but no arms, and their prominent central bulges make them appear like ellipticals, especially when viewed face-on. In the eyepiece, NGC 4026's disk may be difficult to detect. Look for the more luminous galactic core.



MARTIN GERMANO

Westernmost **NGC 4026**, a north-south lenticular galaxy, contains a super-massive black hole. In my 16-inch at 229× a brilliant nucleus dominates this edge-on. The extremely thin disk is a very faint needle, elongated perhaps 15:1 [Gottlieb 5:1].

Southernmost **NGC 4100** appears as an open-armed barred spiral in photographs. At 229× in the 16-inch it runs north-northwest to south-southeast, and is elongated 8:1 [Gottlieb 3:1]. It shows a faint nucleus, with a knot at the southern end of the disk.

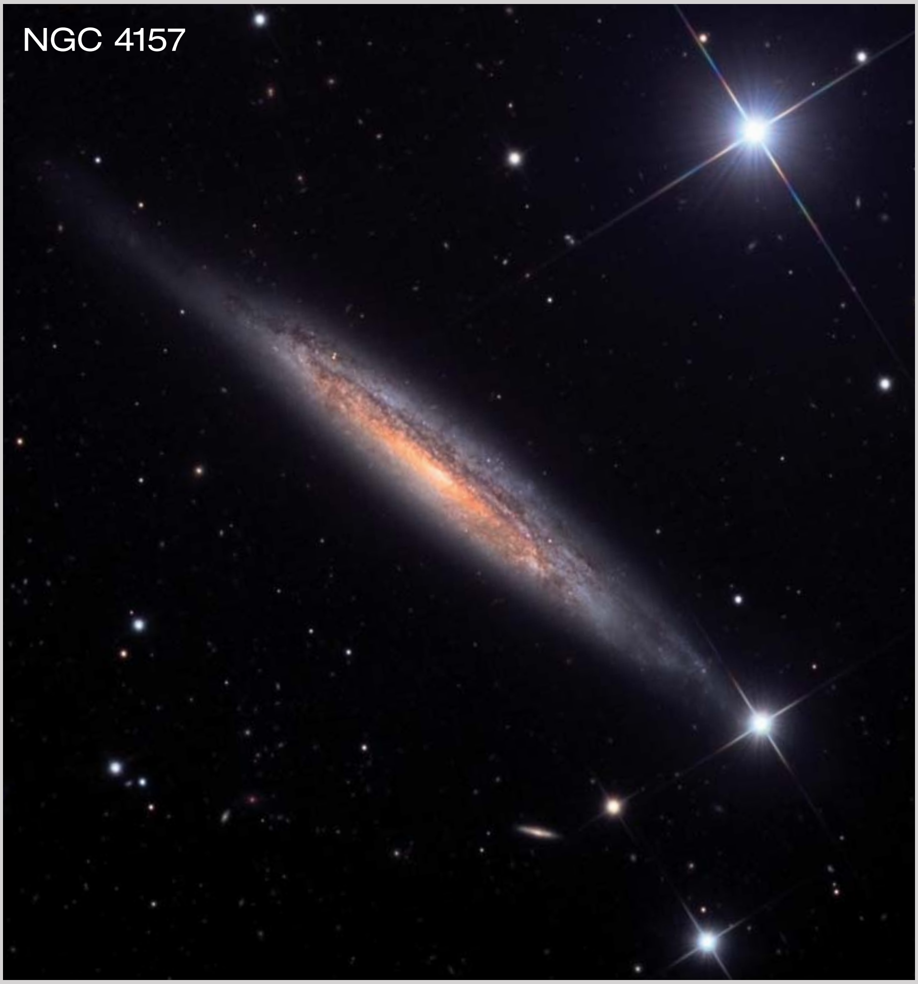
NGC 4157, on the border with Canes Venatici, is a spiral galaxy of type SABb. In the 16-inch at 229× it appears about 5′ long, a 12:1 [Gottlieb 7:1] splinter in position angle 66° (east-northeast to west-southwest) with a very elongated core. The fairly faint nucleus was only intermittently visible. I found knots at both the preceding and following ends of the disk — they, too, were only intermittently visible. The preceding end of the core seemed to be crossed by a transverse dark lane. This galaxy is a winner!

A sketch made by Atlanta observer and *Sky & Telescope* contributor Richard Jakiel with a 20-inch f/4.5 at 175× shows a long dust lane along the northwestern side of NGC 4157's disk, but I couldn't detect it with my smaller scope.

Large **NGC 4088**, an SABbc galaxy, was one of the "spiral nebulae" whose arms were discovered visually with Lord Rosse's 72-inch Leviathan at Birr Castle in Ireland. After a decade of trying, I finally saw spiral structure on June 9, 2015. At 152× the 16-inch reflector showed a bright, spindle-shaped galaxy elongated 6:1 [Gottlieb 5:2] and lying northeast to southwest. The very gradually brighter round core holds a nucleus. The mottled galaxy has a knot near the northeastern tip of the halo. A second look showed elongated knots towards both tips of the halo, more prominently at the northeastern end. "These must be spiral arms," I thought. After upping the power to 203× it clearly looked like a northeastern spiral arm looping around and ending at a knot on the arm just northwest of the nucleus. I also detected what I thought was a tiny knot near the northeastern tip of the galaxy, but was actually the brightest part of the detached arm segment that earned NGC 4088 its place as No. 18 in Arp's *Atlas of Peculiar Galaxies*. But 203× didn't show

▶ NGC 4157 straddles the border between Ursa Major and Canes Venatici. Look for a thickened needle of light running east-northeast to west-southwest. The image at right was captured with the 32-inch Schulman Ritchey-Chrétien telescope at the Mt. Lemmon SkyCenter.

▼ Taken with a 20-inch Ritchey-Chrétien telescope as part of the Kitt Peak Advanced Observing Program, the image below reveals the spiral structure of NGC 4100. The galaxy will show as an elongated smudge with a faintly brighter core in the eyepiece.



NGC 4100: JACK BURGESS / ADAM BLOCK / NOAO / AURA / NSF; NGC 4157: JOSEPH D. SCHULMAN / CC BY-SA 3.0

much at the southwestern end of NGC 4088. An image confirmed that I had detected spiral structure on this night.

NGC 4085, a barred spiral, lies only 11′ south of NGC 4088. As an indication of the small fields of view of Herschel's telescopes, consider that he discovered NGC 4085 more than a year after he found its near neighbor. It wasn't a matter of difficulty since he categorized both objects as Class I: Bright Nebulae.

