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THE ESSENTIAL GUIDE TO ASTRONOMY

SKY & TELESCOPE

AUGUST 2016

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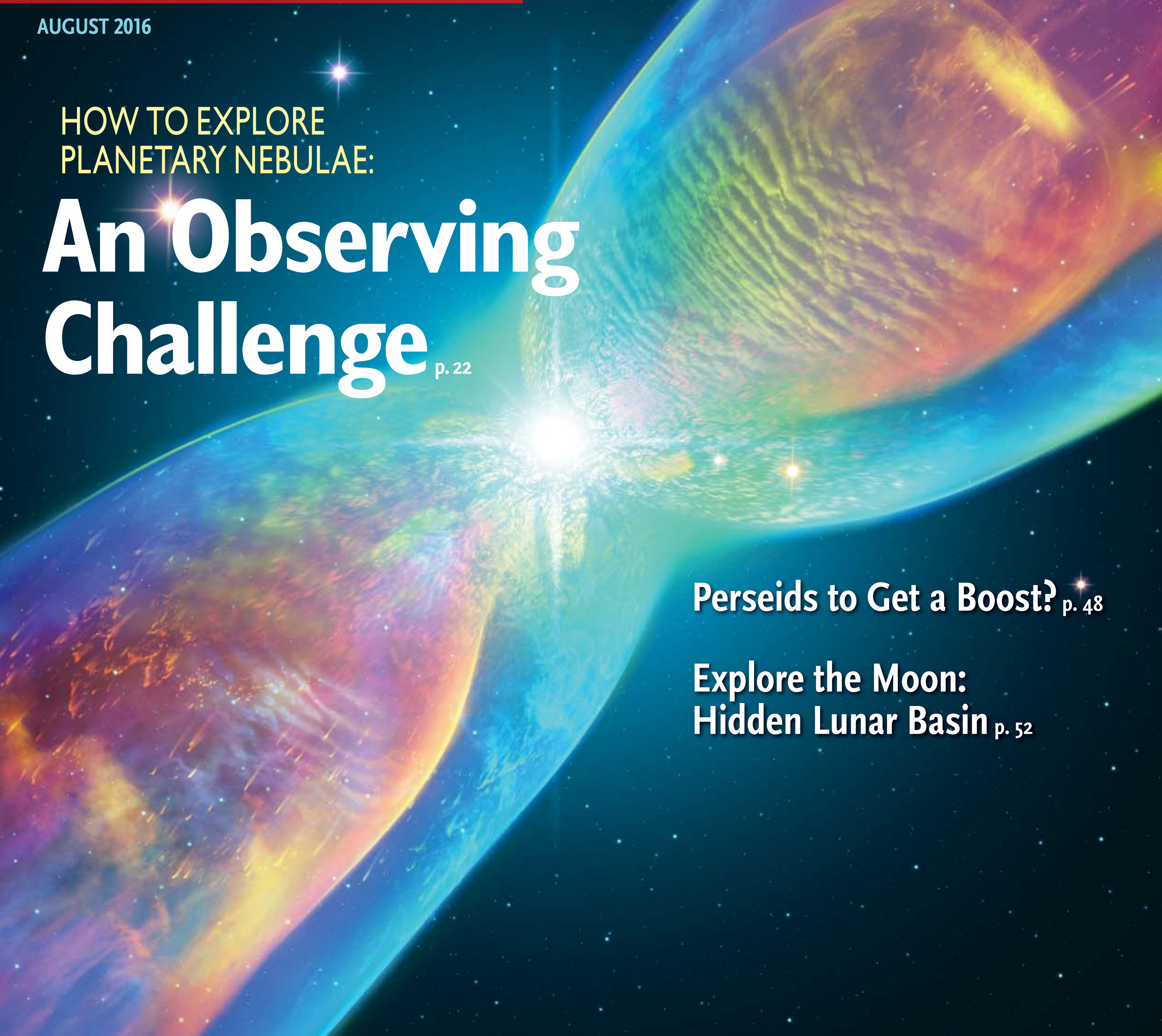

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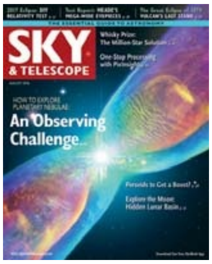

On the cover:
This illustration depicts the Twin Jet Nebula, created by a dying star in a binary system that's expelling its outer layers of dusty gas.

ILLUSTRATION: CASEY REED

FEATURES

OBSERVING AUGUST

S&T TEST REPORT

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  The whisky-winning simulations are showcased in this interactive gallery.
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  Up for an observing challenge? Explore the Minkowski catalog.
- **More from *1001 Celestial Wonders***
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Photo Gallery

Image by Sergio Emilio Montúfar Codoñer

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- **Astronomy in Space**
  David Dickinson keeps up with the latest launches, mission proposals, and more.
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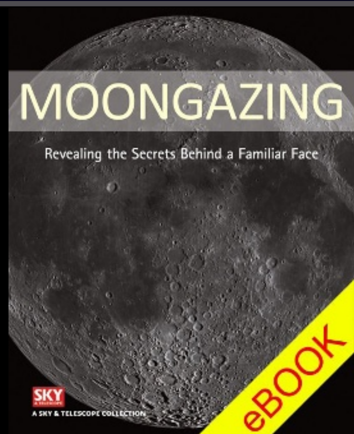

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May, June, and July

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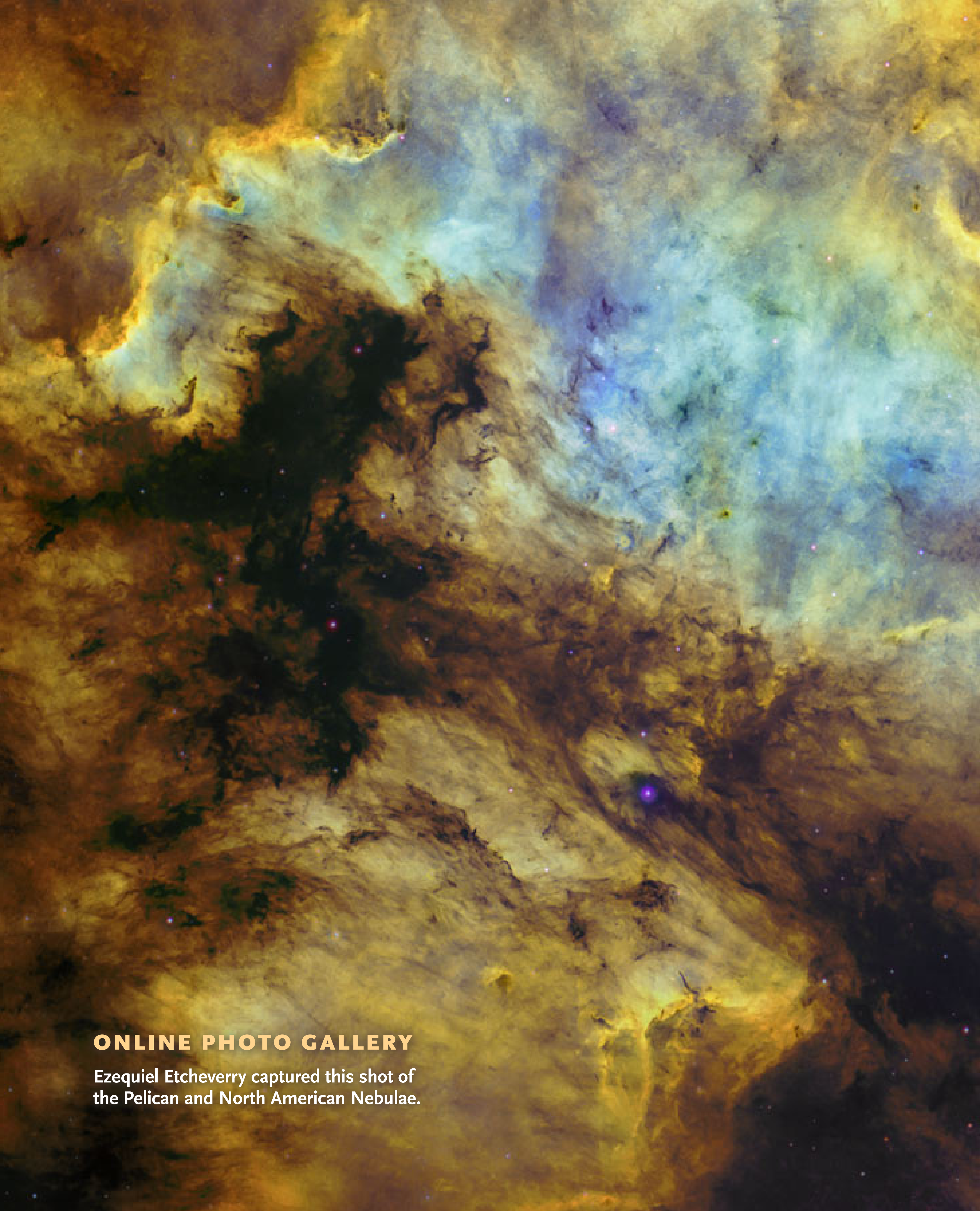

ONLINE PHOTO GALLERY

Ezequiel Etcheverry captured this shot of the Pelican and North American Nebulae.

Peter Tyson
Spectrum

SKY & TELESCOPE
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The Essential Guide to Astronomy

Taking Up the Gauntlet

AMATEUR ASTRONOMERS LOVE a challenge. That was in full evidence on the two clear nights I had the pleasure of attending early May's Texas Star Party, in the ultra-dark Davis Mountains of West Texas.

The TSP organizers had a mission ready for observers at every level. The Fort Bend Astronomy Club crafted a naked-eye list for beginners. The Texas Astronomical Society of Dallas put together three binocular lineups: one for small- to medium-aperture binocs, another for 50 mm or larger, and the third — well, that was "the Binocular Program from Hell." For telescope users, the Columbus Astronomical Society offered a sampling entitled "Spiralmania," with 22 of Ted Saker's favorite spiral galaxies.

S&T: PETER TYSON

Larry Mitchell with his 36-inch Dob

Then there was Larry Mitchell's advanced telescopic list — or should I say tome. Mitchell, of the Houston Astronomical Society, had assembled a compendium of finder charts and background information 50 pages long. His 44 objects bore names leading with Arakelian, Kazarian, or Shakhbazian. These targets, roughly as difficult as the Minkowski planetary nebulae we feature on page 22, are distant galaxies or galaxy clusters discovered in the last century by Armenian astronomers at the Byurakan Astrophysical Observatory.

Each night, all three observing fields at Prude Ranch hummed like beehives. Here were two women leaning over a chart-spread table bathed in red light, one helping her novice friend with the naked-eye tally. Over there was a man rigging up a brand-new 14-inch PlaneWave CDK14 Corrected Dall-Kirkham telescope. Nearby was a knot of amateurs known as the Shade Tree Gang. Its members clustered near the eponymous tree like honeybees doing the waggle dance, offering one another tips on how to locate the best "nectar": a difficult object from one of the lists.

The one person who seemed utterly relaxed and somehow outside the buzz of activity was Mitchell himself. He passed the time, at least during the few instances I stopped by to chat with him, swinging his 36-inch Dobsonian around to miscellaneous awe-inspiring destinations. Anyone willing to climb Mitchell's towering, three-legged ladder was welcome to have a look.

I did so many times. Through that magnificent instrument, M51 looked as you've always thought a galaxy should: like a ghostly Hubble image. The wafer-thin, edge-on galaxy NGC 5907 displayed its slender dust lane impressively. In the Clown-face Nebula, I could readily see the familiar inner ring tinged slightly blue, with the dimmer outer ring bearing a hint of red.

I don't know how many observing pins got handed out by the end of the TSP. But from the concentrated bustle I witnessed, I'm guessing quite a few. Challenges met. ✦

Peter

Editor in Chief

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George Carruthers' Lunar Scope

As a follow-up to Frank Ridolfo's reminder that we've had a telescope on the Moon since the early 1970s (*S&T:* Apr. 2016, p. 6), let me extol its builder: George R. Carruthers, then at the U.S. Naval Research Laboratory in Washington, D.C.

Carruthers dedicated himself not only to such astronomical ventures but also to stimulating interest in science and technology among young African Americans. An early supporter of Project SMART (Science, Mathematics, Aerospace, Research, and Technology) in the District of Columbia, he once told me during an interview that the "overall objective of SMART is to get African Americans involved in science and technology careers and also to become technologically literate, even if they don't choose careers in science and technology."

Among his many mentoring ventures, Carruthers brought local students to his NRL laboratory. One of their projects in the 1990s was to restore the backup engineering model of Apollo 16's far-ultraviolet telescope/camera. We'd had it in our collection for a decade and wanted to bring it up to display-worthy condition. Carruthers and his students obliged — even adding one of the film cassettes that the Apollo 16 crew had brought back to Earth. Their effort has been on display ever since at the National Air and Space Museum in Washington, D.C., where visitors from all walks of life can view it and appreciate its origins.

David DeVorkin
Division of Space History
National Air and Space Museum
Smithsonian Institution

U.S. NAVAL RESEARCH LABORATORY

George Carruthers (at right) stands with the gold-plated ultraviolet camera/spectrograph that he invented and which Apollo 16 astronauts placed on the Moon in April 1972. Project engineer William Conway is at left.

Funding Human Space Travel

Once again, David Grinspoon contrasts hard science and shrinking government support with our passion for space travel (*S&T:* May 2016, p. 16). I too grumble about the budget for the International Space Station compared with those for all our robot probes, which send back so much data at much less risk and lower cost.

But there's change in the air — more private spacecraft are going up, and high-rollers are even contemplating tiny probes that could be sent all the way to the star closest to ours [see page 11]. Somehow, some way, we are going to link up with possible life in our solar system and then to the nearest stars.

I'm 76 now, and I hope to live long enough to share in such news. Then all I'll need will be my Chicago Cubs winning their first World Series since 1908.

Earl Finkler
Medford, Wisconsin

Contrary to Jim Bell's opinion (*S&T:* June 2016, p. 84), I certainly hope it is not "inevitable" that we send humans to Mars. Perhaps such missions will become technically feasible within the near future, but would they be the best use of our resources — and the wisest focus of our aspirations, ingenuity, and collective will?

Almost all of the payload of a human Mars mission would need to be devoted to life support, and, at least initially, the crews would need to return to Earth. With the same investment of money and human capital, how many robots could we send to Mars and leave there permanently? As space-faring machines become ever more sophisticated and autonomous, what scientific purpose would justify the tremendously greater expense and risk of sending human astronauts to Mars?

I fear the romantic frontier fantasy of colonizing other planets could seduce us into ignoring the urgent problems of climate disruption, species extinction, and environmental devastation we have created here on Earth. Preserving this planet is the best possible focus of a global initiative that draws on the best we all have to offer.

So, by all means, let's explore the universe — with telescopes and robots!

Anthony Barreiro
San Francisco, California

Finding Peace in the Stars

After reading Peter Tyson's recent Spectrum, "Escape to the Stars" (*S&T:* Mar. 2016, p. 4), I recalled the following words of Pavel Florensky, a Russian Orthodox priest, philosopher, and mathematician executed in 1937 after several years of imprisonment in a Soviet gulag. He wrote this in one of the last letters to his children: "Look more often at the stars. When you have a weight on your soul, look at the stars or the blue of the sky. When you feel sad, when they offend you — stop yourselves . . . with the heavens. Then your soul will find peace."

Alessandro Maitan
Forlì, Italy

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In Praise of Star Parties

Thank you for Rod Mollise's very important article on the importance, fun, and excitement of star parties (*S&T:* Apr. 2016, p. 34). To his list of major U.S. events, we'd like to add one that celebrates its 30th anniversary this summer: the Rocky Mountain Star Stare (RMSS). Located on land owned by the Colorado Springs Astronomical Society, RMSS takes place under some of the darkest skies in the U.S. With more than 300 attendees (the largest star party in Colorado), RMSS draws visitors from across the country and offers great guest lectures. We invite our fellow *S&T* readers to check out **rmss.org** and to consider attending this year's event from June 29th to July 4th.

Bruce Bookout *and* ***Hal Bidlack***
Colorado Springs, Colorado

I was surprised and disappointed at Rod Mollise's lack of mention of the RTMC Astronomy Expo. Not one word for a gathering that's been going on for nigh on a half century — and for which *Sky & Telescope* is a consistent (and much appreciated) supporter. May I assume that's because you're devoting an entire article to RTMC?

Fred Veretto
San Marcos, California

Kelly Beatty replies: *The legendary Riverside Telescope Makers Conference ranks high on Rod Mollise's star-party "bucket list." While his article focused on star parties designed primarily for observing under very dark skies, RTMC is definitely included in the more exhaustive listing of annual events (**http://is.gd/star_parties**) maintained on SkyandTelescope.com.*

Mollise's insightful view of future star parties was a joy to read and, I feel, an accurate guide to where they're headed. However, he missed an important aspect of the star-party scene: the now-ubiquitous use of green laser pointers. I realize that these are not welcome at gatherings at which fellow stargazers are taking astrophotographs. However, what about at small informal gatherings? And how might the use of these devices be restricted in the future? Green laser pointers have certainly become a welcome (necessary?) tool for the amateur astronomer. I, for one, hope they remain available and acceptable.