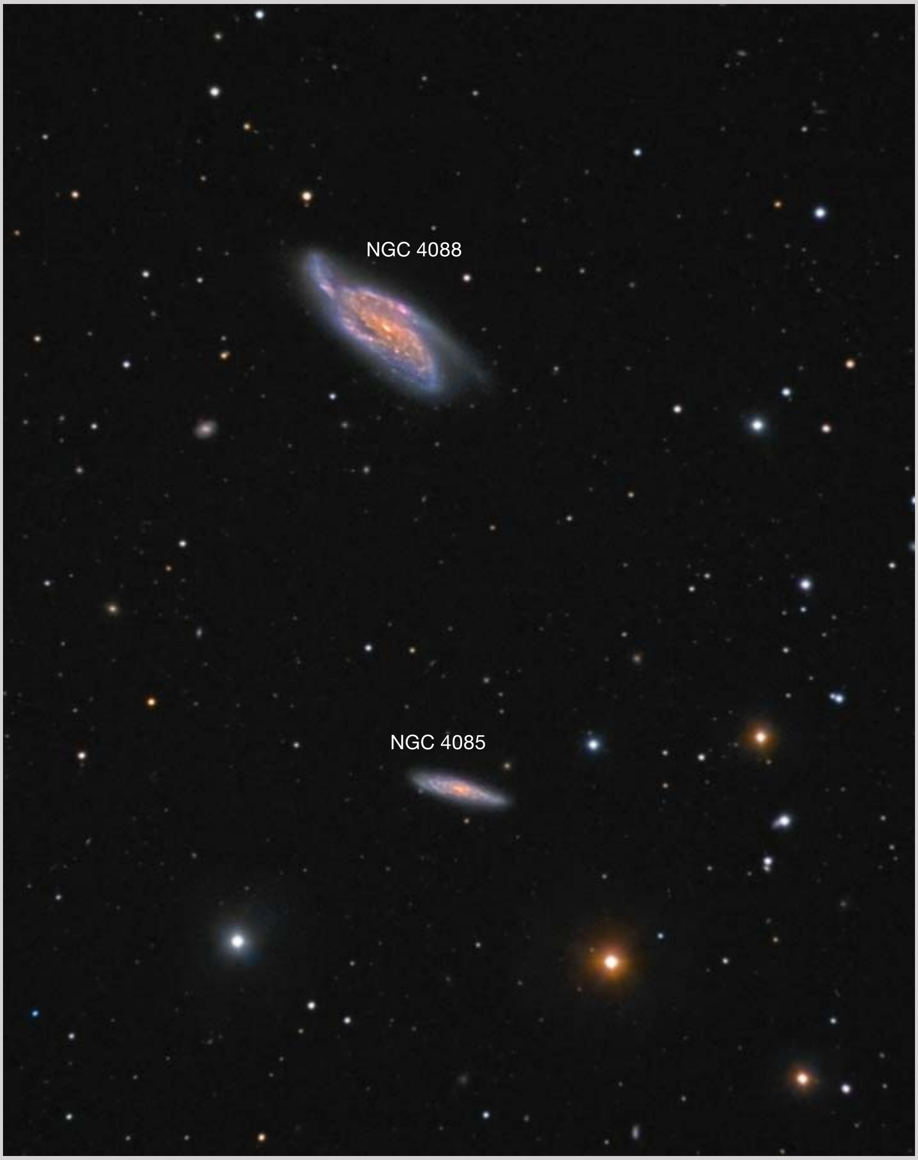
Cigar-shaped NGC 4085 is smaller and fainter than NGC 4088, but at 152× is even more elongated at 8:1 [Gottlieb 4:1] with a position angle of 78° (almost east to west). NGC 4085's faint core is less elongated than the halo. The core sports a nucleus.

■ Contributing Editor **ALAN WHITMAN**'s last article on galaxies was "The Spiral Arms of Spring" in the March 2016 issue.

Leviathan of Parsonstown

William Parsons, the 3rd Earl of Rosse, did his best to streamline his work with the 72-inch reflecting telescope "Leviathan," constructed 1842–1845 at Birr Castle, Ireland. Lord Rosse's managerial efforts included the oversight of the nightly running of the telescope with a small cadre of assistants. A typical observing session saw at least five people at work in the observatory. Two assistants were tasked with moving the optical tube up and down, east and west, bringing objects into the field of view. Another assistant was charged with moving the observing platform ("the gallery") in coordination with the telescope. A fourth person stood on the gallery, ready to observe and record the sights. A fifth helper looked after the lights and other ancillary jobs through the night.

Sir Robert Ball, future astronomer royal of Ireland, began work as an observing assistant at Birr Castle in 1865. The detection of the spiral arms of NGC 4088 is credited to Lord Rosse, but the notes in the observing log for March 28, 1867, were written by Ball, who described the galaxy as "a new spiral with probably many details of interest, of an S shape."



JIM THOMMES

▲ NGC 4088 appears somewhat irregular, its spiral arms distended or even detached, perhaps due to its interaction with nearby NGC 4085. The horizontal field of view is 19 arcminutes.

A Raft of Galaxies in Ursa Major

Object	Type	Mag(v)	Surface Brightness	Position Angle	Size/Sep	RA	Dec.
NGC 4026	S0	10.8	12.9	178	5.2′ × 1.3′	$11^h 59.4^m$	+50° 58′
NGC 4100	SAbc	11.2	13.5	167	5.4′ × 2.8′	$12^h 06.1^m$	+49° 35′
NGC 4157	SAB	11.4	13.4	66	6.8′ × 1.1′	$12^h 11.1^m$	+50° 29′
NGC 4088	SABbc	10.6	13.2	43	5.8′ × 2.2′	$12^h 05.6^m$	+50° 32′
NGC 4085	SBc	12.4	13.1	78	2.8′ × 0.8′	$12^h 05.4^m$	+50° 21′

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.

Takahashi's FSQ-130ED Super APO Astrograph

Takahashi FSQ-130ED astrograph

U.S. Price: $13,150
takahashiamerica.com

What We Like

Outstanding optical performance
Robust mechanical construction
Compact design allows for easy storage and travel

What We Don't Like

Relatively heavy instrument for its aperture

Imaging setups require multiple adapters

This 5.1-inch f/5 telescope promises unsurpassed imaging performance for today's large-format astronomical cameras.

TAKAHASHI, the Japanese firm long known for crafting some of the world's finest telescopes and astrographs, has upped the ante for wide-field, deep-sky astrophotography. The company's new FSQ-130ED Super APO astrograph is the big brother to the FSQ-106ED and the latest addition to a line of astrographs that have achieved legendary status among astrophotographers. Chances are better than not that those spectacular wide-field celestial vistas you've seen in magazines and on the web were made with one of Takahashi's FSQ telescopes.

Compared to its smaller sibling, the FSQ-130ED adds about 1 inch of aperture and 4¾ inches of focal length. The new scope's optical tube assembly also has added heft, tipping the scales

▲ The Takahashi FSQ-130ED astrograph coupled with an FLI ProLine 16803 CCD camera created a powerful deep-sky imaging system that captures a 3¼°-wide field with pin-point stars from corner to corner. This view of the Andromeda Galaxy is 225 minutes of total exposure through red, green, and blue filters.

at about 27 pounds (12.2 kg) or almost twice the weight of the FSQ-106ED. But the real eye-opening increase is the price – at $13,150 the new scope is nearly two and a half times more expensive than its predecessor. With such added cost comes the expectation of uncompromising performance, and that's the standard by which I judged the FSQ-130ED that we borrowed from Texas Nautical Repair for testing last spring and summer.

First the Basics

The FSQ-130ED is a 130-mm (5.1-inch) f/5 refractor with a 5-element optical system, which Takahashi proclaims as the "ultimate model of the Takahashi FSQ series." The 3-element front objective and 2-element rear corrector include three lenses made from what the manufacturer calls "super ED glass" (where the ED stands for extra-low dispersion) that is capable of correcting spherical and longitudinal chromatic aberrations to "almost zero."

The scope has a nominal focal length of 650 mm (25.6 inches), but there are optional 0.73x and 0.60x focal reducers that deliver effective focal lengths of 470 mm (f/3.6) and 390 mm (f/3.0), respectively. These focal reducers each produce a usable imaging circle 44 mm in diameter, which is large enough for full-frame DSLR cameras and astronomical cameras built around the popular KAF-11000 CCD sensor. There are also 1.5x and 1.6x focal extenders for the FSQ-130ED that yield 980 mm (f/7.5) and 1,040 mm (f/8.0) local lengths with the same 44-mm imaging circle. I didn't test these accessories, but Takahashi is known for living up to its optical specifications.

With its 650-mm focal length, the FSQ-130ED has a native image scale of 317 arcseconds per millimeter. But the most impressive spec is the scope's huge 110-mm imaging circle that spans a whopping 9.7° of sky. This imaging circle far exceeds the grasp of any CCD camera currently intended for the amateur market, or, for that matter, anything on the foreseeable horizon. The largest cameras I used on the scope have KAF-16803 CCD chips, which covered a 3¼°-wide field of view with a resolution of 2.86 arcseconds per pixel. But on paper the FSQ-130ED would be an incredible scope to pair with FLI's new MicroLine 50100 camera with its KAF-50100 CCD sensor (**flicamera.com/microline/index.html**). This setup would cover a 4⅓° x 3¼° swath of sky at a resolution of 1.9 arcseconds per pixel — excellent parameters for a f/5 wide-field, deep-sky imaging setup.

With its dew shield retracted and no adapters attached to the focuser, the FSQ-130ED is impressively compact, being slightly less than 21 inches (53 cm) long. As such it would fit diagonally into standard carry-on airline luggage, though it might exceed the weight limits of some airlines. The scope's overall construction is exceptionally robust, living up to Takahashi's well-deserved reputation for building rugged equipment.

This is especially true of the precision 5-inch dual-speed, rack-and-pinion focuser and 360° camera rotator. The focuser has just 35 mm of travel and is so smooth and friction-free that even light cameras will cause the drawtube to slide outward when the scope is pointed at high elevations. To prevent this from happening there's a locking lever that doubles as an adjustable-friction clutch on the focus knob. It worked very well, and even when I set the friction high enough to securely hold my heaviest CCD camera in place, I could still finesse the focus with the hand knobs, including the 10:1 fine-focus knob. This was an unexpected benefit since the majority of dual-speed focusers I've used in the past simply let their fine-focus knobs slip when the drawtubes were "locked" down. The only issues I had with the focuser involved the relatively short travel of the drawtube, and I'll return to this in a moment.

In addition to my Apogee and FLI CCD cameras mentioned above with KAF-16803 chips, I also tested the FSQ-130ED visually and with a full-frame

▲ All astronomical images accompanying this review were made with the Takahashi FSQ-130ED astrograph mounted on a Paramount MX in the author's backyard observatory under moderately light-polluted skies less than 20 miles from the heart of downtown Boston.

▲ The telescope's 3-element objective and 2-element rear corrector include three lenses made from "super" extra-low-dispersion glass.

ALL PHOTOS BY THE AUTHOR / ASTRONOMICAL IMAGES PROCESSED BY SEAN WALKER

▲ This collection of adapters (with several comprising two pieces already screwed together) is what the author needed to use the FSQ-130ED with 1¼- and 2-inch eyepieces, with his Nikon DSLR camera, and with Apogee and FLI large-format astronomical CCD cameras.

Nikon DSLR camera. Anyone familiar with Takahashi equipment knows that configuring a scope for visual and imaging applications involves adapters. As one of my friends and a long-time Takahashi owner recently quipped, the company "has a fetish for adapters, and adapters for adapters, and also adapters for adapters for adapters." It's true.

Glancing at the system chart in the manual for the FSQ-130ED shows a bewildering number of bits and pieces that screw together for the various visual and imaging setups. But fortunately the folks at Texas Nautical Repair are experts, and the scope I tested arrived with exactly what I needed for each of the setups I told them I intended to use. The downside is that many of these adapters cost between $100 and $200 each if ordered à la carte. There are, however, kits offered by Texas Nautical that bundle popular adapters at a reduced price. And while I'm on the topic of manuals, there currently isn't one available online for the FSQ-130ED, but the one for the smaller FSQ-106ED (**takahashiamerica.com/manuals/FSQ-106ED.pdf**) is very similar and can be downloaded for free.

Performance

If I had to use one word to describe the optical performance of the FSQ-130ED, it would be "outstanding." Stars were absolute pinpoints from corner to corner with all my cameras, and the falloff in illumination (vignetting) even in the corners of a 38-mm-square KAF-16803 chip is less than 10% and easily fixed with a standard flat-field calibration. My astrophotography showed no signs of flaring or ghost images due to bright stars in or around the field of view, and the small haloes that surrounded exceptionally bright stars were almost certainly caused by the window and filters in my CCD camera rather than by the telescope optics. The scope's visual performance is equally superb.

I've used other high-end instruments that are in the same category as the Takahashi. The most notable ones being the Astro-Physics 130mm f/6.3 Starfire GTX with its f/4.5 focal reducer and the Tele Vue-NP127is, which is a 127-mm f/5.2 system. Without a side-by-side comparison under controlled conditions, I can't say any one of these scopes delivered better star images than the other two. But the FSQ-130ED does have the largest imaging circle and easily covers a KAF-16803 sensor, while the other two are near their limits with this size chip. It's difficult for me to imagine anyone expecting more performance from a 130-mm f/5 astrograph than what the Takahashi delivers.

When testing equipment for our product reviews, I try to use telescopes the same way that readers would typically use them. The FSQ-130ED, however, was a bit of an exception. I think this caliber of telescope would likely end up permanently installed in a dark-sky observatory and set up as a dedicated imaging platform with a single camera and some type of add-on motorized focuser. Furthermore, high-end scopes like the FSQ-130ED are usually run as fully automated systems, leaving routine focusing adjustments and camera control to sophisticated computer programs. While I did install the scope (on a Software Bisque Paramount MX) in my backyard observatory, it was under the moderately light-polluted skies of metropolitan Boston. And almost all of my imaging was done the old-fashioned way with me next to the scope focusing it manually and operating the cameras.

▲ As described in the accompanying text, an adjustable-friction locking lever on the focuser prevents the drawtube from slipping while still allowing focusing with the coarse and 10:1 fine-focus knobs.