Bert Probst
Ellicottville, New York

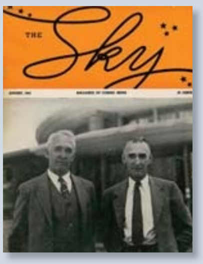
For the Record

✷ *In the plot of our eyes' response to luminance (*S&T*: June 2016, p. 24), the value "0" along the x-axis should be "1".*

✷ *Due to a production error, the evening-sky illustration for June 12–14 appears twice (*S&T*: June 2016, p. 46).*

75, 50 & 25 Years Ago

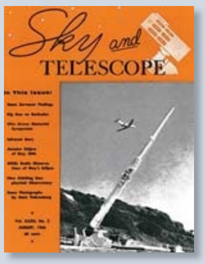
Roger W. Sinnott



August 1941
The League is Born "The Washington convention of amateur astronomers is now past. . . . Soon there ought to be an invitation to hold it on the West Coast. . . . This would help toward establishing [a] national organization of amateur societies, since representation of all regions is of great importance. And the proposed constitution of the **Amateur Astronomers League of America,** as revised by the Washington convention, comes close to making such [an] organization possible and permanent."

Through their editorials and personal contacts, S&T *founders Charles and Helen Federer vigorously supported what has become today's Astronomical League.*

August 1966
Big Gun "Barbados is a coral island 18 miles long by some 14 miles wide. [There] we find the largest gun in the world, 119 feet of 16-inch caliber barrel. . . . But the island is not expecting an attack from the direction of South America, for this gun is just one more piece of equipment in man's effort to understand the earth's



upper atmosphere, on the fringe of space. . . .

"This is operation HARP, the letters standing for High Altitude Research Project, an experimental program being conducted by McGill University of Montreal, Canada, and the U. S. Army Materiel Command. Brainchild of Prof. G. V. Bull at McGill, HARP is a means of lifting research loads into the upper atmosphere. . . . A disadvantage is that all experiments in the vehicle must be engineered to withstand accelerations of some 25,000 *g* (gravity)."

As meteor astronomer Peter Millman noted, the HARP launcher utilized two U.S. Navy battleship gun barrels welded end to end. It had many firings in the 1960s, during which nighttime chemical releases yielded valuable data on wind shear at altitudes up to 130 kilometers (81 miles). Thereafter Gerald Bull's career took a dark turn. In the 1980s he sold Saddam Hussein on the idea of a supergun, dubbed "Big Babylon," with which Iraq could target the capitols of both Israel and Iran. In March 1990 Bull was mysteriously assassinated in Belgium, and a few months later the First Gulf War curtailed Hussein's plans for a supergun.

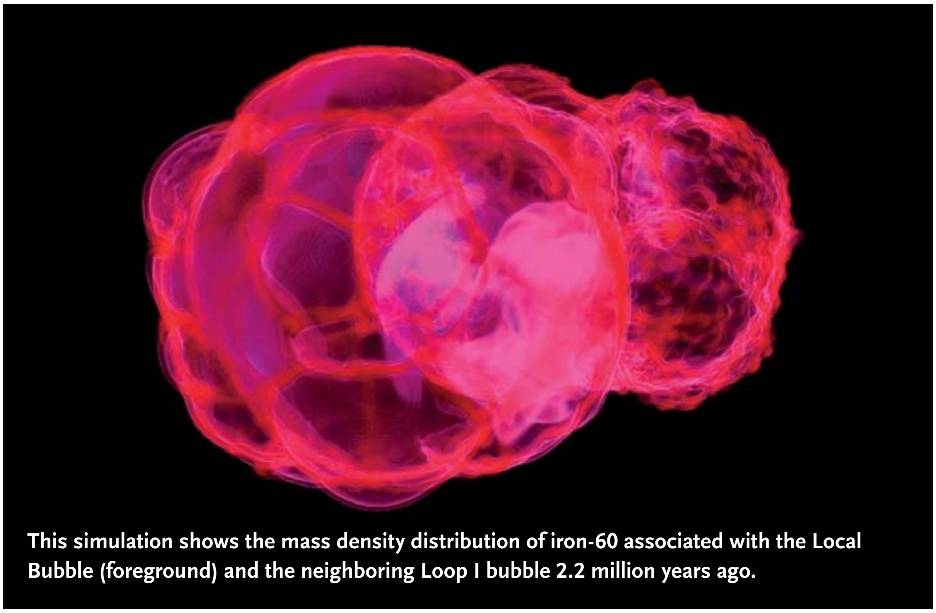
August 1991
Resolving Stars' Disks "The astronomer's impossible dream has always been to resolve features on the disks of stars. Optically it can't be done, [but] an ingenious trick can sometimes accomplish the impossible. The technique of Doppler imaging can map the surface of a rotating body that has bright and dark regions as seen at a narrow wavelength. Radar astronomers have used this method to map planets, especially Venus. Now it is being applied to stars of type Ap, where intense magnetic fields segregate chemical elements into different areas on the stellar surface. . . .

"Artie P. Hatzes (University of Texas) created [global maps of the highly magnetized star Theta Aurigae] by analyzing the changing absorption-line profiles of singly ionized silicon and chromium."

A more powerful technique has since emerged: interferometric imaging in visible light. The University of Georgia's CHARA Array, set up at Mount Wilson Observatory, uses six 1-meter mirrors on a Y-shaped track. It can measure stellar sizes and resolve flares and starspots as small as 0.0002 arcsecond.

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

SUPERNOVAE | Long-Ago Blasts Littered Earth



MICHAEL SCHULREICH

This simulation shows the mass density distribution of iron-60 associated with the Local Bubble (foreground) and the neighboring Loop I bubble 2.2 million years ago.

Radioactive iron and simulations of a nearby stellar association suggest that, roughly 2 million years ago, supernovae showered Earth with debris.

Scientists have long suggested that supernovae could explain an isotope of iron that's embedded in the crust deep under the Pacific Ocean. The isotope, iron-60, has a half-life of only 2.6 million years, so the layers must be the result of something that happened more recently. This isotope is almost exclusively created in supernova explosions.

The other hint is the Local Bubble, a vast peanut-shaped and plasma-filled cavity in which the Sun lives. The death of stars in what's now the Scorpius-Centaurus association carved out this bubble.

Now Dieter Breitschwerdt (Berlin Institute of Technology) and colleagues have put these pieces together to pinpoint which supernovae did the deed. The results, published April 7th in *Nature*, show that two supernovae, both roughly 300 light-years away, could explain much of the iron.

All stars are born in clusters. A cluster's highest-mass stars die first. So when astronomers spot a cluster made of only low-mass stars, they assume the missing heavyweights have already gone supernova. Using the surviving relatives of the stars that created the Local Bubble, the team estimated the masses of those presumed dead and determined when they would have exploded. According to those calculations, 16 supernovae in this stellar family went off like popcorn during the past 13 million years.

The team then calculated how much iron-60 would have come from the supernovae and how long the isotope would have taken to reach Earth. "It's like if you put milk in your coffee, the milk starts to diffuse out, and then you take the spoon and stir it in order to distribute it," Breitschwerdt says. "The supernova explosions are like spoons: they stir the iron-60 into the surrounding medium. And that has to be calculated in detail to find how long it takes to travel to Earth." The calculations show that two supernovae — one that occurred 2.3 million years ago and one that occurred 1.5 million years ago — contributed roughly half of all the iron-60. The rest comes from the other supernovae.

A second paper in the same issue of *Nature* by Anton Wallner (Australian National University) reports iron-60 in crust samples from four different locations in the Pacific, Atlantic, and Indian Oceans. This evidence is exactly what scientists expect to see if supernovae rained the isotope down across the entire globe.

Although the supernova theory isn't new, the new papers led a bit of a bandwagon. Leticia Fimiani (Technical University of Munich) and her team announced a week later in *Physical Review Letters* that iron-60 levels in Apollo lunar samples match what these supernovae would have deposited.

But besides a brilliant flash and some debris, the explosions probably had little effect on Earth. Supernovae have to be much closer to do any real damage, says Adrian Melott (University of Kansas). "What we call the kill zone — where you get a really big mass extinction — is like 8 or 10 parsecs [26 to 33 light-years]," he says.
■ **SHANNON HALL**

MISSIONS | Hitomi Rescue Called Off

The Japanese space agency JAXA announced on April 28th that it will end recovery attempts for its Hitomi X-ray satellite. A series of problems with the spacecraft's self-orienting systems led to out-of-control rotation that flung off several parts of the observatory, including the solar panels. Losing the solar panels deprived Hitomi of power and effectively ended the mission. The failure is a major blow for X-ray astronomers. An observatory-class replacement probably won't hit the launch pad until at least 2028, with the European Space Agency's Athena, although smaller missions will launch before then. Read the autopsy report at **http://is.gd/hitomidead**.
■ **DAVID DICKINSON**

SOLAR SYSTEM | A Moon for Kuiper Belt's Makemake

Of the four dwarf planets now recognized in the outer solar system, Pluto, Eris, and Haumea all have at least one moon. The fourth, Makemake, seemed to be the "odd dwarf out." Astronomers used the Hubble Space Telescope to search for companions in 2006 but turned up nothing. Now they've turned up "something."

Images taken in April 2015 show an object traveling together with Makemake, which is currently some 52.4 astronomical units (7.8 billion kilometers) from the Sun. It's 1,300 times fainter than Makemake itself. And that's about all that Alex Parker (Southwest Research Institute) and his three codiscoverers know about this thing, whose official designation is S/2015 (136472) 1 — but which they nicknamed "MK2" when announcing its existence this spring.

The problem is that the object shows clearly in Hubble images from April 27, 2015, but not in another set recorded just two days later. Parker's team concludes that MK2 is playing "hide and seek" with observers, hiding in the glare of Makemake at some times and popping into view at others. That's likely if we're seeing the moon's orbit nearly edge on and if it's not too distant from Makemake itself. As the team points out in a write-up posted April 25th to the preprint arXiv site, the Hubble images really don't constrain the orbit well.

Uncertainties aside, the moon's discovery appears to solve an observational puzzle that has nagged astronomers for years. Far-infrared observations by the Spitzer and Herschel space observatories showed that Makemake's surface wasn't radiating heat in a way that's consistent with one material. Instead, Parker explained via Twitter, "it seemed like most of Makemake was very, very bright, but a small part of it must be dark and warmer." The dark, warm spectral component could come from this moon. If MK2's surface is very dark — just 4% reflective — then it has a diameter of 175 km, or 12% Makemake's size.


NASA / ESA / ALEX PARKER ET AL.

A Hubble Space Telescope image taken April 27, 2015, reveals a moon (arrowed) around the distant dwarf planet 136472 Makemake. The companion, nicknamed "MK2," is 0.6 arcsecond away from Makemake.

Parker says that another round of Hubble imagery could be scheduled as early as this summer, but more likely early next spring. Once the team pins down MK2's orbit, they'll quickly deduce the bulk density of Makemake, estimates for which range from 1.4 g/cm^3 (mostly ice) to 3.2 g/cm^3 (mostly rock), even though frozen methane dominates its spectrum.

If the four dwarf planets' moons were all created by collisions, their ubiquity suggests that giant collisions are a common theme in the Kuiper Belt's evolution.

■ **J. KELLY BEATTY**

GALACTIC | Milky Way's New Neighbor

Astronomers have discovered a "feeble giant": one of the largest dwarf galaxies ever seen near the Milky Way.

The standard model of cosmology, which suggests that dark energy and dark matter govern the universe's evolution, predicts many more small galaxies near the Milky Way than what we've observed so far. Dwarfs should be the building blocks of larger galaxies like our own, so the lack has puzzled astronomers — are they not there, or are we just not seeing them?

With the advent of large surveys such as the Sloan Digital Sky Survey and the Dark Energy Survey, observers have begun to identify hard-to-find dwarf galaxies. They've spotted dozens over the last 15 years. But theory suggests perhaps even hundreds more have yet to be discovered.

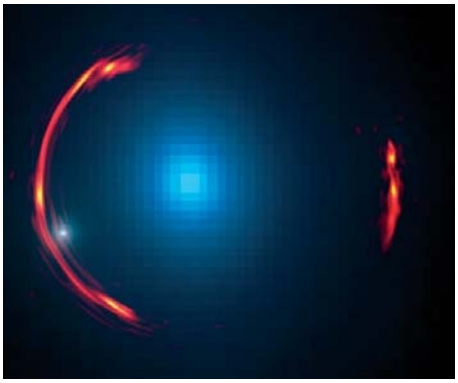
Now, the list of known dwarfs has just added one of its largest members: Crater 2. Gabriel Torrealba (University of Cambridge, UK) and others discovered the dwarf galaxy in survey data collected at the Very Large Telescope in Chile. The team used specialized software to spot overcrowding among stars, searching for dim clumps of old, evolved suns that marked an ancient stellar population separate from the youthful Milky Way disk.

Crater 2 lies 391,000 light-years from Earth. That makes it one of the most distant dwarf galaxies found. And at 6,500 light-years across, it comes in fourth in size among our galaxy's neighbors, after the Large and Small Magellanic Clouds and the torn-apart Sagittarius dwarf galaxy. But because it's incredibly diffuse, Crater 2 is much fainter than those companions, 1/100 as luminous as Sagittarius and 1/10,000 as bright as the Large Magellanic Cloud. The result appears in the July 1st *Monthly Notices of the Royal Astronomical Society.*

The discovery of Crater 2 may help unlock an ongoing puzzle in the Milky Way's evolution. Some dwarfs cluster in their orbits, and Crater 2 is no exception: the dwarf's orbit lines up with that of the Crater globular cluster, as well as those of the Leo IV, Leo V, and Leo II dwarf galaxies. The similar orbits suggest that these objects might be a group that fell together into our galaxy's gravitational well. Astronomers have recently found similar groups near the LMC, suggesting that such group captures might have helped build our galaxy's halo.

■ **JOHN BOCHANSKI**

GALACTIC | Distant Dwarf Discovered with ALMA



Y. HEZAVEH (STANFORD UNIV.) / ALMA (NRAO / ESO / NAOJ) / NASA / ESA / HUBBLE SPACE TELESCOPE

This composite, false-color image shows a massive elliptical galaxy called SDP.81 (center, from Hubble Space Telescope) surrounded by the light from a distant background galaxy (red, imaged by ALMA) that's been gravitationally lensed by SDP.81. The ring is 3 arcseconds across. When Yashar Hezaveh (Stanford University) and others employed the Blue Waters supercomputer to analyze the ALMA ring, they found a dwarf galaxy hidden within the depths of the background galaxy's distorted image. (It's marked by the white dot near the left arc in the image.) The dwarf, a neighbor of the elliptical, contains the mass of a billion Suns. Although it doesn't emit observable light itself, the dwarf nevertheless has enough mass to add its own distortion to the background galaxy's image. The researchers report in an upcoming *Astrophysical Journal* that they also found hints of even smaller clumps, presumably dominated by dark matter as this dwarf is, floating in SDP.81's halo. All together, the clumps match what's expected from simulations modeling the evolution of the universe in the presence of dark matter (see page 11). The elliptical and its dwarf are roughly 4 billion light-years away.

■ **MONICA YOUNG**

EXOPLANETS | Nearby Earth-size Planets

Forty light-years away, a star just one-tenth the size of the Sun holds three Earth-size planets in orbit, where none was expected. Although the worlds probably aren't habitable, their proximity to Earth makes them excellent targets for attempts to observe any atmosphere they might have.

The star is an *M*8 red dwarf, containing only 8% of the Sun's mass and emitting only 5% of its luminosity. It's what's known as an *ultracool dwarf*, a class of objects with effective temperatures less than half that of the Sun. (Technically, the term also includes brown dwarfs.)

Some scientists suspected that such small stars might not host planets. Smaller stars should form with smaller planet-forming disks around them, and ultracool dwarfs might have such small disks that they wouldn't be able to form even tiny, rocky planets. According to Michaël Gillon (University of Liège, Belgium), who led the new study, the controversy was enough to dissuade time-consuming observations of the smallest, faintest stars — until the robotic 0.6-meter TRAPPIST (Transiting Planets and Planetesimals Small Telescope) began its work in 2010 at La Silla in Chile.

In the May 12th issue of *Nature*, the authors report 11 signals of objects passing in front of a star, called TRAPPIST-1. Two planets, TRAPPIST-1b and TRAPPIST-1c, made nine of the 11 transits, orbiting their star every 1.5 and 2.4 days, respectively. The two planets are so close to the star that they're probably tidally locked with it.

The last two transit signals might be from a third planet, 1d. The team couldn't pin down its exact orbit.

Planets 1b and 1c aren't in their star's habitable zone. The third planet might lie in the habitable zone, or beyond it — there isn't enough information on its orbit yet to tell. Regardless, the planets could be a great chance to study exo-Earth atmospheres, previously out of reach.

■ **MONICA YOUNG**

SCIENCE & SOCIETY
$100M for Probes to Alpha Centauri

The Russian billionaire Yuri Milner, who last summer committed $100 million to boost SETI searches to a new level (*S&T:* Nov. 2015, p. 10), announced on April 12th a second, far more ambitious $100 million project. Breakthrough Starshot will conduct research and development toward accelerating gram-scale interstellar probes to 20% of the speed of light, using lightsail technology and a 100-gigawatt laser array on Earth.