I also spent a couple of evenings using the scope visually to hunt down a selection of double stars and brighter deep-sky targets in the summer sky. This is admittedly unusual testing for an instrument mainly designed as an astrograph, but it was sent to me with adapters for conventional 1¼- and 2-inch eyepieces, so why not. While the FSQ-130ED did deliver exquisite views through an eyepiece, it was not an easy scope to use visually. Because of the focuser's limited travel, switching eyepieces, adding a star diagonal, or using a Barlow lens for increased magnification often required adding or subtracting adapters from the setup. And because most of the adapters thread together, this proved to be challenging and time-consuming in the dark. Despite

▲ Although light pollution interferes with recording traditional RGB color images of faint deep-sky objects from the author's observatory, exposures made with narrowband filters are only mildly impacted. This 5¾-hour exposure of the Horsehead Nebula was made through a 7-nm hydrogen-alpha filter. The small halos around the two brilliant stars in Orion's Belt are almost certainly caused by the CCD camera and its filters rather than by the telescope optics.

the nearly flawless views, I wouldn't recommend this scope solely for visual use. Furthermore, today there are many high-quality refractors in this aperture range that offer excellent visual performance. You don't need the advantages of a premium astrograph to enjoy first-class views through an eyepiece. But it's also nice to know that if you want to look through the FSQ-130ED, you can.

The focuser's relatively short travel was also an issue that cropped up when I was shooting with a DSLR camera. The evening before the Mercury transit last May I made sure the scope was properly set up for my Nikon D700 camera by focusing on stars. In the morning while waiting for the transit to begin, a flock of brilliantly colored goldfinches descended on our birdfeeder about 100 feet from the scope. It seemed like the perfect photo op for this exceedingly sharp 650-mm "camera lens," but I couldn't rack the drawtube out enough to reach focus, and I wasn't about to mess with changing adapters in the waning moments before the transit's start. There's no doubt the scope is a great lens for terrestrial photography, but it's not one that can adapt quickly to focusing over a large range of relatively nearby distances.

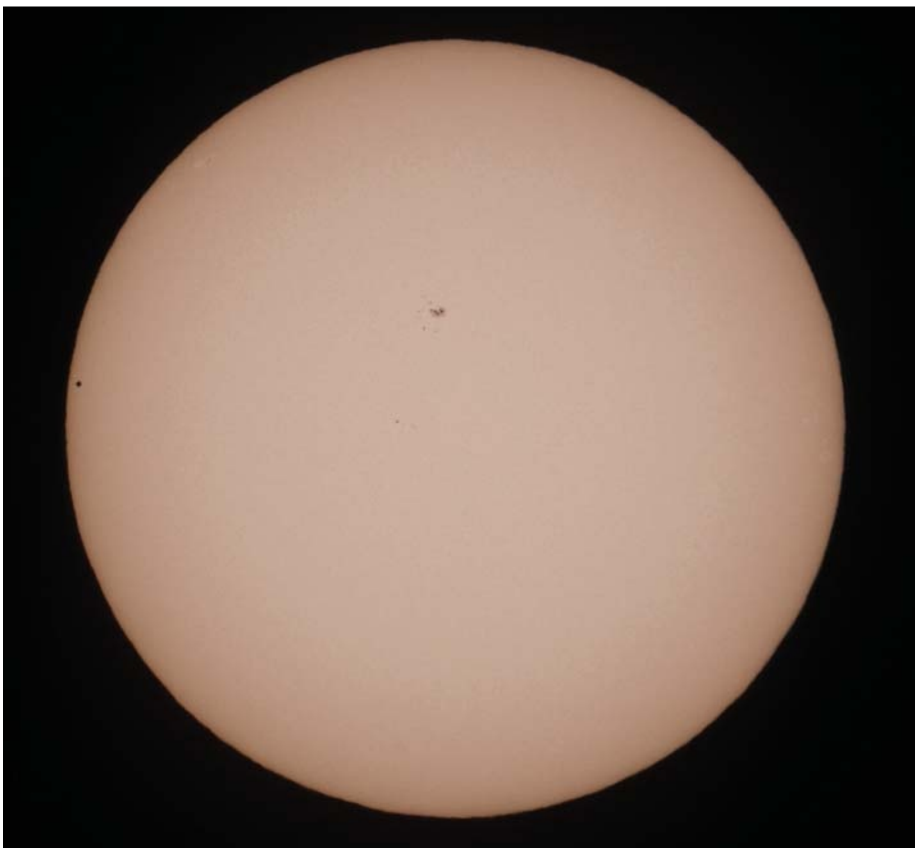
With the focuser stripped of any adapters and the dew shield retracted, the 27-pound optical tube assembly is only 21 inches long.

Where the FSQ-130ED's optical and mechanical features coalesce to form a virtually perfect system is when the scope is used as an astrograph. As mentioned above, the superb star images across a huge field of view, coupled with the scope's solid construction and smooth focusing, left nothing to be desired. The accompanying deep-sky images speak for themselves.

I was pleased that the scope required no refocusing when switching between color filters for RGB imaging, but it was necessary to tweak the focus in conditions of significantly changing air temperature. This was especially true during my late-spring imaging sessions, when pleasantly mild evenings rapidly descended to sub-freezing temperatures, requiring me to adjust the focus at least once, and sometimes twice each hour. But when the temperature was stable to within about 4°F (2°C), the scope's focus was also quite stable over many hours. One good example is the lead image in this review of the Andromeda Galaxy. It was assembled from exposures gathered over a 5-hour period spread across two consecutive nights when the scope's focus remained fixed and the air temperature varied by less than 5°F. And, of course, as I mentioned earlier, routine focus updates are of little concern for anyone running a fully automated imaging setup.

It's never easy to stick a "best" label on any telescope or astrograph; there are simply too many subtleties involved when it comes to defining what makes a perfect instrument in the eyes of each observer. But I will say that when it comes to a 5-inch telescope designed for wide-field, deep-sky imaging, I've never used a better one than the Takahashi FSQ-130ED.

▼ This early-morning snapshot of Mercury transiting the Sun last May 9th was made with the FSQ-130ED and a full-frame Nikon D700 DSLR camera about 10 minutes after the planet first crossed the Sun's eastern limb.



■ **DENNIS DI CICCO** has been writing about equipment in the pages of *Sky & Telescope* for more than 40 years.

Launching Astronomy into the Wilds of Colombia

Were we crazy?

What would happen if we combined astronomy, ecology, long-distance horse trekking, and cross-country paragliding — for a 1,000-km (600-mile) journey of science-education outreach through some of the wildest terrain of Colombia? Just the two of us?

Well, life belongs to the bold. Our dream project took on a name: *Cielo y Tierra*, "Sky and Earth." Here we were: Marja Seidel, 27, an astrophysicist at the Carnegie Observatories in Pasadena, California, and Kira Buelhoff, 26, a biologist specializing in alpine ecology based in Grenoble, France. Our plan was to use astronomy and ecology as tools to excite people rarely reached by hands-on science — children in particular — to explore, discover, and keep studying, and at the same time raise awareness about the uniqueness of our planet and the need to care for it.