The laser array would boost the probe out of Earth orbit by aiming at the probe's super-reflective lightsail and, with radiation pressure, accelerating it to one-fifth the speed of light in the two minutes the mini craft is within laser range. It will have to do this without vaporizing the sail or probe. The lasers would then take a day to recharge their batteries (from a dedicated power plant), before sending off the next probe.

The nanoprobes would take only 20 years to get to Alpha Centauri, if they survive both the laser blast and the trip. In theory, as each zips through the star system, a tiny camera and atmosphere analyzer would grab pictures and data on any planets there. Then it would transmit these data 4.3 light-years back to Earth using a "compact laser." The total mass of each probe, including power supply, camera, sensors, processors, fine-navigation thrusters, and that amazing transmitter, is to be just a few grams.

If you think this sounds impossible, you're in good company. But for years now, blue-sky engineering analyses have concluded that while this technology is rather beyond us at present, it could come into reach if Moore's Law continues, if materials science and ultra-micro manufacturing develop as hoped, and if lasers keep getting cheaper and more powerful. Milner's $100 million will go toward investigating whether all of this can happen.

■ **ALAN MACROBERT**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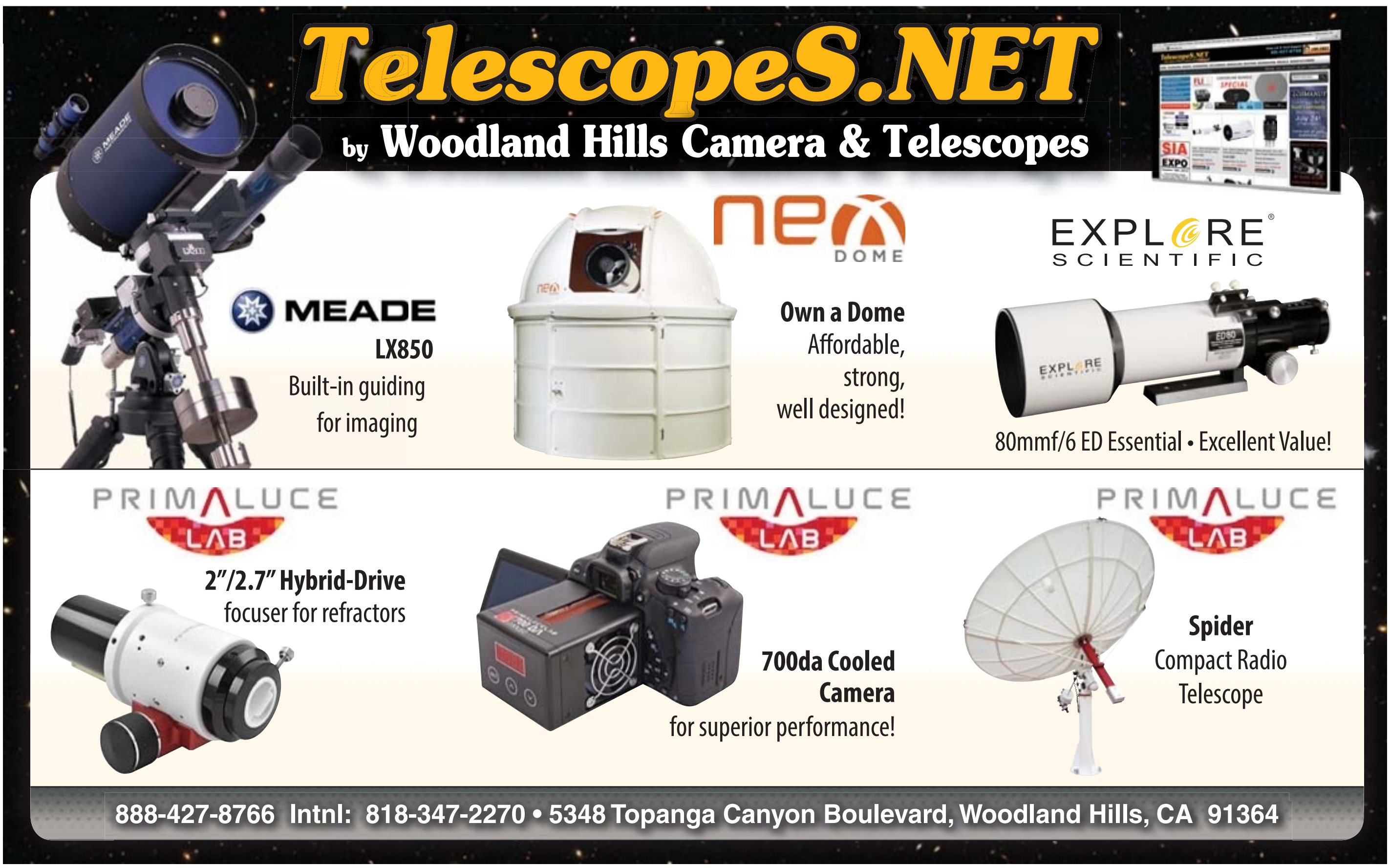
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IN BRIEF

BY CAMILLE M. CARLISLE

Did Fermi Detect LIGO's Merging Black Holes? Scientists with NASA's Fermi Gamma-ray Space Telescope say that the observatory detected a weak, 1-second burst just 0.4 second after LIGO sensed the merger of two black holes (*S&T:* May 2016, p. 10). The flash was so weak that it didn't trigger the space telescope's onboard alert system (partly because the burst went off "underneath" the spacecraft) or show up in data from the European Space Agency's Integral satellite. Furthermore, astronomers don't expect the black holes to have set off a light show: any emission would have to come from gas, and merging black holes of these masses (a few tens of solar masses) should have swept up all surrounding material during their prolonged fatal approach. Yet based solely on timing, Valerie Connaughton (Universities Space Research Association) and her colleagues estimate in their paper on the preprint arXiv site that there's only a 0.2% probability Fermi would have detected a signal by chance so soon after LIGO's. (That probability doesn't take into account whether the signal is real.) The two regions on the sky that the signals could have come from do overlap for 200 square degrees, or roughly the area of Cassiopeia's W. Read more at http://is.gd/fermiligo16.

Big Bird Neutrino Came from Blazar? One of the most energetic neutrinos detected by the IceCube Neutrino Observatory (*S&T:* Jan. 2014, p. 18) might — stress *might* — have come from a blazar. The neutrino, dubbed Big Bird, had 2 petaelectron volts of energy, roughly a hundred times more than protons zipping around CERN's Large Hadron Collider. One possible source for energetic cosmic neutrinos is blazars, but a previous attempt to pair two other IceCube blips with blazar flares was inconclusive. Matthias Kadler (Würzburg University, Germany) and colleagues tried again and found that the blazar PKS B1424-418 had an outburst around the same time as Big Bird arrived in IceCube. But blazars are notorious flickerers, and with a 5% chance of coincidence, the result is only a hint. The report appeared online April 18th in *Nature Physics*.

SOLAR SYSTEM | Saturn Moons Could Be Young

Planetary scientists suspect that some of Saturn's moons may be only 100 million years old.

Saturn waltzes through space surrounded by an entourage of 62 moons. Alongside its lone gallant, Titan, orbit an assortment of icy, midsize moons, their diameters ranging from Mimas's 400 km (250 miles) to Rhea's 1,525 km (948 miles). Together, they have a mere 1/20 as much mass as Titan does. Interspersed are a vast collection of moonlets.

In terms of numbers, Saturn's retinue matches that of the king of the planets, Jupiter, whose current satellite tally is 67. Yet Jupiter boasts a more glamorous court with its four large Galilean moons, and it doesn't have any midsize moons.

Planetary scientists have long wondered why Jupiter has come out so much the winner when it comes to big moons. In 2013, for example, Erik Asphaug (Arizona State University) and Andreas Reufer (then at University of Bern, Switzerland) suggested that Saturn started with a Galilean system of its own, but the moons crashed into and obliterated one another. The rubble then coalesced into Titan and the midsize moons.

A new paper explores the collision idea further. Matija Ćuk (SETI Institute) and his colleagues turned back time by simulating the icy moons' orbital evolution and figuring out when and how they could have interacted, given their current locations and orbits. The team found that the moons can't have migrated much from where they first formed. But that doesn't make sense if they've been orbiting the planet from the solar system's early days: Saturn's tides are just too tenacious — the moon Enceladus and its tidal-triggered geysers confirm that.

Instead, the team argues, the midsize moons can only be about 100 million years old. The moons formed from a ring of debris, born from the collisions of large precursor moons, the team suggests in the April 1st *Astrophysical Journal*. (The researchers exclude Titan from the list of phoenix moons.)

Ćuk's team offers a test: craters. If the midsize moons are indeed young, they won't have had time to build up a perfectly homogenous peppering of pockmarks. Instead, craters on moons within Titan's orbit (all the midsize moons but Iapetus) would concentrate around those satellites' equators, because the moons would have been exposed to a lot of debris in the plane of their birth ring but not nearly as much from other angles. Many of the moons are heavily scarred, so it'll take dedicated work to tease out whether the moons have these crater girdles.

■ **CAMILLE M. CARLISLE**

MISSIONS | Russian Space Observatory Launches

Russia's Mikhailo Lomonosov astrophysics observatory took to the skies on April 28th. Named after the Russian 18th-century writer and scientist (also known for his observations of the 1761 transit of Venus; *S&T:* June 2012, p. 32), the Lomonosov has a three-year mission. The primary target is the high-energy regime, including gamma-ray bursts (GRBs), cosmic rays, and the source of elusive atmospheric flashes known as *transient luminous events* on the nighttime side of Earth, often referred to as "upward lightning." In addition, the satellite will observe GRBs simultaneously in both optical and gamma-ray wavelengths in a manner similar to NASA's Swift satellite. The spacecraft will also monitor for potentially hazardous asteroids.

The satellite follows a Sun-synchronous polar orbit. This is a highly inclined, retrograde orbit that precesses 1° per day, enabling the spacecraft to view Earth at the same local time on successive passes.

Lomonosov Moscow State University will operate the satellite with agencies in six other countries, including the U.S. ✦

■ **DAVID DICKINSON**

A Million STARS

—syncth

Crashing code, unasked-for black holes, and months of work lost to mistakes — astrophysicists battled many foes in their quest to create the Holy Grail of star cluster simulations.

Benjamin Skuse

Long Wang describes his work as "code development and data analysis." It sounds unremarkable. But the 27-year-old PhD student, based at Peking University in Beijing, China, is much more than a programmer and number cruncher. Wang has solved a problem in astrophysical simulations thought so difficult that in 2010 distinguished Professor Emeritus Douglas Heggie (University of Edinburgh, UK) offered a bottle of fine whisky to the first person to solve it. Five years later in December 2015, Heggie happily handed over the prize to Wang.

Wang's achievement? As main code developer on the international Dragon Simulation Project, he conducted the first-ever million-body simulation of a globular cluster: he built a code that describes every single star's movement and evolution during the cluster's entire 12-billion-year history.

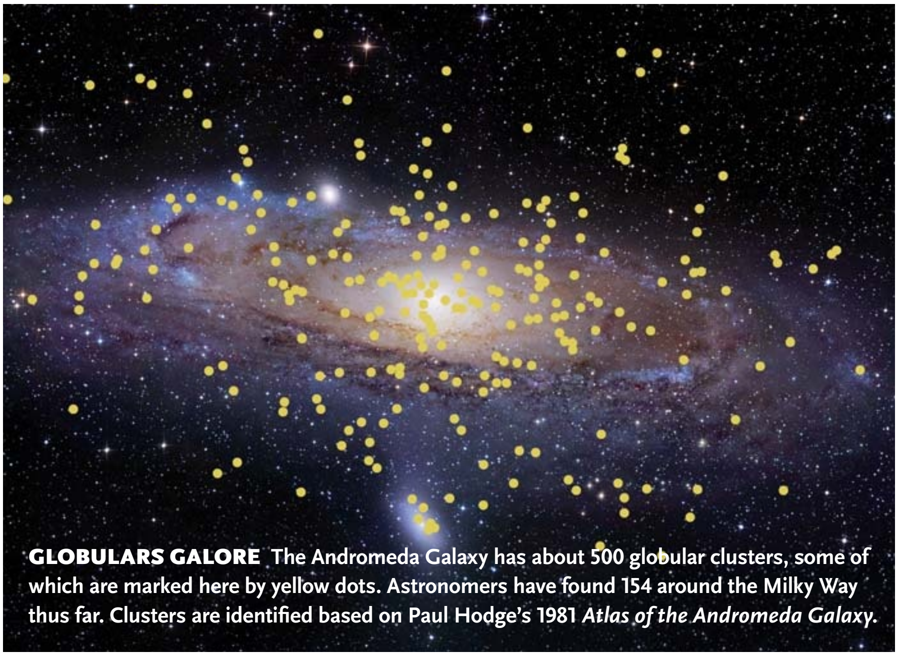
Globular Clusters

Globular clusters (GCs) are big balls of old stars. On average they contain well over a hundred thousand stars, densely packed together and bound by their mutual gravity into a roughly spherical shape. In our galaxy and others like it, many GCs were born at the galactic beginning, forming in the growing primordial gas cloud as it flattened into a spiral disk. They are thought to orbit all massive galaxies.

Among the most ancient structures to have formed in galaxies like our own, GCs have no young stars today. Star formation ceased billions of years ago, and all of the largest stars exhausted their hydrogen reserves in the distant past, leaving only stars with masses comparable to that of the Sun or less.

Despite their age, GCs are hotbeds of activity, with their stars performing a type of interminable chaotic dance that has enticed great minds including Laplace, Lagrange, and Poincaré. They may even hold the key to understanding how galaxies form. "In distant galaxies, due to the

STELLAR COUNTERFEIT The product of thousands of hours of supercomputer time, this simulated globular cluster closely mimics what astronomers find in real clusters. Overlaid are snippets of code from the Dragon Simulation.



ROBERT GENDLER

GLOBULARS GALORE The Andromeda Galaxy has about 500 globular clusters, some of which are marked here by yellow dots. Astronomers have found 154 around the Milky Way thus far. Clusters are identified based on Paul Hodge's 1981 *Atlas of the Andromeda Galaxy*.

LONG WANG

CODE DEVELOPER Long Wang and his team wrote and ran the Dragon Simulation that successfully followed four globular clusters through 12 billion years of evolution (at least, the computer equivalent).

LONG WANG

NO MAN IS AN ISLAND The Dragon team has nine members, including Wang; shown here are Mirek Giersz (left), Rainer Spurzem (middle), and Sverre Aarseth (right).

observation limit, GCs might be the only bright tracers of star-formation history and dynamics," Wang explains. Careful measurements of GCs therefore provide tantalizing insights into galactic and cosmological evolution.

But to fully understand these ancient clusters, astronomers need to know how they change over time. That's not something easily done with observations. So researchers mimic on computers how stars interact with one another and behave at grand scales, then they compare those results to clusters in the real world.

A Backwater of Astrophysics

"When I was a young post-doc somebody said to me: 'Globular clusters — that's a backwater of astrophysics, who wants to study those?'" recalls Heggie. "But it turns out that the subject really did come to life within a couple of years of him saying that . . . and it's never gone off the horizon since then."

Fueling this interest has been the challenge of replicating the lives of star clusters through ever more realistic mathematical models. Unfortunately, in this respect GC dynamics is neither fish nor fowl: the equations are too complex to be solved by cunning algebraic manipulation, yet not complex enough to effectively apply approximations like those designed to imitate the dance of atomic particles in fluids or gases.

Instead, the equations underpinning the interactions among the stars of a GC are best solved by a computer code called an *N-body simulation*. An N-body simulation is a computer program that follows the behavior of a large number of particles ("N") over time. Each particle represents a unit of something — whether a protoplanet, a star, or even a galaxy. In the case of GC simulations, each body is a star.

As in all astronomical systems involving more than two bodies, the dynamics inside these clusters is chaotic, meaning to understand how the system evolves requires numerical analysis, a type of mathematics that uses algorithms to approximate answers to complex problems.

The code cuts each star's motion into tiny manageable slices of time. In one time slice, the forces exerted on each star by all the other stars are calculated, and the star takes a small step forward. But by the time it has moved the forces have changed, so they are calculated again and the next step is taken. And so forth. The smaller the time slices taken, the more accurate the simulation.

Unfortunately, for a 10-billion-plus-year GC simulation, each individual star requires many millions of time steps, meaning the more stars in your cluster, the longer it takes to calculate the cluster's evolution. The computational effort is proportional to the cube of the number of particles being modeled. "Thus, in order to double the number of stars that you can include in your simulation, you need a computer that is eight times as fast (at least)," explains Heggie. Even though computers have been getting faster for decades — processor performance has grown about 50% per year since the mid-1980s, until a slowdown in the 2000s to about 20% per year — this cubic relationship has meant the size of simulations has grown much more slowly.

Before parallel computing and advanced acceleration hardware, scientists would be doing well if they could model the evolution of more than a handful of stars. "What you could do on a desktop PC at that time was maybe 100 particles if you were lucky," recalls Simon Portegies Zwart (Leiden University, The Netherlands). And even supercomputers of the time could only handle about 1,000 stars. Yet that wasn't good enough: astronomers needed million-body (and more) simulations, for two main reasons. First, the majority of GCs start their lives with at least this number of stars. Second, the results of smaller simulations cannot be scaled up to model larger clusters — the scaling inevitably leads to unphysical behavior. Just as trying to smooth out wallpaper bubbles with your hand leads to more pesky bubbles appearing elsewhere, fixing one problem when scaling up smaller simulations always leads to another.

But the computers just weren't up to the simulating task. Indeed, at the start of the 1990s, solving the GC million-body problem was regarded as a pipe dream.

But then came GRAPE (Gravity Pipe) — a computer specifically designed to simulate the evolution of a GC and a quantum leap in computing, being the first in the world to perform a trillion operations in a single second. "With GRAPE 4, we could go up to 10,000 particles," Portegies Zwart explains. "This jump was absolutely amazing." GRAPE drove an almost exponential increase in the number of bodies that could be simulated: from 10,000 in 1996 to 100,000 in 2003, 200,000 in 2012, and, most recently, 485,000 in 2014 by Heggie.

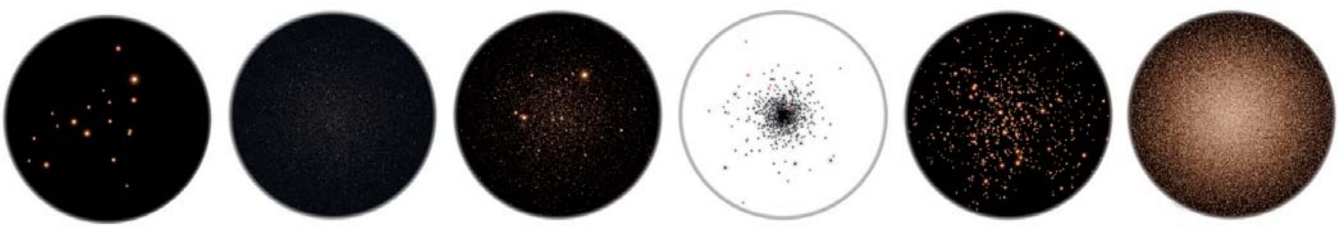
Bugs in the System

Heggie's 485,000-body simulation was run on "the kind of PC that you would put under your office desk, though on the big side" and took around 2½ years to complete. With so much time invested in one simulation, it was important that there were no bugs. However, after just one year he noticed something was wrong. "The simulation had one unfortunate feature: there was a line in the code which meant that black holes would have a much larger diameter than they should have," he recalls. "This, in turn, meant that they collided and coalesced much more often than they should."

This type of problem is common to GC simulations. "If you get a result [you don't expect] there are two things you can do: you can distrust the answer, but then you have to reevaluate the code you have been writing; or you have to take it seriously and publish it," offers Portegies Zwart. "And that's a bit scary sometimes because there are bugs in every code — the question is, how serious are they?"

By its nature, designing astrophysical models (of stars, clusters, or whole galaxies) involves extreme simplifications and assumptions of very intricate processes. As Corinne Charbonnel (University of Geneva, Switzerland) elucidates, this can add another level of uncertainty and frustration to the mix. "Sometimes we need months of computations before we can validate or disclaim each assumption, and sometimes one single new observation invalidates most of the previous work."

The longest of the four initial simulations Wang has done so far took about a year to complete, and so the



A MILLION STARS THROUGH TIME **The Dragon team ran four cluster simulations and created mock observations of their models so that they could compare the simulated clusters with observed ones. Shown here is the end result of one simulation *(left)*. The simulation began with 1,050,000 stars and followed their evolution over 12 billion years. Step by step, the simulation calculated each star's gravitational effect on the others, even as it tracked the stars' aging and deaths. Above, the series of six snapshots show different populations of objects within the cluster after 12 billion years: from left, AGB stars, white dwarfs, binary stars, black holes, red giants, and main-sequence stars (those fusing hydrogen in their cores, as the Sun does). Over time, these populations appeared and grew. The black holes notably settled to the center as the cluster aged. How concentrated the cluster became depended primarily on how top-heavy the initial stellar population was in terms of mass. Watch two clusters evolve at http://is.gd/dragonsims.**

DRAGON SIMULATION PROJECT

EDER IVAN

LOOKS LIKE THE REAL THING The Dragon clusters reproduce the properties of the real-world globular cluster NGC 4372, which lies deep in the Southern Hemisphere. The cluster (left center) appears here with the Dark Doodad.

Dragon team is equally wary of bugs. "I am nervous at the start of simulations — if something goes wrong, it's a disaster!" Wang says. "I have suffered this kind of problem before, once having to restart the simulations several times in one project, costing me half a year."

It Works!

Despite these setbacks, the Dragon team last year succeeded in simulating a million-star GC, causing ripples of excitement throughout the community. "A million-body direct simulation was something completely crazy till they achieved it," comments Michela Mapelli (Astronomical Observatory of Padova, Italy).

Published in the May 11th *Monthly Notices of the Royal Astronomical Society,* the team's first results show that their four simulated GCs, followed over 12 billion years, match up so well with both theoretical models and observational data that they can reproduce the properties of real-world cluster NGC 4372.

While there is some fine-tuning still to be done, the simulations already confirm that a bunch of stellar-mass black holes should huddle in clusters' cores, persisting for billions of years. Before, these black holes were expected to slingshot each other out of the GC, due to close gravitational encounters between them. The Dragon simulation shows that the black holes' long-term presence can dramatically change the evolution of GCs. For example, the team noticed that some binaries formed from these black holes will eventually merge and emit gravitational radiation very similar to that recently detected for the first time by the Laser Interferometer Gravitational-Wave Observatory (LIGO) team.

Most important, though, is that the Dragon team has shown that the code works. "I think it's an important

The AMUSE Project

Many teams are writing codes to tackle different aspects of stars' lives, and Simon Portegies Zwart has created an open-source "metacode" called the Astrophysical Multipurpose Software Environment (AMUSE) to bring them together. AMUSE is a software framework in which existing codes — modeling stellar dynamics, stellar evolution, hydrodynamics, and radiative transfer — can be used simultaneously. Like a structure made of LEGO bricks, a simulation within AMUSE is made up of individual codes (the bricks), and each code can be added or taken away according to requirements in order to create a new simulation. This plug-and-play capability makes AMUSE a very powerful framework for astrophysical star cluster simulation.

step in our ability to simulate globular clusters and star clusters in general," Portegies Zwart remarks. "I would have loved to have done this calculation, in all honesty, but I am very happy for him that he did it. It's fantastic." He's not overegging the accomplishment: million-body clusters have only been modeled approximately up to now, so the Dragon team's ability to realistically simulate them on a star-by-star basis represents a completely new phase in GC science.

Multiple Populations: The Next Challenge

With the gravitational million-body problem solved, you would be forgiven for thinking that GCs will soon return to being "a backwater of astrophysics." The truth is quite the opposite. Numerous crucial questions remain. For instance, Wang and the Dragon team have yet to find a way to include stars of different ages in their simulations. Astronomers only discovered near the turn of the 21st century that stars in GCs can have different ages and initial chemical compositions. Before then, scientists thought all stars in a GC were created at about the same time in protogalaxy halos. But more precise observations have exposed multiple generations of stars in GCs. As the assumption that all stars formed at the same time underpins most theoretical models of these clusters, multiple generations present a serious challenge.

Two groups in Europe — one led by Mapelli and Mario Spera in the Formation and Dynamics of Stars (ForDyS) team, and the other by Charbonnel and an International Space Science Institute team — want to shine a light on this problem, aiming to resolve why observations suggest not all GC stars were formed over 10 billion years ago. "We need to understand if the mechanisms that lead to the formation of multiple stellar populations in massive star clusters are universal, both in time and space, in order to uncover the link between the two types of clusters, young and old," explains Charbonnel. "This is crucial to probe the formation of galaxies and their evolution over cosmic times."

Charbonnel is working on this problem by devising new models of all types of stars in GCs, incorporating a number of complex internal processes that should help illuminate how they came to be. Meanwhile, ForDyS focuses on star birth near supermassive black holes and why stars prefer to form close to other stars in clusters. "We are sure that there is a tiny but very important *fil rouge* which connects all star clusters in the universe," argue Mapelli and Spera. "We are searching for this guiding thread!"

The Galactic Trillion-body Problem?

With so much effort being made to understand the origin and evolution of multiple stellar populations, there is little doubt that soon these too will be incorporated in Wang's code or one of its successors. And it is this constant cross-pollination of new ideas and techniques — through collaboration, open-source code projects, and healthy competition — that is allowing the small but highly industrious star cluster community to make rapid progress in simulating and understanding these fascinating and venerable components of the universe.

Wang and the Dragon team's achievement will only accelerate this progress, not only opening up new scientific realms to explore but also opening the minds of star cluster scientists to just what might be possible if they dream big. "What I would like to do in the future is simulate the entire Milky Way, including all the stars and planets — there may be a trillion planets in the galaxy," Portegies Zwart envisions. "It sounds completely ridiculous, but if you had said that you can do a million-body simulation of a globular cluster 10 years ago it would have sounded ridiculous, too."

If someone does solve the trillion-body problem, one wonders what Heggie might offer as a prize to celebrate the achievement. Perhaps a barrel of whisky? ✦

***Benjamin Skuse** is a science communicator and writer based in Bristol, UK. He has a PhD in mathematics from the University of Edinburgh, where he also had the privilege of enjoying undergraduate astronomy lectures from Douglas Heggie.*

COURTESY LONG WANG

WHISKY PRIZE Douglas Heggie (right) presents Long Wang with a bottle of single-malt Scotch whisky at a stellar science conference in December 2015.

FURTHER READING

Long Wang et al. "The DRAGON simulations: globular cluster evolution with a million stars." *Monthly Notices of the Royal Astronomical Society.* (May 11, 2016: 1450-65)

Douglas Heggie and Piet Hut. *The Gravitational Million-Body Problem: A Multidisciplinary Approach to Star Cluster Dynamics.* Cambridge: Cambridge University Press, 2003.

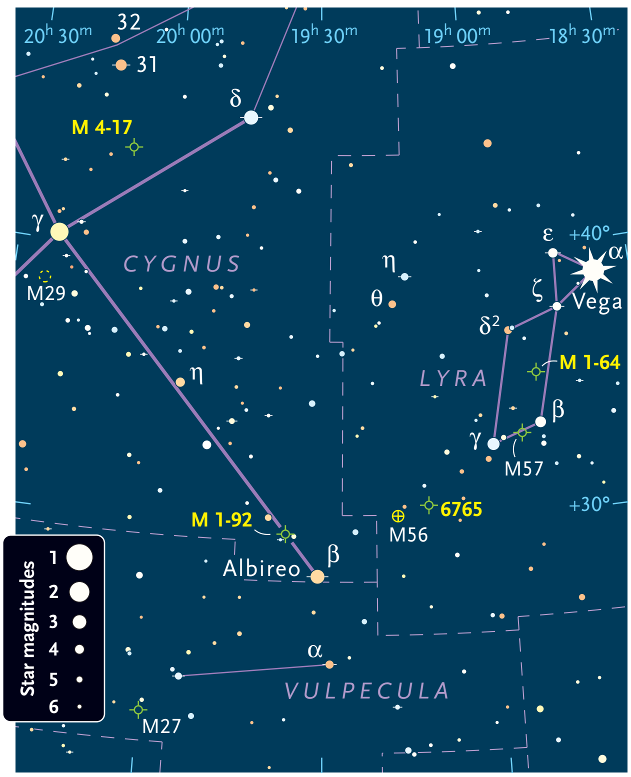
Meet the Minkowskis

TED FORTE

The Minkowski catalog of planetary nebulae will keep you at the eyepiece for years to come.

GERMAN-AMERICAN ASTRONOMER Rudolph Minkowski fled Hitler's Germany to join the staff of the Mount Wilson Observatory in 1935. His interests were many, and he's well known for his spectroscopic studies of supernovae. Less familiar are his studies of gaseous nebulae. In his early years at Mount Wilson, he conducted a survey to find new planetary nebulae (PNe) using an objective prism mounted on the 10-inch Cooke wide-angle camera. He later obtained slit spectroscopy of the suspected planetaries with the 60-inch and 100-inch telescopes.

Find the data table for the Minkowski planetary nebulae discussed here at http://is.gd/MinkPNe.



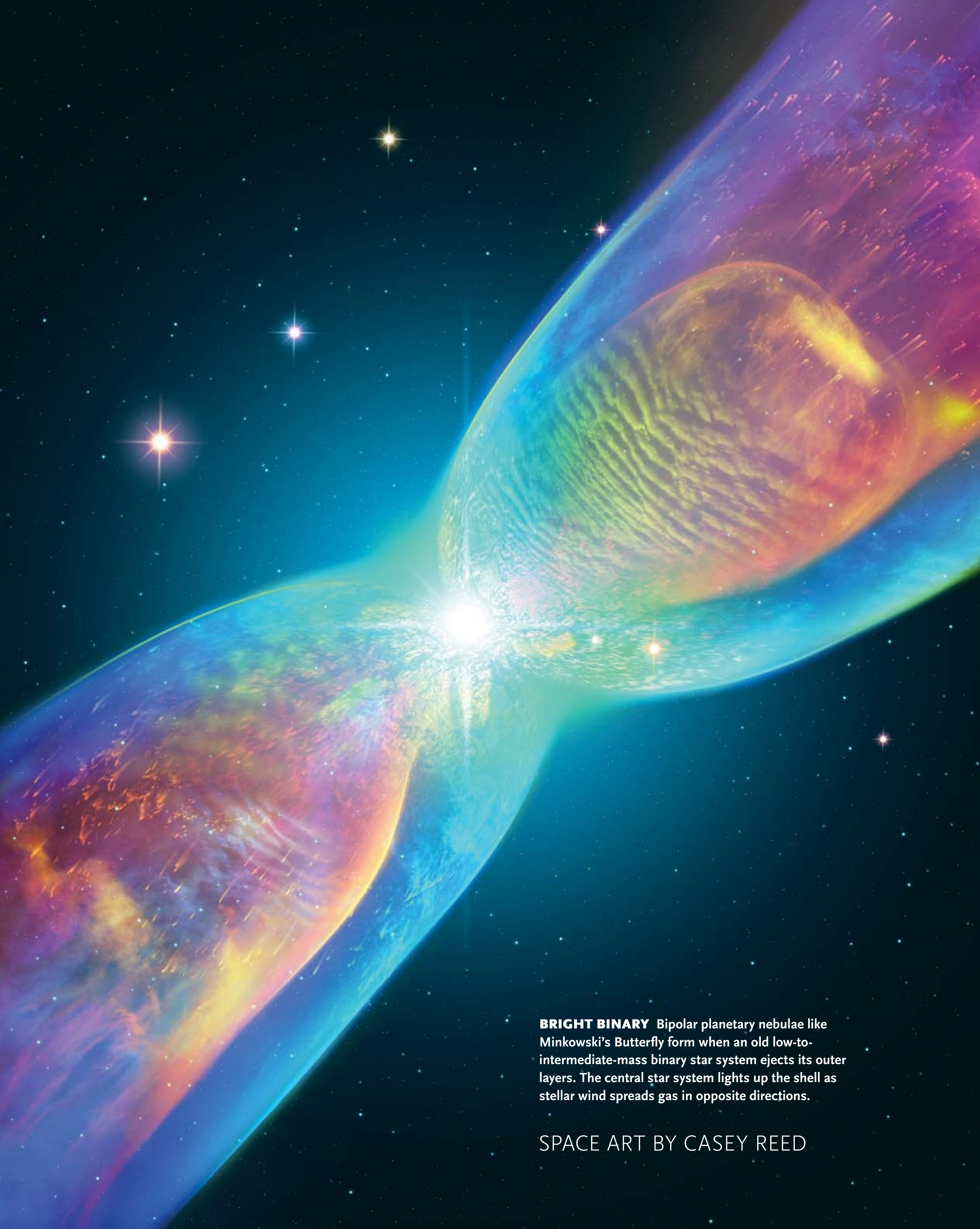
Minkowski's work more than doubled the number of planetary nebulae known at the time. In three papers published in the *Publications of the Astronomical Society of the Pacific* entitled "New Emission Nebulae" in 1946, 1947, and 1948, he gave us a catalog of nearly 200 real or suspected PNe, as well as a number of other nebulae, some of which are proto-planetary nebulae (PPN). The PPN are a short-duration phase of stellar evolution that precedes the planetary nebula phase. They typically exhibit morphological shapes similar to PNe but have central stars that aren't yet hot enough to ionize their circumstellar material and produce the characteristic emission of true planetaries.

While Minkowski didn't number the objects in the original lists, the PNe listed in those three papers are now universally recognized by the designators M 1-*NN*, M 2-*NN*, and M 3-*NN*. Later, Perek and Kohoutek added additional objects from Minkowski's observations that then became known as the M 4-*NN* list. Collectively, all of these objects can be described as just "Minkowski Planetaries," with the acronyms "Min" and "Mink" frequently used in the literature.