▲ **BY RUGGED WAYS** The authors (Kira Buelhoff, left, and Marja Seidel) covered more than 1,000 km by paraglider, horse, mule, and foot to bring astronomy to 1,600 kids and adults. It wasn't easy.

ALL PHOTOGRAPHS COURTESY THE AUTHORS

Packing two telescopes, we crossed back-country little reached by science education to spread excitement about the ecology around us and the universe overhead.

In accordance with our theme of Sky and Earth, we planned sustainable means of travel: by horse on rugged trails and roads, and by paraglider through mountain skies. This unusual combination, drawing on our adventure-sports backgrounds, was very practical for the geography. We could minimize the loads on the horses, because as soon as wind conditions allowed, one of us could cover the daily distance in a paraglider while the other advanced with three horses transporting the bulk of our gear.

Colombia is a fascinating country. Its people and nature are extraordinary. Horses remain a major part of rural culture, and the Andes offer some of the best paragliding conditions. But we did not choose our route just because of this. A huge gap in wealth and education exists between the urban and rural areas. While cities like Bogotá and Medellín have advanced greatly in recent years, the people in the countryside are often forgotten. Remote regions suffer from a lack of school resources and are neglected by NGOs and government development programs. This leads many children to drop out even from primary school. Very young rural kids often go to work in the fields, or drift into Colombia's notorious drug-trafficking business, because these are the only possibilities they can see for themselves. Time spent in further education can seem like a waste.

We wanted to learn more about the situation and make a first step toward changing it. And, we knew, astronomy is ideal for exciting people! It's one of the most visual sciences. Experiencing your first view of the Moon through a telescope, or Jupiter or Saturn or even a fuzzy deep-sky object, can become a life-changing moment. Very little lecturing is needed; people bring up questions naturally as sparks of curiosity light up.

▲▲ **THE SUN UP CLOSE** At the school in San José de Suaita, Marja helps children focus the PST solar telescope for views of prominences in hydrogen-alpha light.

▲ **NO AC** "In the village of Jordan at the bottom of the Chicamocha Canyon, we tried to cope with midday heat of almost 50°C (122°F) by holding our workshops in a shaded pavilion."

S&T MAP: LEAH TISCIONE

▲ **TRAVELING BY UPDRAFT** One member of the expedition would often cover the daily distance flying, with some luggage in the backpack of her harness, while the other led horses and a mule with the rest. Here, Marja takes flight.

From February to April 2016, we made our way from Bucaramanga to Cali offering workshops, celestial observing, and small ecology experiments. We put on programs for almost 30 schools, associations, and sometimes just on a village's central plaza — an event every other day. Often we met with an entire school, from the youngest through the graduating high-school class. In the most remote places this could mean only 20 or 30 children, but in the slightly bigger villages, we had up to 300 kids to entertain for an entire day. Parents, grandparents, and preschoolers joined our sessions; everyone was fascinated by the telescopes.

During the day we observed the Sun in hydrogen-alpha light with a Personal Solar Telescope, and at night we used a LightBridge Mini, both generously donated by Meade Instruments. All told, we educated and inspired 1,600 children and adults. We still receive messages such as, "You really changed my perception of the world." These make it all worth it! Because we faced trials and tribulations indeed.

But let us invite you to join our expedition from the start.

Launch Day

Here we are in Bucaramanga, in Colombia's north. We're staying with Ricardo Mantilla, a Colombian paragliding pilot whom we met in Europe. His vast smile mirrors the findings of a Gallup international survey: Colombia, yet again, has ranked as the happiest country in the world. This may surprise North Americans who never hear about Colombia except for drug cartels and guerrilla war. But the country is so much more.

Ricardo's place is a little paradise, a hostel next to the takeoff on the Ruitoque mountain overlooking the giant city. Between scouting local stables for horses and enjoying excellent flying conditions, we offer our first public observing sessions. We set up the solar telescope at the takeoff site in the afternoons, entertaining local families as well as the paragliding community. At night we observe the Moon with the hostel's backpackers. Everyone is excited about our project and cannot really believe that we two young women will set off alone with three horses, two paragliders, two telescopes, and a bunch of other educational materials through remote and perhaps dangerous terrain.

A couple of days later we're off. While Kira loads the horses we've acquired, Marja sets off with her paraglider. We choose a meeting point on our GPS units, remain in radio communication for much of the time, and meet up with no problems after covering 15 kilometers. Our concept seems to work!

And then our guardian angel apparently decides "They'll be able to handle it on their own," and goes on holidays.

The El Niño phenomenon has Colombia by the short hairs. Extreme temperatures and a 100-year drought complicate our plans. Kira gets sunstroke, Marja injures her ankle, and one of our horses falls ill. And now we are about to cross the Chicamocha Canyon, a dream for paragliding pilots, but for horses? It's a breakneck descent on a steep dirt track. While Marja tries to take off with one lame foot, Kira is responsible for too many feet: her own and the 12 of the

▲ **SOLAR SYSTEM TUTORIAL** Which planets are in which order from the Sun? Marja (left) introduces the "planet challenge" to kids in the Chicamocha Canyon.

horses, all sliding perilously close to catastrophe.

But we make it. We arrive in the fiery furnace of Colombia: the village of Jordan, deep down in the Chicamocha Canyon, with 80 inhabitants and temperatures well over 42°C (110°F). Jorge, a farmer, has arranged for us to stay with him. He makes a place for our horses in his paddock and meadows — but the meadows are crispy yellow, since no rain has fallen in months. Our sick horse deteriorates. The steep climb down into the canyon was too much; his legs give out. We let him lie and rest.

Discoveries Night and Day

In the evening we gather with the locals on the small village square. Of the 80 inhabitants, half seem to be policemen. But they join in the observations, along with many children. So there we are on a 100° night in a tiny square mobbed by kids and men with guns — and all are fascinated by the craters on the Moon. They never stop asking us questions. If curiosity for our planet, life on other planets (of course), and ultimately science in general can be so easily triggered, we wonder why schools do not use astronomy more often?

We get up the next morning before sunrise in hopes of escaping the heat, which proves impossible. Our horse has not recovered. Jorge, our host, tries to help us and offers his mule in exchange for the sick horse. It's a generous offer. Mules are everywhere in Colombia, able to transport heavy loads over mountainous paths and long distances. The trade of animals is really more like a present to us.

Relieved, we can focus completely on spending the next hours with the entire local school on the central square. We've brought a model solar system. The kids love to play with the inflatable planets while learning that life as we know it is completely impossible on any of these other worlds. With the kids, we estimate the true size of the Earth with respect to our Sun: Earth would be no bigger than half of their pinky's fingernail. "Woooow." They cannot stop being amazed at the sizes and distances, and we note that, at the scale of our beach-ball-size Sun, even the far end of town would be too close for Neptune.

Our final part is the solar observations. The surface of the Sun is not very active today, but that doesn't matter. The kids cannot get enough of observing the red ball with the tiny filaments on its sides, prominences made visible by the scope's H-alpha filter. "This looks like feathers — does the Sun fly?" Well, in a way it does, but not because it has feathers; those are massive explosions. And again, they can't believe what they are seeing and hearing. "I always wanted to be a soccer player, but I think being an astronomer is just so awesome!" It's magical sharing this experience. We just let them discover.

But eventually we have to move on and travel to the next village. "Do you have to leave?" "Please stay another day." "Here you have a new family." Those are the words of goodbye. We take contact information for teachers and older students in order to remain in touch. The aim of this project is to incite curiosity, to transmit the joy of discovering and the awareness that there is so much more out there! And day by day we think that we are achieving this.

But guardian angels are fickle. A line from one of our favorite poems, spoken by Sarah Kay, begins:

She's gonna learn that this life will hit you, hard, in the face, wait for you to get back up so it can kick you in the stomach—

And this is how we feel the day, just after a week into the expedition, when we get robbed. Much of our equipment is stolen from our guesthouse, including our phones and computer, along with the belongings of others. It is just bad luck, the wrong place at the wrong time. Never during the expedition were we personally attacked. Luckily the telescopes are still here, and the paragliders and horses and mule. So of course we decide: Let's keep going!

The next day we find ourselves atop a huge cliff, again having to climb down for hours with the horses and mule almost sliding off. Finally we reach a path, then a bigger road at dusk. We ride through the dark, and finally arrive at our next intended homestead. Our friend Leonardo comes for a visit and finally we think we're okay, but he gets bitten by a dog and we spend all night in the local hospital.

However, during all the difficult times the local people help us as best they can, and it is amazing to feel so much support.

—but getting the wind knocked out of you is the only way to remind your lungs how much they like the taste of air.

▲ **LUNAR OBSERVATIONS** The Moon is a sure crowd-pleaser with any telescope. At left, a military policeman is amazed by the Moon's craters. At right, a boy tries his hand at aiming the telescope himself.

◀ **THE DEPTH OF THE ORDINARY** Kira explains the role of plants as the base of all ecological systems to a girl in Sueca.

▼ **SHARING CIRCLE** " 'What did you learn today and what did you like most?' We usually ended each day's activities with a circle for the children to tell their favorite stories of the day. This helps them to remember what they've learned."

▲ **ONWARD** "Time to say goodbye was always really tough." Kira and Marja pose with kids of the school in San José de Suaita.

Our trek continues, the routine becomes set, and weeks pass like a blink of an eye. And then after a month and a half, we cannot believe it when in Sopo, close to Bogotá, we have to sell our animals. The El Niño heat keeps us from taking them across the broad, blazing Magdalena Valley. The drought is so severe that the Magdalena, Colombia's largest river, is at its lowest in 50 or 100 years. Cattle are dying in the fields. It would be suicide to make the attempt with pack animals. So we drastically reduce our luggage, cross the valley by bus, and continue on foot and by paraglider. It may be the first time in history that a paraglider flies with a telescope in its luggage pack, but it works.

We hike and fly our way along the Cauca Valley towards Cali, still offering ecology workshops and sky observing in the villages we pass through. During these last days especially, Colombia offers breathtaking night skies. We observe Jupiter beautifully in Leo, and Saturn and Mars together, along with the locals. The kids love to play with our green laser pointer, under our guidance for safety, and we lie on the grass inventing and tracing old and new constellations with them.

Two incredible months. We are so thankful for all the supporters of our trip: Meade Instruments for the telescopes, Skywalk for paragliders that carried us about 400 km, GoPro for cameras, and Paula Iglesias and Ana Serna from Al Borde films, who came with their equipment to film part of the journey. Also Spot for the GPS live tracking (helping to preserve our parents' mental health!), Salewa for good helmets and clothing, Petzl for lights, Le Bip Bip for solar pads and instruments, and Colombia Paragliding, Leito Rey, and Ricardo Gómez for their local support.

■ Astrophysicist **MARJA SEIDEL** is an expert in integral-field spectroscopy. She analyzes stellar kinematics and populations to better understand the formation and workings of galaxies.

■ Environmental biologist **KIRA BUELHOFF** specializes in alpine and arctic ecosystems. When not doing research, she guides hiking tours of glaciers and mountains.

FOR MORE INFORMATION

We would be extremely happy to tell you more about our outreach adventure and what we learned, so please contact us via our webpage: **cieloytierra-project.com**. Here you can find videos of our trip and updates about other expeditions. We are not done yet!

Let There Be Less Light

How to darken your relations with your neighbors.

OUTDOOR LIGHTS ARE THE BANE of amateur astronomers' existence. For many of us, our backyards or driveways would be great places for observing if it weren't for those $#@! lights shining at us from all sides. Fortunately the International Dark Sky Association and many medical professionals have been getting the word out that too much light is not only bad for astronomy but bad for people's (and animals') health. That means we have more ammunition than ever in convincing our neighbors to let us shield their lights.

And that means we need to be ready to shield those lights the moment we get permission. It may seem simple — and it is — but you don't want to be fumbling around on your neighbor's front porch learning how when the time comes. You want to know exactly what to do and do it efficiently and well. Here's how:

You can always buy a shielded fixture and install it. I recommend the Hampton Bay #HB48017MP-237 from Home Depot, seen on the facing page. It's fully shielded and has a motion sensor so the light will stay off until it's needed.

Or you can make a shield yourself out of galvanized tin. What you want is to block light from going outward and upward, while letting it shine downward onto the porch and walkway. The first step, then, is to make sure the existing fixture will allow light to shine down. Many carriage-lantern style fixtures won't. They're generally too bulky to shield anyway, so you'll need to buy a small fixture that lets the bulb point downward. Fortunately those are both common and cheap.

While you're buying the smaller fixture, get a length of galvanized tin about 18 to 22 inches long and 7 to 10 inches high. File the edges smooth so you don't cut yourself on them. It will probably already be curved from being on a roll. Gently adjust the curve to make a half cylinder out of it. Then get (or make) some simple right-angle mounting brackets.

Paint the outside of the shield whatever color your neighbor prefers, but leave the inside galvanized so it will reflect light.

Now simply mount the new fixture (make sure the power is off!) and install the light bulb. I recommend a 40-watt equivalent (7-watt actual) LED floodlight. Get the warmest color temperature you can find (probably 2700K).

▲ A carriage-lantern style light, one of the worst kind for glare. Note that it doesn't shine downward, where the light is needed most.

Then install the shield around the fixture and bulb. You do that by screwing the brackets to the wall, then attaching the shield to the brackets. It should be positioned to completely block the bulb from view for anyone standing more than a few feet away from it, while letting the downward-

▲ **Left:** Replace the carriage light with a downward-facing fixture and a downward-facing flood bulb. Note the brackets for mounting the shield that are attached to the siding. **Middle:** Install the brackets on the wall, and then attach the shield (shown assembled). **Right:** The finished shielded fixture casts its light downward where it's useful, not outward into your eyepiece.