Blink the Mink

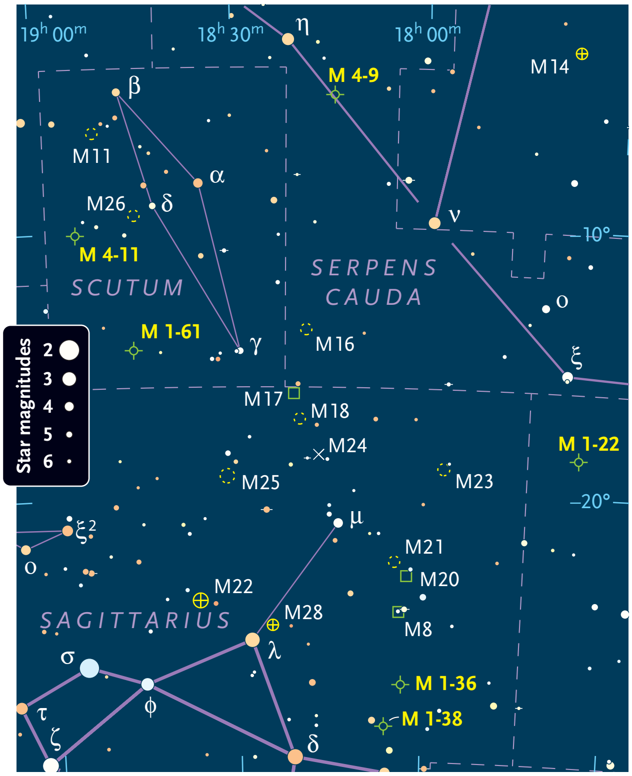
Most of the objects in the Minkowski catalog escaped detection by generations of visual observers, so it's no wonder they're considered to be challenging targets and require some special techniques to detect. Emission in specific wavelengths distinguishes these objects from ordinary stars in the eyepiece, so a nebular filter is often a necessity. Experienced observers of PNe typically own a variety of filters and regularly employ more than one on any given object.

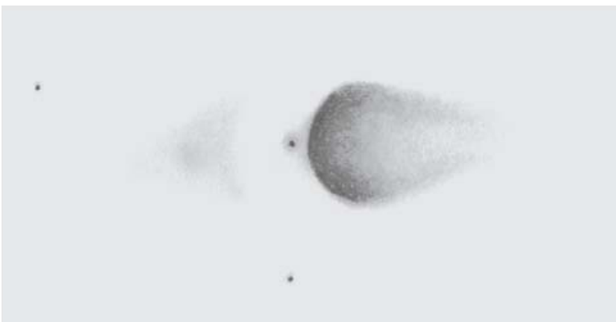
PNe normally exhibit strong emission from doubly ionized oxygen (O III) at 500.7nm and 495.9nm, so filters that pass these wavelengths are the most effective. UHC (ultra-high contrast) filters pass O III as well as a variety of other wavelengths, making them very effective for



BRIGHT BINARY Bipolar planetary nebulae like Minkowski's Butterfly form when an old low-to-intermediate-mass binary star system ejects its outer layers. The central star system lights up the shell as stellar wind spreads gas in opposite directions.

SPACE ART BY CASEY REED





COSMIC TRACKS Proto-planetary nebula M 1-92, known colloquially as Minkowski's Footprint, consists of a white dwarf surrounded by gas shaped by stellar winds. This composite image combines exposures taken through Hubble-specific filters. The field of view is only about 36 arcseconds across. ***Sketch above:*** Viewed at 1465× in a 27-inch reflector, M 1-92 shows a distinct two-part structure with a sharp central star.

IMAGE: ESA / HUBBLE / NASA / SKETCH: UWE GLAHN

most planetary nebulae. The truly narrow bandwidth filters, like the O III and H-beta, pass a lot less light than wider band filters, so aperture also comes into play. More restrictive filters will be of less utility in smaller scopes since they block so much light as to make detection of fainter objects more difficult.

Software programs that predict visibility based on contrast thresholds rarely account for the enhancements created by nebular filters. Don't let their predictions of invisibility deter you from attempting detection.

No matter the size of your scope or the passband of your filters, the most powerful technique PN hunters can employ is "blinking." By holding a filter between thumb and forefinger and passing it in and out of the light path by sliding it between eye and eyepiece, a PN can be made to blink. The filter dims the entire field, but since it preferentially passes the principle wavelengths emitted by the nebula almost undiminished, the PN stands out from the more dimmed field stars. It actually appears to brighten.

The blink effect is usually very subtle, and it takes good concentration and a lot of practice, but once mastered, you'll have a very essential skill at your disposal that will enable you to pick out a tiny planetary from among a field of ordinary stars. The smallest PNe will benefit from the blinking technique; larger disks will reveal themselves with a filter inserted in the eyepiece. If your telescope is equipped with a filter wheel or slide bar that can quickly switch between the filtered and unfiltered view, it may serve you well, but I find that even when I have a filter wheel available, the manual blinking method is more effective. A range of magnifications will increase the chance of detection.

Getting acquainted

In the August sky, there are more than 90 Minkowski PNe well placed for observing from mid-northern latitudes, and that number goes up as you move south. From my location in southern Arizona, 130 are well above the horizon during August. Most of the PNe described below can be viewed with an 8-inch scope, but very few are well enough known to have earned popular nicknames. There are two notable exceptions, however.

Minkowski's Footprint, **M 1-92**, is a proto-planetary nebula in Cygnus. It gets its moniker from a Hubble Space Telescope image that reveals it as a bipolar nebula with a very vague resemblance to a footprint. It's quite bright, and yet I found it difficult to detect its extended shape. Only a slight elongation can be seen in the eyepiece, and since it's a reflection nebula, filters won't enhance its visibility. It lies in a fairly crowded star field about 20′ east of 9 Cygni, adjacent to a 9th-magnitude star.

Minkowski's Butterfly, **M 2-9**, in Ophiuchus, also derives its name from a striking Hubble image that shows a beautiful bipolar structure that mimics the

STEFAN BINNEWIES / JOSEF PÖPSEL

GHOSTLY GOLDFISH M 1-68, also cataloged as NGC 6765, was discovered by Albert Marth in 1864 with a 48-inch speculum reflector. Under increased aperture and magnification, this planetary resembles a broad-finned carp swimming in a starry pond.

wings of a butterfly. It's also known as the Twin Jet Nebula. Without its enticing nicknames, it might get far less attention, as in smaller apertures it's quite challenging. While a 10-inch scope should reveal some elongation, it probably takes at least 16 inches of aperture to detect a bipolar structure. In 30 inches, it's quite remarkable, however. Filters don't seem to enhance the object much and high power is a must.

Three of the PNe identified by Minkowski were already in the *New General Catalogue* and two more were listed as IC objects. NGC 6765 (**M 1-68**) in Lyra and IC 4673 (**M 1-36**) in Sagittarius, are well placed for observing this month. NGC 6765 lies a little over 1° west-northwest of the globular cluster Messier 56. It's elongated north-south and irregular; larger apertures will show a bipolar structure that's brighter to the north. Apply a narrowband filter to improve its visibility. I wasn't able to detect the 16th-magnitude central star.

IC 4673, 3½° above the spout of Sagittarius's Teapot, sits in the middle of an arc of four 13th-magnitude stars. It appears as a small disk with a hint of annularity visible when viewed through a filter. This ring structure illustrates the importance of applying filters even to the objects that are obvious without them — the enhancement reveals details that would otherwise be missed.

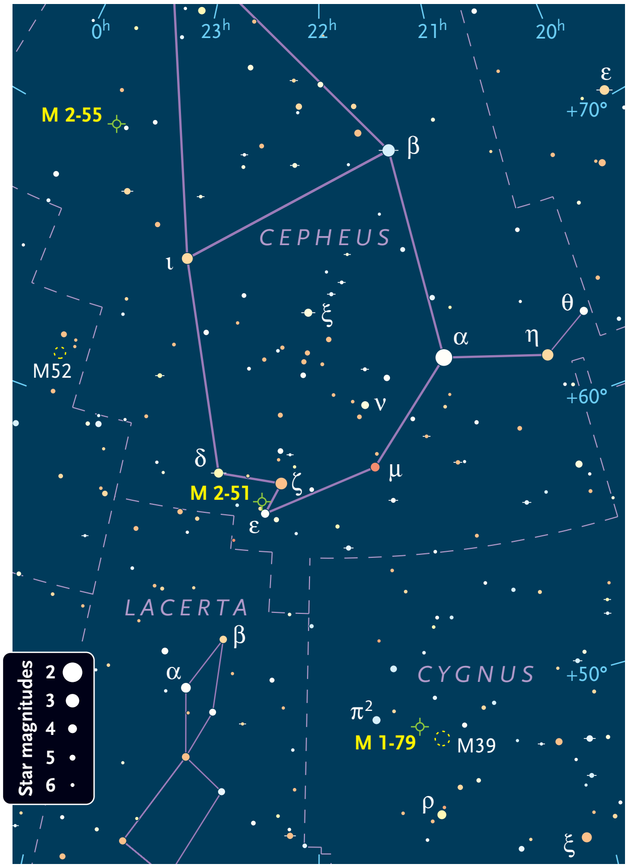
Typical targets

M 3-34 in Aquila is typical of many of the planetaries in the Minkowski catalog. It's fairly bright and easy to see as a star, but it doesn't reveal its disk without a filter and medium to high power. The challenge of detecting objects like M 3-34 is threefold. Concentrated in the plane of the Milky Way, they often lie in very crowded star fields, so the first hurdle is to locate them precisely. Since it's far easier to compare your star field to your map without a filter inserted, this first step will often just pinpoint a likely "star" with no hint of an extended disk. Then confirm its true nature by detecting its emission nebulosity. Successful detection involves the best combination of filter and magnification through trial and error. It's this added level of difficulty that makes observing PNe so rewarding. Not everyone gets it; PN observers are a unique breed, it seems.

Several Minkowski planetaries will be quite easy to see as stars but remain stellar at all powers. Some will seem to brighten with a filter (we say they "respond" to a filter) but show no actual disk at any power. Notable examples in the August sky are **M 1-61** in Scutum, and **M 3-21** and **M 1-38** in Sagittarius. All are bright and easy and respond to filters, but none can be made to blossom into a disk.

To be honest, only the most dedicated PN observers get satisfaction from observing objects that differ from ordinary stars only spectroscopically, so any "best of" Minkowski PNe list must contain those objects that exhibit a disk or a ring in backyard telescopes. Fortunately, there are a number of them in the August sky.

M 1-64 lies 2° 19′ north-northwest of the more



famous Ring Nebula (M57) in Lyra. M 1-64 appears as a small faint disk in an 8-inch telescope. In larger apertures, a ring structure reveals itself, especially in the filtered view. Look for the star embedded northeast of the planetary's center.

Cepheus contains two Minkowski PNe that certainly belong on the "best of" list. **M 2-51** lies about 54′ southeast of Zeta (ζ) Cephei. Eight inches of aperture show it as a disk. In my big 30-inch Dob, I see an irregular oval even without a filter and can hold it with direct vision. Extend the imaginary line connecting Zeta and Iota (ι) Cephei another 5.5° northeast to find **M 2-55**. Its 1.1′ disk can be seen without a filter but is much enhanced with a UHC filter. Look for brighter star-like knots in its angular body.

M 4-17 in Cygnus is a small faint disk. Extend a line through 32 and 31 Cygni, 3° toward the western wing of the Swan, to find it. Low power and a filter help reveal the round nebula, although in my largest scope, it's easily seen without a filter.

The Swan holds another ghostly looking disk, **M 1-79**, which is found less than 1° northeast of the open cluster Messier 39. Smaller scopes will easily show a smooth disk, especially through a filter. It's surrounded by many faint stars. In larger scopes, a ring structure is apparent as the center darkens to show annularity when a filter is applied to the view.

Scutum contains the small faint disk of **M 4-11** 1½° south of the globular cluster NGC 6712. At moderate to high power, it can be seen without the benefit of a filter, but it's at its best at low power and through an O III filter.

THE OTHER RING ***Below left:*** **The faint star at the north edge of M 1-64 shows in this sketch made at 586× with a 27-inch reflector.** ***Right:*** **A 14.5-inch reflector reveals M 1-64's ring structure.**

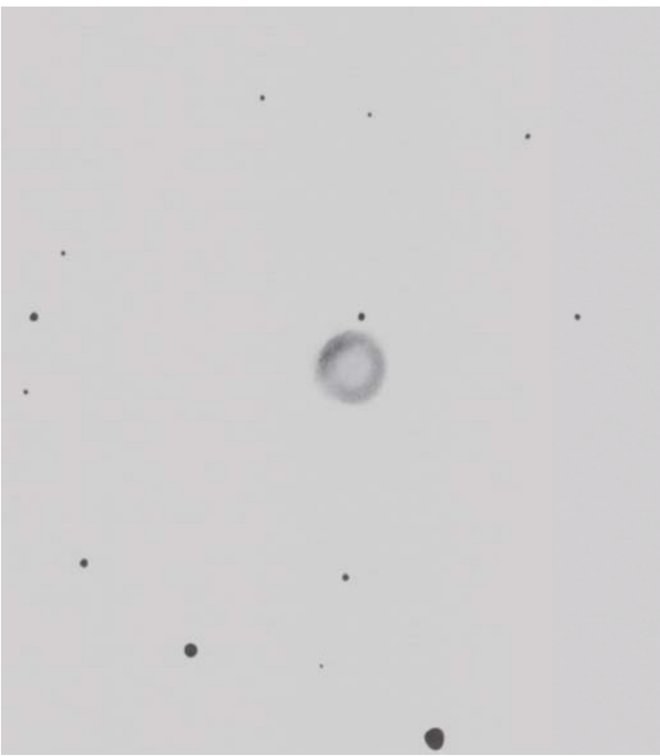


IMAGE: MARTIN C. GERMANO / SKETCH: UWE GLAHN

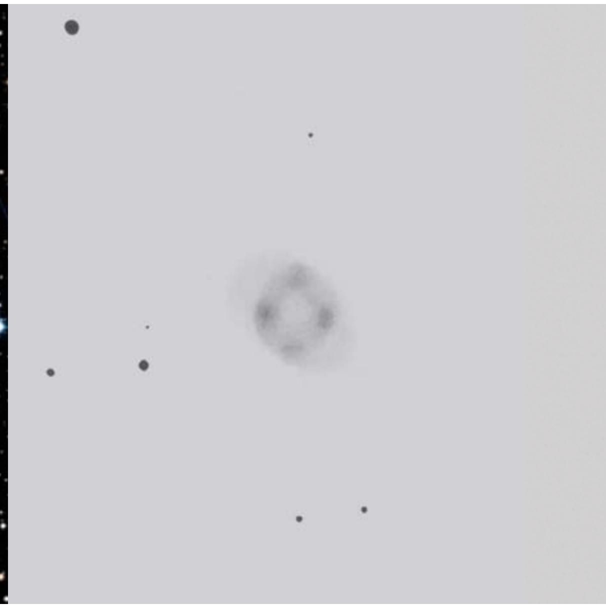


IMAGE: POSS-II / CALTECH / PALOMAR OBSERVATORY / SKETCH: UWE GLAHN

CEPHEUS SIGHTS ***Above:*** **M 2-55 appears elliptical or as a slightly uneven smudge until you pump up the magnification and throw on a filter. Look for the star-like knots in its body.**

Right: **Even without a filter, the view through a 27-inch reflector at 419× displays M 2-55's annularity and knotty structure.**

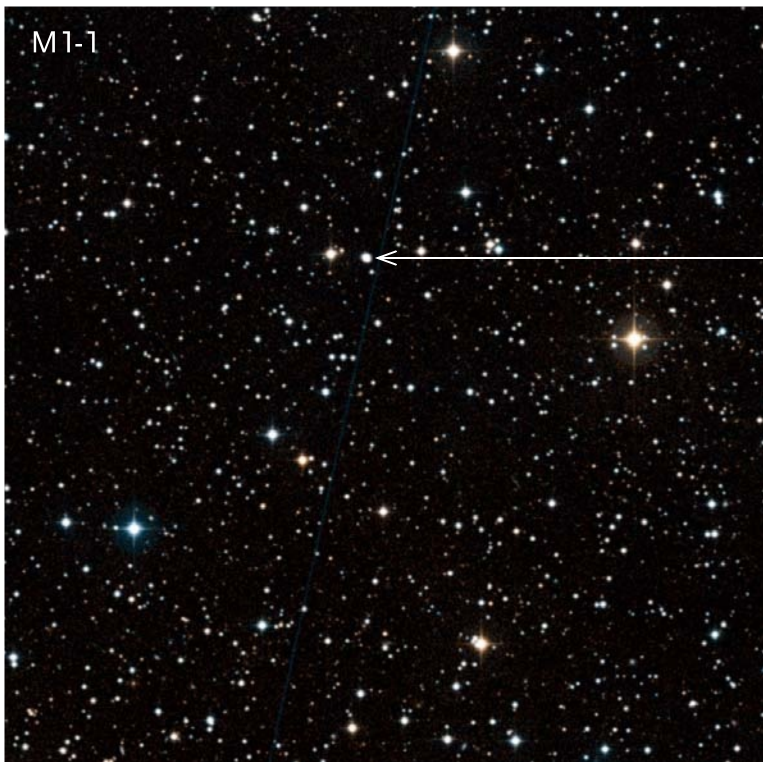
Challenge Targets

Some Minkowski planetaries are particularly tough objects, where it's possible to detect a disk but it's anything but easy. I offer three challenge objects that, while easy enough to see as a star, will be devilishly hard, but not impossible, to detect as a disk. **M 1-1** lies on the Andromeda–Perseus border about 2° north of 51 Andromedae. It's tiny, just 6″ in diameter. **M 1-22** in Ophiuchus is only a little larger in listed dimension at about 9″. Its classification implies a ring structure, but I've yet to see annularity. M 1-22 is in a busy neighborhood between the globular cluster Messier 9 and the open cluster Messier 23. **M 4-9**, 2° 41′ southwest of Eta (η) Serpentis in Serpens Cauda, shows a ghostly disk even without a filter. These three should present owners of 8- and 10-inch scopes with a significant challenge.