JERRY OLTION (4)

◖ Do you have a telescope or ATM observing accessory that *S&T* readers would enjoy knowing about? E-mail your projects to Jerry Oltion at j.oltion@sff.net.

cast light illuminate the porch, steps, walkway, or whatever else it should actually be shining on. It shouldn't shine upward or outward.

If you get the height wrong, you can move the shield or buy a different height light bulb. They come in several sizes.

That's all there is to it. Now may I suggest you practice on your own light? I know you don't use it because you're an astronomer, but it would serve as a good example to your neighborhood if yours is shielded. And you can say to your neighbors: "See, this is what it's going to look like if you let me shield yours."

■ Contributing Editor **JERRY OLTION** has seen the light, but prefers it off.

JERRY OLTION

▲ A commercially available shielded light with motion detector. This is the Hampton Bay #HB48017MP-237.

▷ **FLUFFY SPIRAL**

Bruce Waddington

Astronomers refer to NGC 3521 as a "flocculent" spiral because its arms are patchy and not well formed. This system lies 26 million light-years away in Leo.

DETAILS: *PlaneWave CDK12.5 astrograph, QSI 640ws CCD camera, and LRGB filters. Total exposure: 12.7 hours.*

▽ **SUPER-SIZE MOON**

José Chambó

November 2016's full Moon coincided with our satellite's closest approach to Earth since 1948. Here it looms over Xàtiva, Spain, aglow from the setting Sun.

DETAILS: *Canon EOS 100D DSLR camera at ISO 200 and 70-to-300-mm zoom lens used at 300 mm. Exposure: 1⁄125 second.*

▷ ORION ENSNARED

Tom O'Donoghue
& Olly Penrice

Faint dust and gas virtually unknown to amateurs roughly a decade ago permeate the constellation Orion in this ultra-deep mosaic.

DETAILS: *Takahashi FSQ-106 astrographs, Atik 11000 and Starlight Xpress H36 CCD cameras, and five filters. Total exposure: 400 hours.*

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LUNAR HALO

Steve Irvine

Icy cirrus clouds frame the full Moon with a rainbow-like halo 22° in radius.

DETAILS: ***Canon EOS 6D DSLR camera at ISO 250 and 17-to-40-mm zoom lens at 17 mm. Exposure: 13 seconds.***

◁ **ZODIACAL LIGHT**

Kurt W. Hillig II

The glow of sunlight scattered by interplanetary dust, framed by Aldebaran, the Pleiades, and Capella, shines after a late-March sunset.

DETAILS: *Canon EOS 5D Mark II DSLR camera at ISO 2500 with 16-to-35-mm zoom lens at 16 mm. Total exposure: 75 seconds.*

▽ **CLUSTERED SCENE**

Dan Crowson

Cassiopeia boasts the fine open clusters IC 166 (top left), NGC 654 (top right), and NGC 663 (bottom).

DETAILS: *Astro-Tech AT90DT apochromatic refractor, SBIG ST-8300M CCD camera, and LRGB filters. Total exposure: 4 hours.*

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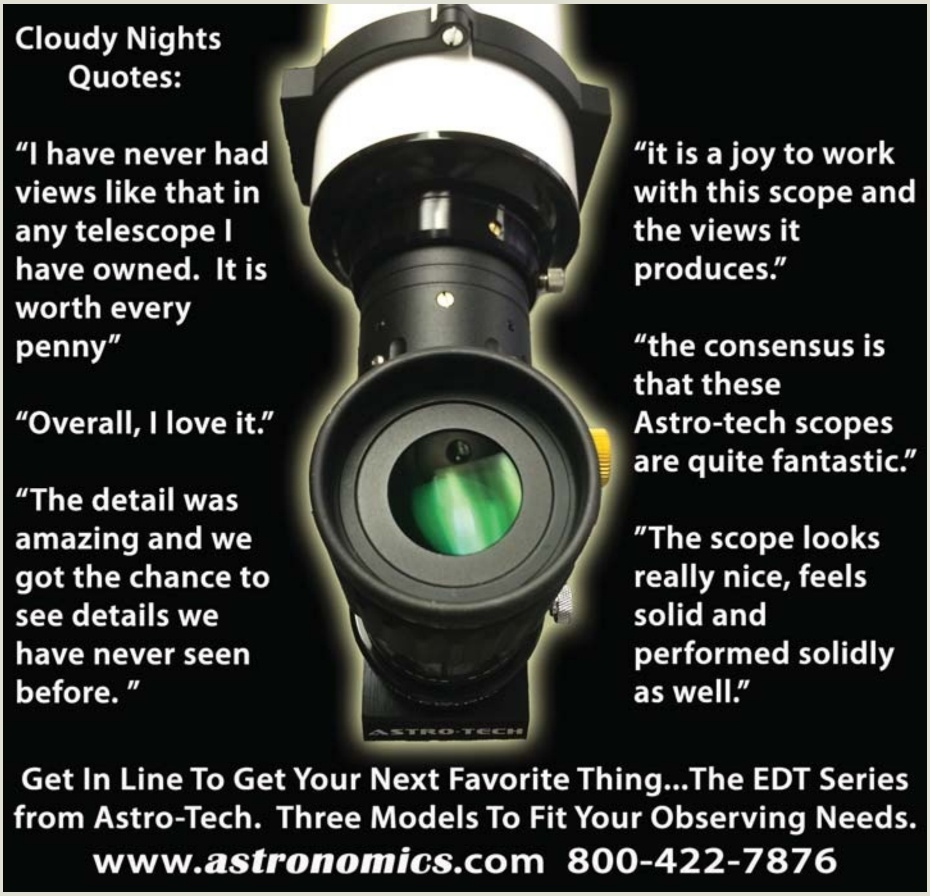

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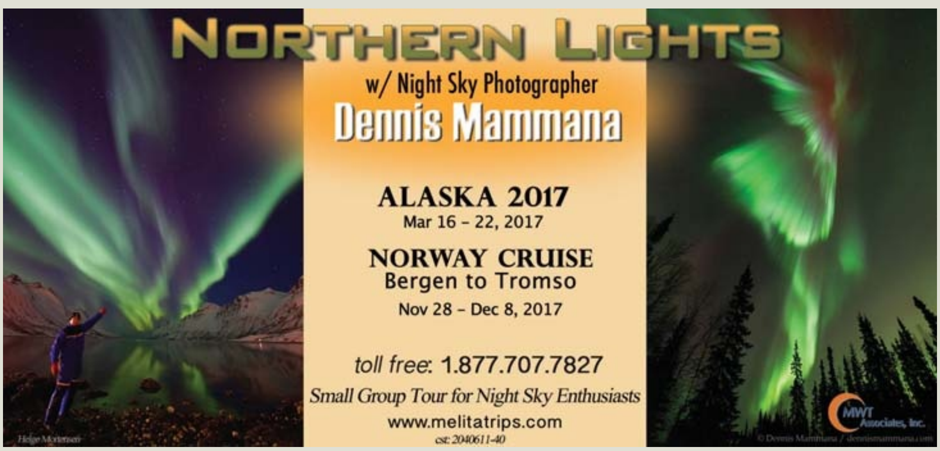

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Event Calendar

Here's the info you'll need to "save the date" for some of the top astronomical events in the coming months.

January 27–28
DEATH VALLEY STAR PARTY
Furnace Creek Resort, CA
lvastronomy.com/index.php/events/upcoming-events

February 20–26
WINTER STAR PARTY
West Summerland Key, FL
scas.org/winter-star-party

March 22–26
HODGES GARDENS STAR PARTY
Florien, LA
brastro.org/hgsp.html

April
GLOBAL ASTRONOMY MONTH
Everywhere!
astronomerswithoutborders.org/global-astronomy-month-2017.html

April 8–9
NORTHEAST ASTRONOMY FORUM
Suffern, NY
rocklandastronomy.com/neaf.html

April 22–28
INTERNATIONAL DARK SKY WEEK
Everywhere!
darksky.org/dark-sky-week-2017

April 27–30
SOUTHERN STAR
Little Switzerland, NC
charlotteastronomers.org/southernstar

April 27–30
STARGAZE STAR PARTY
Trap Pond State Park, DE
delmarvastargazers.org/event/2017-stargaze-star-party

April 29 (also September 30)
ASTRONOMY DAY
Everywhere!
astroleague.org/al/astroday/astro-day.html

May 21–28
TEXAS STAR PARTY
Fort Davis, TX
texasstarparty.org

May 25–29
RTMC ASTRONOMY EXPO
Big Bear City, CA
rtmcastronomyexpo.org

June 22–25
CHERRY SPRINGS STAR PARTY
Coudersport, PA
astrohbg.org/CSSP

June 17–24
GRAND CANYON STAR PARTY
Grand Canyon, AZ
nps.gov/grca/planyourvisit/grand-canyon-star-party.htm

June 21–25
ROCKY MOUNTAIN STAR STARE
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rmss.org

• For a more complete listing, visit https://is.gd/star_parties.

Against All Odds

Despite fire damage, light pollution, a bright moon, and a filthy mirror, the night was an outstanding success.

TWILIGHT WAS TURNING to darkness as we bumped slowly through a stark forest of burned, dead trees, up a dirt road off Angeles Crest Highway. We were on our way to Stony Ridge, an amateur-built and -operated observatory in Southern California's San Gabriel Mountains, six miles from historic Mount Wilson Observatory. Stony Ridge boasts a landmark 30-inch Newtonian-Cassegrain. When it saw first light in 1963, it was the eighth-largest telescope in California and one of the biggest amateur telescopes in the world.

We passed through the locked gate, continued up the road and, finally, there it was, a large dome silhouetted against the sky. Like me, my two guests had aviation backgrounds, and they were curious about the little-known observatory they'd seen from the air. In addition, Saturn, Mars, Jupiter, and the Moon would all be visible simultaneously that night. So I took a gamble and arranged this visit.

Why a gamble? For one thing, it was a classically bad night for serious observing. A full moon blasted down through a sky further brightened by light pollution from the Los Angeles metropolitan area, just over Mount Wilson to the south. We were guaranteed lousy deep-sky views.

I also worried that the sorry condition of the 30-inch's primary mirror would limit us. The instrument's basic structure was fine, and we'd recently restored the right ascension and declination motions to the original chain-drive systems with modern digital stepper motors and electronic controls.

But the primary mirror's coating was old and, more significantly, had suffered substantial damage from heat and smoke in the 2009 Station Fire. That blaze ravaged 160,000 acres of the Angeles National Forest, threatening Mount Wilson and almost taking out our observatory (see https://is.gd/Hseui7). We hadn't yet re-aluminized the huge mirror, and its surface looked like it had a terminal case of acne. That would really degrade the contrast even for bright planets, I thought as I brought Saturn into focus through a 27-mm, 2-inch Nagler eyepiece.

I needn't have worried. Saturn was breathtaking.

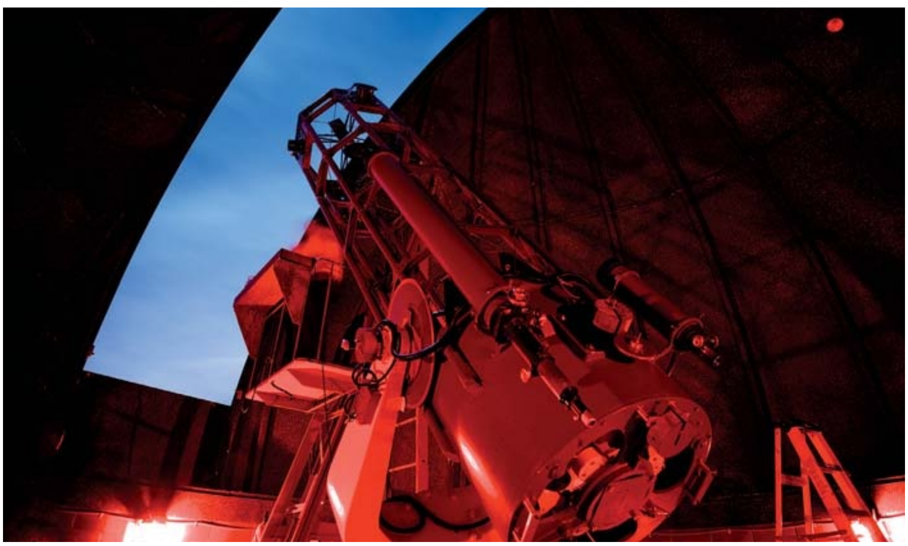
Before my eye hung a razor-sharp, rock-steady planet. I could see clear divisions in the rings, ring shadows on Saturn's surface, detailed cloud bands, and three moons. Aided by excellent seeing, our venerable telescope was working through her disability. In fact, it was the best view of Saturn I'd ever had.

When the first of my guests saw the ringed planet, she gasped and asked if it was some kind of trick. Had I pasted a picture of Saturn inside the telescope or something? Her husband followed, and his reaction was similar. For the next half hour, as we took turns observing a few other easy objects, several thoughts occurred to me:

First, much like pilots when it comes to peering out of cockpit windows, we amateur astronomers can get a bit jaded. We fail to realize that the same old Saturn, Jupiter, or Moon that we've viewed hundreds of times can be astonishing, even unbelievable, to someone getting a first good look.

Second, providing first views of what we regard as the "easy" stuff may be the very thing that entices newcomers into the field.

Finally, the beautiful images we obtain with Stony Ridge's currently cruddy primary mirror offer ample caution to amateurs not to clean their optics too often. A little dust doesn't impair the image, and too much cleaning may do more damage than good.



▲ The 30-inch telescope at Stony Ridge. Note the 5-inch finderscope (right) and the 6-inch guidescope (center), as well as the fuzzy-looking observatory member standing atop the electric lift (left).

STEVEN TSZ K CHAN

■ **JOHN HAZLET**, a retired airline pilot, is an amateur astronomer and member of the Stony Ridge Observatory.