Many objects have been known to mimic planetary nebulae, and, of course, there are some misidentified objects with Minkowski designations. I've been fooled by a few of them. For instance, the eclipsing binary star V471 Persei has the designation **M 1-2**, and my logbook contains the description of a nebulous-looking star that was easy to see without a filter.

The densest concentration of Minkowski planetaries is found in Sagittarius. That constellation contains more than 60 objects from the catalogs, with another 49 in neighboring Scorpius and Ophiuchus. Nearly all of these objects are tiny and well hidden among the dense star fields of the Milky Way. This, of course, is the ultimate challenge for the observer of Minkowski PNe. For North American observers, the southern declinations add significantly to the difficulties, and observers who set a goal of observing the entire catalog have their work cut out for them. For dedicated PN fans, however, it can be a real labor of love and a very rewarding observing project. ✦

Contributing Editor ***Ted Forte*** *observes from his home near Sierra Vista, Arizona.*



POSS-II / CALTECH / PALOMAR OBSERVATORY

Visual Filters for Deep-Sky Observing

S&T: CRAIG M. UTTER

While not a magic bullet for defeating light pollution, "nebula filters" are still a boon for many urban observers.

Rod Mollise

Those of us interested in observing the universe beyond the solar system have a big problem: light pollution. How can we see distant marvels when our skies are painted pink from countless sodium streetlights?

Our best strategy is to get out from under the light dome that covers urban areas and to view instead from a dark site. How often can we do that, though? We might get to our club's observing site once or twice a month, and some of us might make it to a star party at a dark location only once or twice a year. Most of us want to observe more often than that.

There are tricks to seeing star clusters, and even galaxies, in the midst of light pollution. Choosing a large-aperture telescope and an eyepiece that yields contrast-enhancing, medium-high magnification can make dimmer objects show themselves to some degree.

But nebulae are another story. These clouds of dust and gas are harmed more by light pollution than any other class of deep-sky object. Most nebulae are subtle in the first place, being barely brighter than the sky background even when viewed from a dark site. Increase the background skyglow's intensity and they're just "gone." So, are dimmer nebulae out of the picture for city and suburban observers? Not at all, thanks to light-pollution-reduction (LPR) filters.

LPR filters, also known as nebula filters, can make the difference between seeing and not seeing dim objects from a suburban backyard. That doesn't mean LPR filters are a replacement for dark skies, though. They are not. Given the choice between using a filter in my suburban backyard and the view through an unfiltered eyepiece out in the country, I'll always take the latter. But LPR filters are a help even if they can't perform magic, and they do have some significant limitations.

How do LPR Filters Work?

Contrary to what some novices believe, deep-sky filters don't make objects brighter. Instead they increase contrast by blocking the "bad" wavelengths of light pollution. That is, they make the sky background appear darker in the eyepiece without dimming the target object. More contrast makes the nebula look better.

The way these filters work is easy to understand. An LPR filter is a piece of glass coated with multiple layers of various substances. These coatings have the ability to block the transmission of certain wavelengths of light while allowing others to pass. The *bandpass* of a filter — the range of wavelengths it allows through to the eyepiece — is tailored to the specific purpose of the filter, and it's determined by the exact types and number of coatings applied to the glass.

LPR filters are typically mounted in cells identical to those used for photographic filters or the colored filters used by planetary observers (*S&T:* July 2016, p. 52). They screw into the threads machined at the end of the eyepiece barrel. Almost all modern 1¼- and 2-inch oculars feature these standard filter threads.

If you haven't picked up on it already, LPR filters are only good for observing nebulae — and then only emission and planetary nebulae. These filters offer little advantage for observing star clusters because the light from streetlights and other light-pollution sources covers the same range of wavelengths as that emitted by stars. LPR filters dim starlight as much as they dim artificial skyglow and thus do not improve contrast for these objects. For the same reason, LPR filters are also ineffective on reflection nebulae, since these objects shine only by the reflected light of stars.

Finally, since the light we see from galaxies is mostly starlight, LPR filters don't improve their visibility either. There is, sadly, no such thing as a galaxy filter. Some observers have commented that a mild LPR filter can enhance galaxy viewing to some extent, dimming the background a little without also dimming the galaxy much, but I've never considered any LPR filter very helpful when I'm viewing galaxies.

DENNIS DI CICCO

TYPICAL TARGET The Veil Nebula, a giant supernova remnant in Cygnus, is a prized target for many observers. In modestly light-polluted skies its visibility can be significantly improved by viewing through an O III filter.

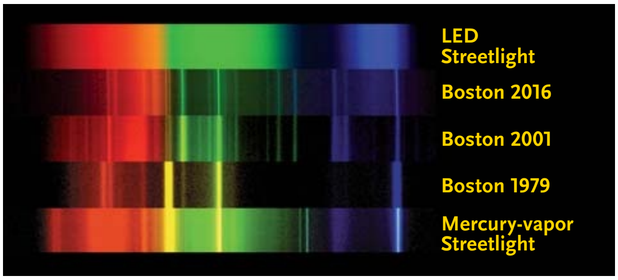
HELPFUL AIDS For observers who must contend with some level of artificial skyglow, light-pollution-reduction (LPR) filters can improve the visibility of many emission nebulae.

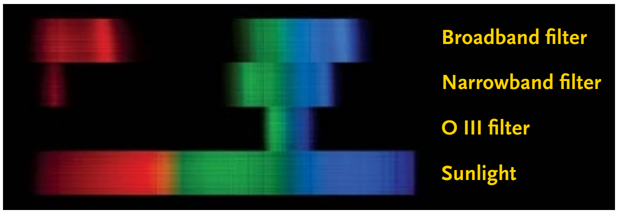
ROD MOLLISE

Three Types of Filters

One look at the filter section of an astronomy dealer's website or catalog reveals a confusing number of types and brands. Once you understand a simple fact, though, it'll be easy to make a choice. Filters fall into three general classes: *broadband* (so-called mild or deep-sky filters), *narrowband* (UHC or ultra-high-contrast), and *line* (ultra-narrowband). As for the different brands, LPR filters from most manufacturers are basically similar, but it can still be true that "you get what you pay for," as more expensive filters are often made with premium optical glass that can offer better performance than some inexpensive ones do.

Broadband filters have a wide bandpass; they allow a broad range of wavelengths to pass through to the eyepiece. They are the least expensive LPR filters but often prove the least effective. The sky background with a mild filter can be almost as bright as without it, and therefore you gain only a little increase in contrast.





DENNIS DI CICCO (2)

SKYGLOW DECONSTRUCTED Evolving streetlight technology has changed the nature of light pollution. During the 1970s the skyglow above Boston was dominated by bright emission lines from the then-ubiquitous mercury-vapor streetlights. By 2001, however, widespread use of sodium-vapor lighting added more emission lines to the skyglow, making it increasingly difficult for LPR filters to block all the offending wavelengths. Now LED streetlights, with their nearly continuous spectral emission across visual wavelengths, are rapidly replacing older lights.

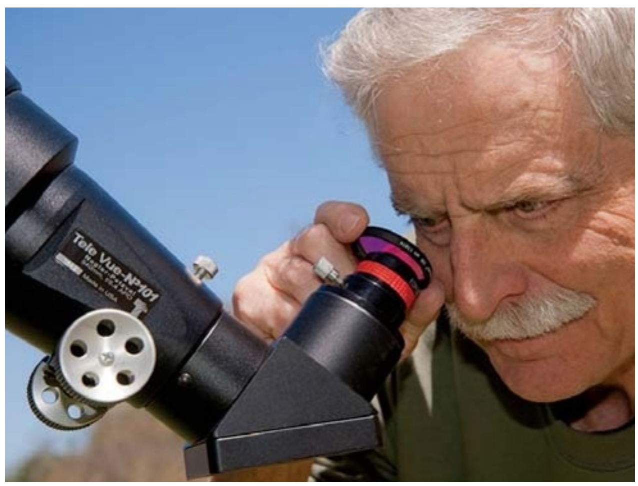
FILTER TYPES The three principal types of LPR filters described in this article are distinguished by their transmission characteristics, which were recorded with a spectrograph for this illustration. Because narrowband and O III (line) filters allow progressively less light to pass through to the eyepiece, they work best with medium- to large-aperture telescopes.

Narrowband (UHC) filters are the bread and butter of deep-sky observers. One of these can dramatically improve the appearance of emission nebulae and will also improve many planetary nebulae. While UHCs darken the sky background substantially, they are not so strong as to render dim stars in the field invisible, so they present the most attractive and normal-looking views.

Line filters have a still narrower bandpass, admitting only a small slice of wavelengths. The most common types are O III and hydrogen-beta (H-beta or Hβ) filters. I find the O IIIs by far the most useful line filter, since they suppress everything except the spectral lines of doubly ionized oxygen that are a major component of the light of planetary nebulae like M57, the Ring Nebula. These filters can do an amazing job on planetary nebulae or any other nebula that radiates strongly in O III light. O III filters are fairly dense and thus work best with the light-gathering power of at least a 4-inch telescope.

Caveats? Line filters work on most, but not all, planetary nebulae, and they work on some, but not all, emission nebulae. The Orion Nebula, M42, for example, looks worse to me with an O III than without. On the other hand, it makes the Veil Nebula, a supernova remnant, look much improved. Unlike UHC filters, O III filters dim field stars considerably, sometimes even to the point of making focusing difficult.

The hydrogen-beta filter is engineered to pass only the blue-green light of this spectral line. If an O III does not work on all nebulae, the H-beta does not work on most. It is often referred to as the "Horsehead Nebula filter," since it's mainly used by observers pursuing that faint object. The H-beta will also work on a few other similarly dim objects, like the California Nebula, but it's certainly not a general-use filter.



DENNIS DI CICCO (3)

CONTRAST IMPROVEMENT *Left:* These images of the Crescent Nebula in Cygnus give a rough approximation of how the nebula's appearance is enhanced when viewed through an O III filter. The back-to-back exposures through clear (*left*) and O III (*right*) filters were made when the nebula was in a part of the sky moderately brightened by light pollution from Boston. *Right:* In a low-power field of view, many small planetary nebulae are difficult to distinguish from stars. But they can often be identified by rapidly moving an LPR filter, especially a narrowband or O III filter, in and out between your eye and eyepiece, causing the stars to flicker while the planetary remains relatively constant.

PRIZED NEBULA As described in the text, the Horsehead Nebula in Orion is one of the few emission objects best seen with a hydrogen-beta "line" filter.

CHUCK MANGES

Which Filter To Buy First?

A UHC-type narrowband is without question the best "first" LPR filter. It works on more objects than an O III filter, and many more than a broadband filter. A UHC might not be optimum for some planetary nebulae, but almost all will be improved by it.

After you have a UHC, the next most useful filter for your kit is the O III. It won't help with as many objects as the UHC, but those that it does enhance are sometimes spectacularly improved. The Veil and Helix nebulae, for example, look far better with an O III than with a UHC.

From there? You might not need any more filters. Round out your collection with an H-beta if you want to be fully equipped, but if you're like me you will use it only rarely.

How much are your choices going to cost? LPR filters are not cheap. They are specialized low-production items, and they are complicated to manufacture. Expect to pay around $100 for 1¼-inch UHC or line filters, and about twice that much for 2-inch versions.

You wouldn't think there'd be much to using LPR filters. Screw one into your eyepiece, and away you go. Actually there's a secret to using them effectively — and if you don't know it, you will be disappointed by their performance.

If a filter is to do its best, you must not allow ambient light to enter the eyepiece from the eye end. When stray light enters the eyepiece — and that *will* happen unless your eye is tightly jammed up against the eye lens — the ocular will be flooded with ambient light and you will see *less* with the filter than without.

There is a simple fix, however: use a rubber eyecup on the eyepiece. If the ocular doesn't have one, you can buy cups that fit over almost any eyepiece. Or cup your hands around the eyepiece when you're viewing to shield it from ambient light. Best of all, especially under brutal light pollution, is to cover your head and eyepiece with a dark cloth.

LPR filters *can* be highly effective. They're not a complete cure for light pollution because they are not effective on all objects, but they've been a big help for backyard deep-sky observers over the three decades since they became popular.

Unfortunately, their effectiveness will likely be compromised in the future. Cities, mostly just the larger ones at this time, are beginning to convert from high- and low-pressure sodium streetlights to LED lighting. Unfortunately, LEDs are broad-spectrum emitters compared to sodium lights; their wide range of wavelengths is not as easy to filter out.

Some of the light from these new streetlights falls in the bandpass of a UHC filter but not the most intense portion of their emission. The same is true for O III filters. Their bandpass falls within the spectrum of an LED but not in the highest intensity part. In other words, both filters can still be effective — but not as effective as they are with sodium-vapor lights. Also, we probably have some breathing room, since replacing sodium lights with LEDs is expensive and will take time to implement.

It will happen eventually, however; that seems inevitable. So we amateur astronomers need to continue our crusade to reduce light pollution, led by the Astronomical League and the International Dark-Sky Association (**darksky.org**), by encouraging the use of sensible light fixtures and, especially, limiting the number of lights to no more than those really needed.

Even without the threat of LED lighting, LPR filters are hardly a panacea. They are not 100% effective at darkening the sky background, and they only work on a relatively small percentage of objects. However, they have allowed me to view many deep-sky marvels that would otherwise have been invisible from my backyard, and they've enriched my experience of amateur astronomy immeasurably. In other words, they are "worth every penny and then some." ✦

Veteran observer and telescope guru Rod Mollise writes frequently on astronomical topics in this magazine and at **uncle-rods.blogspot.com**.

A DO-IT-YOURSELF

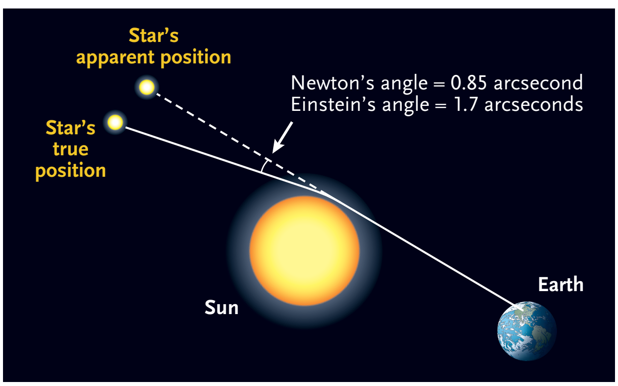
Relativity Test

Using off-the-shelf equipment during next year's total solar eclipse, you can prove that Einstein really was right.

DONALD BRUNS

In the long and colorful history of scientific expeditions to view total solar eclipses, two are particular standouts. On July 29, 1878, a small group of visitors that included Henry Draper and Thomas Edison watched totality from near Rawlins, Wyoming (see page 36). They were looking for Vulcan, the hidden, close-in planet thought to influence the orbit of Mercury. The second, on May 29, 1919, involved Sir Arthur Eddington's measurement of the deflection of starlight — and a triumphant confirmation of Einstein's general theory of relativity.

Next year, 139 years after Draper and Edison ventured West, I will be in Wyoming to repeat the 1919 experiment that made Einstein famous. I'm going to measure the Sun's deflection of starlight too, and to succeed I'll need to determine star positions accurate to a small fraction of an arcsecond, during only 140 seconds of totality, with no second chance if something goes wrong. It's going to be a very challenging experiment!



S&T: LEAH TISCIONE; SOURCE: DONALD BRUNS

BENDING LIGHT The apparent position of a star seen near the solar limb is deflected a very small amount by the Sun's gravity. Einstein's general theory of relativity correctly predicts the observed deflection angle. (Not shown to scale.)

The most recent attempt to do this, organized by the University of Texas in 1973, required moving 6 tons of equipment to Africa and leaving the telescope assembled but untouched for 6 months in a guarded shed. The researchers used a 200-mm-aperture refractor with a 2.1-meter focal length, and they recorded images during the eclipse on 12-inch glass plates. Despite their heroic efforts, the result still had an uncertainty of 11%.

With today's technology, a capable amateur should be able to get a far better result with much less effort. In order to measure a tiny deflection of as little as 0.02 arcsecond, excellent stellar images are needed — and that's entirely possible today. CCD cameras have replaced glass plates, image-processing software has supplanted scanning microdensitometers, and satellite-based star catalogs have eliminated the need to measure star positions six months before or after the eclipse. All that is left to do is careful planning and attention to detail.

Equipment and Experiment Design

By analyzing all of this project's requirements and comparing them with a wide variety of amateur telescopes and cameras, I selected an optimum combination of optics and detector. Your picks might be slightly different, but here's a recap of my rationale.

For the telescope, I chose the highly portable Tele Vue-NP101is. This apochromatic refractor's 101-mm aperture can capture 10th-magnitude stars with 1-second exposures, and its diffraction limit is only 1.3 arcseconds at a red-light wavelength of 630 nm — much smaller than the 2½-arcsecond daytime seeing I expect to encounter. The objective's 540-mm focal length provides a 2° field of view with a medium-format camera.

Since I'll need to pinpoint the centers of star images to within 0.02 pixel, those stars falling near the edges and corners of each frame must be as sharp as the ones in the center. The NP101is has a flat, color-free image plane, perfect for creating these very accurate star images, and I can adjust the focuser so that the camera remains perfectly square to the optical axis. Finally, the rugged, lockable focuser allows me to slew to multiple

DONALD BRUNS

STARS AND SPECTACLE A feathery corona, created by carefully calibrating and combining 55 images, surrounds the Moon's silhouette during the total solar eclipse of August 1, 2008. This composite also reveals more than 450 stars, including the Beehive Cluster (upper right of the Sun). *Right:* The author's "relativity test kit" consists of a Tele Vue-NP101is refractor, FLI Microline 8051 CCD camera, and Software Bisque MyT Paramount and field tripod.

sky locations with minimum risk of camera movement, essential for good calibration.

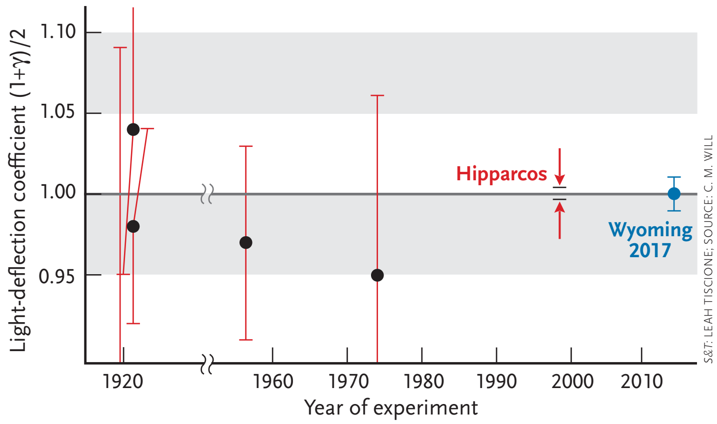
Next came the choice of imager. My pick was the 8-megapixel monochrome Microline 8051 CCD from Finger Lakes Instrumentation, a camera that I've used on previous astrometric projects. Its pixels are only 5.5 microns wide, a perfect match for the focal length of the NP101is, yielding 2.1 arcseconds per pixel. I opted against using a larger-format camera, as that would have required more time to digitize each image. Besides, any stars recorded far from the Sun will have a very small deflection and wouldn't help much in the final analysis.

By contrast, the 8051's fast 12-megapixel-per-second digitizing rate will be critical during my brief time in totality. Moreover, its interline CCD sensor requires no mechanical shutter; this avoids vibrations and ensures that every star is exposed simultaneously. I didn't want a color sensor, whose different filters on adjacent pixels would make determining the stars' exact centers very difficult. A monochrome camera like the 8051 provides the spatial resolution I need.

Since the eclipse is far from home, I'll also need a tracking mount on a portable tripod. For the NP101is refractor, my Software Bisque MyT Paramount on its field tripod is perfect. I can either do a good polar alignment the night before or use a handheld GPS to orient the mount to within about 1° of Polaris and the celestial pole on eclipse day (especially if I change sites to avoid cloudy weather). The Paramount features permanent periodic-error correction, or PEC, and the resulting tracking error is less than 1 arcsecond — just what I need for perfectly round star images.

Capturing the Stars

An important pre-eclipse planning task is to determine how dim a star I can record near the Sun during totality



PAST EXPERIMENTS Astronomers have attempted to measure the deflection of star positions during only a few eclipses over the past century, while Hipparcos made a very precise determination from space. The vertical scale is normalized to the deflection of star positions predicted by Einstein.

— there'll be no time for trial-and-error! After searching hundreds of websites, I found only *one* eclipse chaser who'd used a calibrated, monochrome astronomical camera. In March 2006, Christian Viladrich of France took an SBIG STL-11000 camera to Egypt to record the inner corona. His exposures were only 5 milliseconds long, so I stretched his image brightness by 200× to simulate a 1-second exposure. Then I estimated the background brightness levels near the Sun to calculate which stars would be easily visible. The result? More than 60 stars brighter than magnitude 12 should be in the field of view; with a limiting magnitude of 10, I hope to get good astrometric measurements from 8 of them.

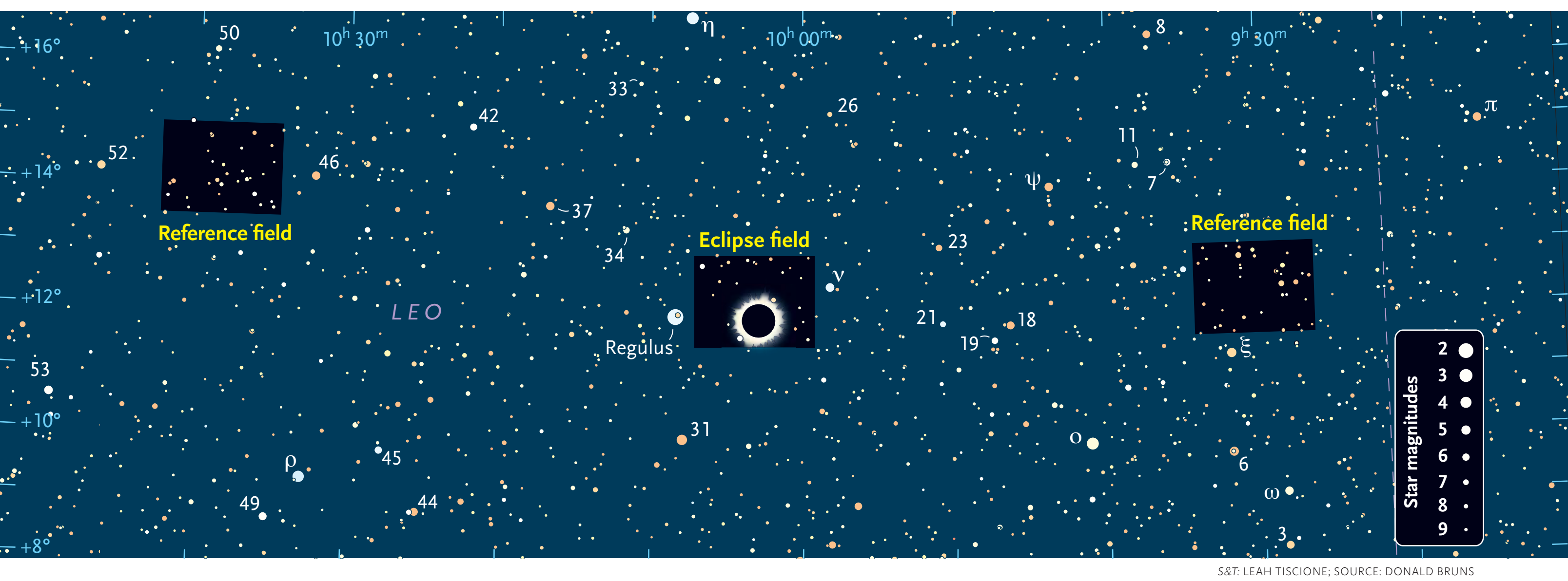
Assuming moderately poor seeing, I expect my star images to average close to 2.8 arcseconds (1.3 pixels) across. So how am I going to measure their positions down to 0.02 arcsecond? An astrometric rule of thumb is that the achievable accuracy for a given star equals its image radius divided by its signal-to-noise ratio (SNR). If I only measure stars with SNRs of at least 14, then at worst I'll get positions accurate to 1.3/14 = 0.1 arcsecond; adding the effects of atmospheric turbulence might increase this error to 0.2 arcsecond.

However, that's for only one image. Averaging multiple measurements reduces the error by the square root of the number of images. So, for 25 images, the positional errors would drop by a factor of five, yielding 0.04 arcsecond for the worst errors. Brighter stars, with higher SNRs, yield better accuracy, so I expect the average error to just reach my 0.02 arcsecond goal — if everything goes right!

To make the deflection calculations, I need to know the image scale to within a few parts per million. Since the telescope's focal length changes with temperature and air pressure, this means I'll have to calibrate the image scale obtained during totality. So I'll devote some of those precious seconds to record two reference star fields on opposite sides of the Sun (as shown in the sky chart below).

Immediately after totality starts, I'll shoot the first one, about 8° west of the Sun, for 30 seconds. There, far from the bright corona, the gravitational deflection should only be 0.06 arcsecond. Next I'll spend 60 seconds recording the field surrounding the solar corona. Finally, I'll slew the telescope one more time to record the reference field on the Sun's east side for the last 30 seconds of totality. With these references, the deflection images should be perfectly calibrated.

TARGET FIELDS The author intends to record three star fields during the 2½ minutes of totality provided by August 2017's solar eclipse. Stars are shown to magnitude 10.5.



Modern Star Positions

All previous deflection experiments required imaging the same star field six months before or after the eclipse in order to determine the star positions to sub-arcsecond accuracy — and the telescope and camera had to be left untouched for the duration to minimize mechanical errors. In the 1990s, the Hipparcos satellite generated a very good astrometric reference catalog, obviating the need for a year-long quiescence. However, those measured positions are 25 years old, and their uncertainties are now typically 0.1 arcsecond. The U.S. Naval Observatory's newer UCAC4 catalog is better (*S&T:* Dec. 2012, p. 16), but its 0.05-arcsecond errors still fall short for this experiment's needs.

By this September, however, the situation should improve dramatically! That's when the European Space Agency plans to release the first star catalog compiled by its Gaia satellite. Launched in 2013, Gaia is measuring a billion stars with an accuracy of 0.000024 arcsecond (*S&T:* Apr. 2014, p. 10). While the spacecraft needs more time to measure parallax or proper motion, this first catalog will offer exquisitely accurate positions — just in time for the 2017 eclipse.

But I'll be down on the ground, not in space, and atmospheric refraction will shift the apparent positions of stars. I can calculate those offsets, and to get the most precise results I'll need to monitor the local air temperature to within 2°F and the atmospheric pressure to within 3 millibars.

Then there's the issue of lens distortion, which all refractors have to some degree. Fortunately, I can compensate for this by taking images near the zenith at night and comparing the resulting star positions with the Gaia catalog. This should yield corrections reliably good down to 0.01 arcsecond — and to a negligible level if I average lots of stars.

Once I have all the images, I'll run them through multiple astrometric programs (such as *Pinpoint, Astrometrica,* and *Prism*) to determine the star locations in pixel coordinates and to identify the individual stars. I hope the outputs from these programs will agree to the 0.01-arcsecond level, but I might have to experiment with their various user-adjustable parameters. Then I'll remove the effects of optical distortion and atmospheric refraction before comparing the corrected star locations with the Gaia star catalog.

Ready, Set, Go!

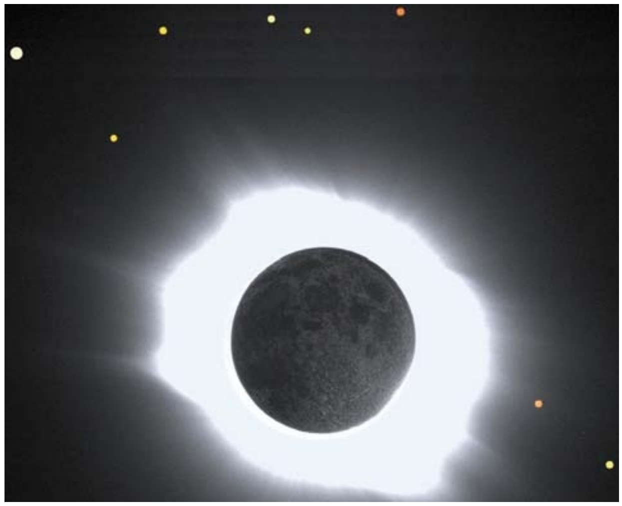
This eclipse won't afford the chance for any do-overs, but I can run a test well before the eclipse date to verify various sources of positional error. The sky during totality is about as bright as when the Sun lies 6° below the horizon. And it turns out that my three planned star fields are roughly at the same elevation during evenings in late March and early April. I'll test my planned exposure sequence during this "dry run," though the results should show a gravitational deflection of zero (since the Sun isn't nearby). This will prove the technique and give me confidence in the real eclipse experiment four months later.

I'll set up my experiment in Wyoming, based on its high altitude and cloud-free forecast (*S&T:* Jan. 2016, p. 22). Even so, I'll follow the day-before weather forecasts closely and move the experiment if needed. I'll also be automating the pointing and exposure sequences so that, after I press "Start," I can enjoy the spectacle!

This challenging experiment repeats the measurements that made Einstein famous. Careful planning and dependable equipment should help avoid disappointment. In many ways, this is a much simpler experiment than any previous ground-based attempt — and the results should be far better. And if things don't go as planned? Well, there's always the next U.S. opportunity to see totality: Texas in 2024! ✦

YOU CAN DO IT TOO!

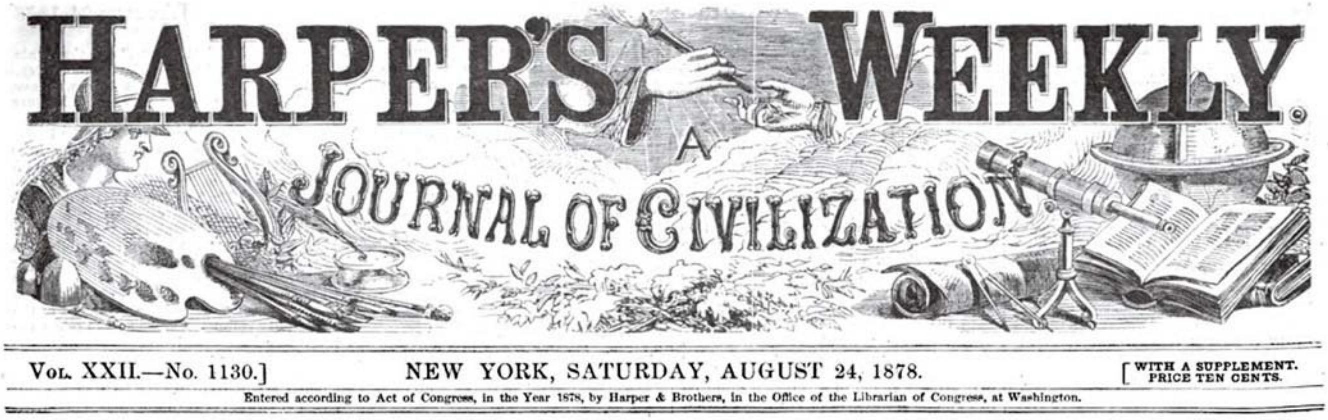
Visit **http://is.gd/DIY_Relativity_Test** for a more detailed explanation of the author's plans. If anyone wants to duplicate or help on this project, contact him directly at dbruns@stellarproducts.com.



CHRISTIAN VILADRICH

SIMULATED STARS **Using a calibrated monochrome eclipse image from 2006, the author simulated the stars he expects to record near the Sun with a 1-second-long exposure during next year's eclipse. Stars near the corners should have a gravitational deflection of 0.4 arcsecond, while the closest one at lower right should be deflected by 0.7 arcsecond.**

A retired optical physicist, ***Don Bruns*** *enjoys reading about exceptional historical experiments — and this is his first attempt at reproducing one.* *He received valuable help from George Kaplan and John Bangert of the USNO, as well as Al Nagler of Tele Vue, Greg Terrance of FLI, Christian Viladrich of France, and Suresh Rajgopal.*



The Great American Eclipse of the 19th Century

In the summer of 1878, astronomers and tourists were newly ready to swarm into the Wild West.

William Sheehan

The total eclipse of the Sun that's coming on August 21, 2017, is already being called the Great American Eclipse. Its path of totality will sweep across the continent from Oregon to South Carolina, while all of North, Central, and upper South America will experience a partial eclipse. Millions will gaze in wonder at perhaps the most stunning predictable celestial phenomenon, while taking in some of the most majestic scenery of the continent: the best clear-sky odds are for the West.

The 19th century also boasted a Great American Eclipse — on July 29, 1878. Not only was it the last total eclipse visible over much of the North American continent in the 19th century, it was the first to be widely observed by astronomers in the western United States. And it came at an opportune moment both in astronomy and in the history of the American West.

There was no question that it would be a spectacle. The maximum duration of totality was 3 minutes 11 seconds. The Moon's shadow, some 116 miles wide, first touched land in northeastern Asia, then crossed to Alaska, Canada near the Pacific coast, and southeast across the vast western United States and its territories. Darkness swept over Yellowstone and the Wind River Range, down through Medicine Bow and into Colorado, crossing Long's Peak, then Boulder, Denver, Colorado Springs, and Oklahoma Indian Country before entering the Gulf of Mexico between Galveston and New Orleans.

Just 30 years before, the Boston aristocrat Francis Parkman, Jr., had set out westward in search of Indians and adventure; his books helped to paint the image of the West as it took shape in the American mind. He arrived at Westport, Missouri, says historian Bernard de Voto, "on the very edge of the frontier . . . that saw all the energies of Manifest Destiny at last in vigorous motion — energies which, before the year was out, would capture Oregon and California and the Mexican Southwest and make the final destruction of the Plains Indians inevitable." Those energies pushed westward the Oregon Trail, the Bozeman Trail, and the Bridger Trail, the latter providing an alternate route to the Montana gold fields skirting the region controlled by the Sioux, Cheyenne, and Arapaho. Then followed the transcontinental railroad, which, said poet Walt Whitman, "joined distances like magic."

By 1878 numerous towns and settlements, in various stages of incipient civilization, dotted the territory from which to view the eclipse. For the first time the region — including the grandeurs of Yellowstone (recently painted in epic canvases by Albert Bierstadt and Thomas Moran, and designated in 1872 as the world's first National Park) — stood wide open to astronomers.

ROCKY MOUNTAIN SPECTACLE The solar eclipse of July 29, 1878, was sketched by St. George Stanley at Snake River Pass, Colorado. "The scene was now one of surprising beauty," he wrote, "for Pikes Peak, far away to the south, still remained in sunlight, looming in rosy outline, while the horizon that a moment before was ochre, now glowed with red, gold, pink, and lilac." The corona "gleamed. . . with a pale nebulous light, and the heavens above acquired a shade of blue that mortal can not describe."

THE GREAT SOLAR ECLIPSE.—Sketched at Snake River Pass, Colorado, by St. George Stanley.—[See Page 675.]

EDISON & FRIENDS Thomas Edison (second from right) made the trip to Rawlins, Wyoming, with one of his lesser-known inventions: a "tasimeter," with which he hoped to measure infrared radiation from the solar corona and find its contribution to the Sun's heat. Others here include (in order to the left of Edison) the party's leader, astronomer Henry Draper of New York; Mrs. Draper; Mrs. Watson; and James Craig Watson, whose observations of possible intra-Mercurial planets was the most controversial report from the eclipse.

CARBON COUNTY MUSEUM, RAWLINS, WY

And they were eager to go. Both American and European (mostly English) astronomers relished the prospect of mixing scientific endeavor with adventure and sightseeing. Thanks to an $8,000 appropriation from Congress, the U.S. Naval Observatory determined to establish no less than eight observing stations between Montana Territory and Texas. Edward Singleton Holden, then at the U.S. Naval Observatory, hoped to set up the northernmost outpost at Virginia City, where gold had been discovered in 1863. He invited C. H. F. Peters of New York's Hamilton College Observatory to come along. The latter politely declined. "You go to Montana," he wrote, adding, "Take care of not being scalped by the Indians!"

The concern was real enough. The year before, the U.S. Army had fought the Nez Perce in that general region, while only two years earlier the Sioux and allied tribes led by Crazy Horse and Sitting Bull had annihilated Custer and elements of the U.S. 7th Cavalry at Little Big Horn. To the south, conflict was brewing with the Utes of northern Colorado. In the end, Holden decided that discretion was the better part of valor and set up farther south, on the flat roof of the Teller Hotel at Central City, Colorado.

The northernmost eclipse station now became lonely Creston, Wyoming Territory, on the Union Pacific railroad. The rail line fortuitously followed the narrow eclipse path in the south-central part of the Territory and offered several choices for observers. Simon Newcomb, Superintendent of the Nautical Almanac Office, proposed to go to Creston itself. So did William Harkness and A. N. Skinner of the U.S. Naval Observatory, Alvan Graham Clark of the famed family of instrument-makers, and the French astronomer-artist Leopold Trouvelot. On his arrival, Harkness described finding "a little bit of a hamlet, situated almost on the backbone of the continent, being only 2 ½ miles east of the divide which separates the watershed of the Atlantic from that of the Pacific. The country in the vicinity is flat and uninteresting. . . [though] the horizon is bounded by the distant peaks of the Rocky Mountains. . . . The place contains only two small cottages, and its population consists of seven white adults, three children, and six Chinese laborers who keep the track in order."

This kind of rude accommodation was typical of what the astronomers would find. But though their shelter and grub might be spartan, the huge skies of Wyoming and Colorado were breathtaking, while the clear mountain air was so limpid that the satellites of Jupiter were claimed to be easily visible with the naked eye.

Pioneering astrophysicist Dr. Henry Draper and his wife, the New York City heiress Anna Palmer Draper, headed to Rawlins, Wyoming, another railroad town, boasting a population of 800 and a good hotel. They traveled with Thomas Alva Edison of Menlo Park, New Jersey, who at 31 was already celebrated for his invention of the phonograph. He brought along one of his inventions:

a pocket-sized device he called a tasimeter to measure infrared radiation, by which he hoped to determine the heat output of the solar corona while the body of the Sun hid behind the Moon.

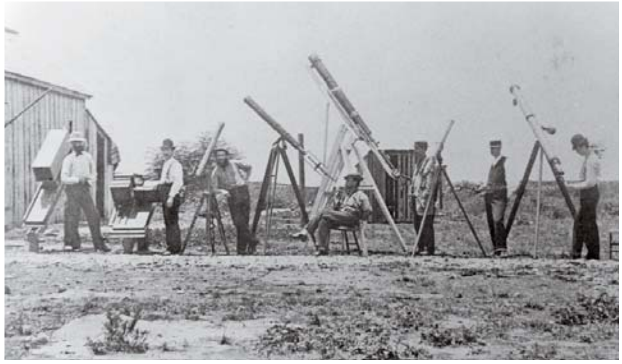
To Rawlins also went University of Michigan astronomer James Craig Watson and his wife Annette. Watson, renowned for his many asteroid discoveries, was in the hunt for the elusive (in fact nonexistent) planet Vulcan. A total eclipse would provide an excellent chance to discover this small planet supposedly circling close to the Sun. Astronomers worldwide had been trying to find it, after the French astronomer Urbain J. J. Le Verrier predicted its existence from a tiny unexplained increment (some 43 arcseconds per century) in the rate of precession of Mercury's perihelion. Mistaken sightings had seemed to confirm the new planet. Only in 1915 was Mercury's drift revealed to be not a perturbation by an unseen planet, but a result of gravity's behavior under Einstein's general theory of relativity (*S&T:* Dec. 2015, p. 18).

Other prominent astronomers flooding to the eclipse path were Allegheny Observatory director and solar astronomer Samuel Pierpont Langley, who climbed the 14,000-foot Pikes Peak to obtain the best possible views of the corona. Princeton solar astronomer Charles Young and visiting English barrister and amateur astronomer Arthur C. Ranyard went to Cherry Creek, near Denver. The U.S. Naval Observatory's George W. Hill and New York amateur Lewis Swift set up in Denver itself. So did Nantucket astronomer Maria Mitchell and five of her female students. Asaph Hall, renowned for his discovery of the two satellites of Mars a year earlier, went to La Junta in southeastern Colorado. David Peck Todd headed for Dallas, Texas, among the southernmost sites. Many members of the public, newspaper reporters, and amateur astronomers came as well. A few were serious observers. Most, like today, were tourists or accidental onlookers.

On the day of the eclipse, the skies over most locations were wonderfully clear. The various observational programs unfolded as planned, though with mixed results.

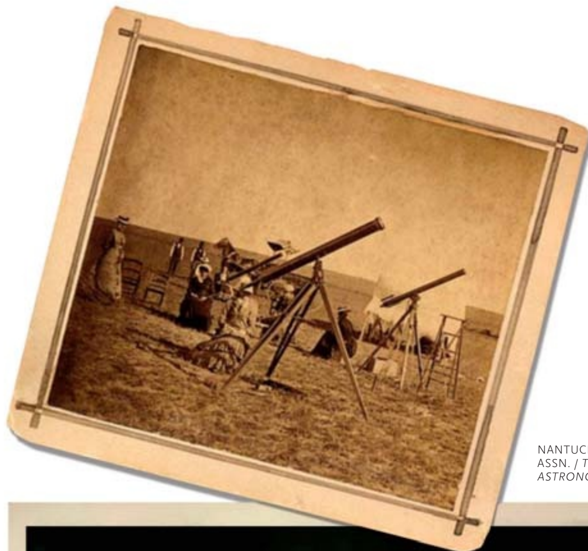
At Rawlins, Henry Draper succeeded in photographing the spectrum of the corona. Poor Mrs. Draper was assigned to a subservient role for the men; she was nominated timekeeper, and dutifully counted the seconds of totality from inside a tent, "blind to the spectacle, lest the sight of it unnerve her and cause her to lose count!"

At Rawlins strong westerly winds were nearly continuous, leading Watson to move his instruments to an isolated Union Pacific rail stop at Separation, about midway between Rawlins and Creston. He was joined there by another late arrival, Simon Newcomb. Sheltering their equipment in the lee of a semicircular sand dune, they prepared to wait out the partial phases of the eclipse in eager anticipation of the scant minutes of totality, when they would scour the solar vicinity for Vulcan. During the excitement of the eclipse, Watson spotted



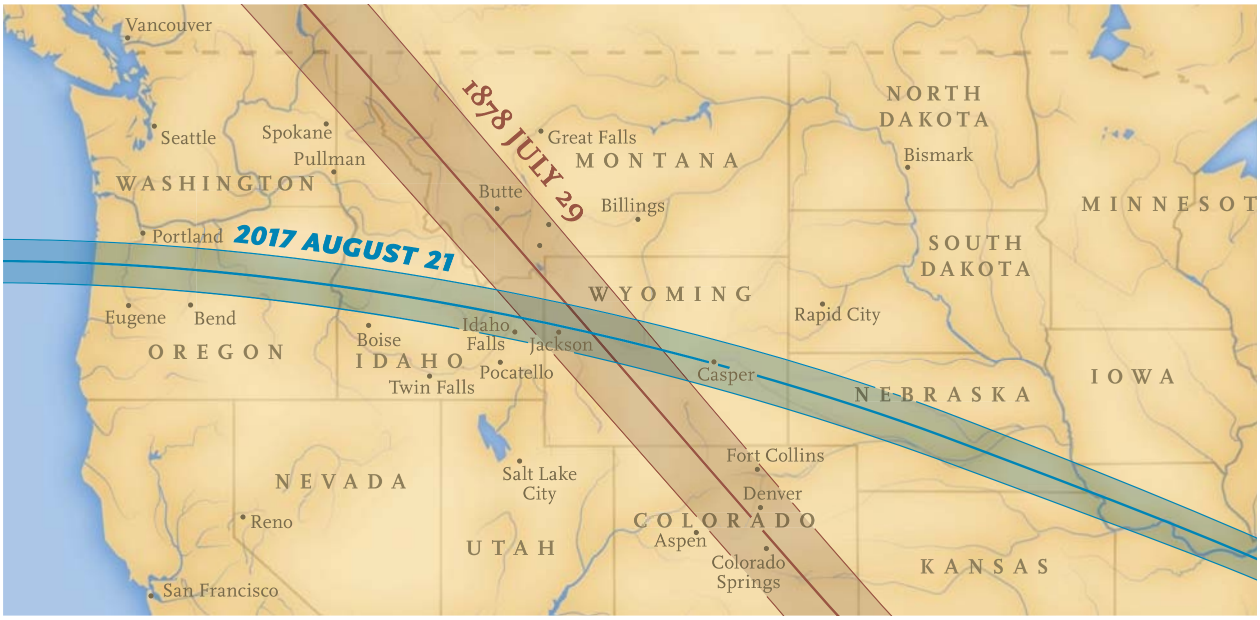
PORTAL TO TEXAS HISTORY, UNIV. OF TEXAS LIBRARIES

NEAR THE ECLIPSE TRACK'S END At the S. W. Lomax farm near Fort Worth, Texas, astronomers stand by their telescopes awaiting the eclipse and a possible glimpse of Vulcan.



NANTUCKET MARIA MITCHELL ASSN. / *THE TROUVELOT ASTRONOMICAL DRAWINGS*

SOUVENIRS ***Middle:*** **Faring better than Mrs. Henry Draper, who was consigned to a tent in Rawlins, Wyoming, the famed Nantucket astronomer Maria Mitchell and five of her female students awaited the eclipse at Denver.** ***Below:*** **This magnificent — if not entirely accurate — chromolithograph of the eclipse was made by the French artist-astronomer Etienne Leopold Trouvelot, recording his impressions from Creston, Wyoming.**



HISTORY REPEATS During the August 2017 solar eclipse, the path of totality will cross that of the 1878 eclipse for parts of Wyoming and southeastern Idaho, including Jackson and portions of the Shoshone National Forest.

two unidentified stars, whose positions he marked on the makeshift paper setting circles with which he had equipped his telescope. He maintained — and would continue to maintain until the end of his life — that they were intra-Mercurial planets. Most astronomers would later accept the verdict of C. H. F. Peters, who argued that Watson had merely misidentified two field stars.

Langley obtained lovely views, and made detailed sketches, of the coronal streamers from the top of Pikes Peak. Lewis Swift reported two suspicious objects which at first were thought to confirm Watson's "vulcans." Only later did they prove not to agree in position, and eventually they too were widely discredited. Todd, also on the lookout for Vulcan, was frustrated by haze.

Meanwhile, ordinary observers submitted their reports — such as St. George Stanley, a correspondent for *Harper's Weekly,* who "with a party of ladies and gentlemen," set up near Georgetown, Colorado, at the Argentine or Snake River Pass upon the Sierra Madre, elevation 13,156 feet. "This point of observation was chosen for. . . its altitude, and the extended view obtained from its summit, embracing a wonderful panorama of the great ranges of the Saguache, Escalente, and Sangre de Christo west and south, the continuous line of the Sierra Madre north and northwesterly, and a broad sweep of stretching plains to the east."

From this vantage point, Stanley and his associates watched the shadow of the Moon approach from the northwest, covering in succession Long's Peak and the Mount of the Holy Cross. Suddenly they too were enveloped. "The scene was now one of surprising beauty, for Pikes Peak, far away to the south, still remained in sunlight, looming in rosy outline, while the horizon that a moment before was ochre, now glowed with red, gold, pink, and lilac." Stars and planets came out, while the corona "gleamed. . . with a pale nebulous light, and the heavens above acquired a shade of blue that mortal can not describe." After totality ended, the great peaks that had been darkened began to reappear from the gloom, and "looked like ghosts." The only disappointment was that "Vulcan. . . managed to hide himself from our scrutiny." *Harper's Weekly* worked from Stanley's sketch to publish an engraving of this scene that filled its front page. It was much reprinted in astronomy books for decades after.

These were accounts of the city slickers from back East. Fewer reports exist about the way the Native Americans perceived the event. Mabel Loomis Todd, in her *Total Eclipses of the Sun* (1894), recounts that a resident of Fort Sill, Oklahoma Indian Territory, claimed the Indians were badly frightened; "some threw themselves upon their knees, others flung themselves flat on the ground, faces down, others cried and yelled in terror." One old man, more resourceful, stepped from the door of his lodge with pistol in hand, carefully directed his aim, and fired at the blotted luminary. "It was unanimously voted," she says, "that the timely discharge of that pistol was the only thing that drove away the shadow and saved them from the public inconvenience that would have certainly resulted from the entire extinction of the Sun."

So passed the Great American Eclipse of July 1878. ✦

Contributing editor ***William Sheehan****, co-author of* Celestial Shadows*, divides his time between psychiatry and astronomy in Flagstaff, Arizona. He will observe the next Great American Eclipse from near Jackson Hole, Wyoming.*

In This Section

Rimae Archimedes and Palus Putredinis stretch southeast of Archimedes Crater (left) to the Montes Apenninus (lower right). **PHOTOGRAPH: CHAD QUANDT**

Sky at a Glance

AUGUST 2016

3 **DUSK**: Use binoculars to pick up Jupiter low in the west about 20 minutes after sunset. Look 16° to its lower right for Mercury and another 8° lower right of Mercury for Venus.

4 **DUSK**: The thin crescent Moon pairs with Mercury about 15° below and right of Jupiter's gleam after sunset; use binoculars to tease them out. Edge 9° lower and farther right to find Venus.

5 **DUSK**: Vivid Jupiter shines less than 2° above the waxing crescent Moon.

7 **DUSK**: The Moon hangs between Spica and dimmer Gamma (γ) Virginis in the west-southwest.

11 **DAWN**: On this or the next few mornings watch the east-southeast horizon about 20 minutes before sunrise for the heliacal rising (first visibility) of Sirius as it emerges from the Sun's glare.

11–12 **LATE NIGHT TO DAWN**: The Perseid meteor shower peaks on the morning of August 12th. Viewing should be best in the early morning hours; see page 48.

23, 24 **EVENING**: Mars forms a vertical line about 6° long with Antares below and Saturn above, about halfway up the southwestern sky.

25 **MORNING TO AFTERNOON**: The Moon occults Aldebaran mid-morning or early afternoon for much of the United States and Central America; see page 51.

27 **DUSK**: Venus and Jupiter appear extremely close together very low in the west; see page 46.

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

◀SUNSET — MIDNIGHT — SUNRISE▶

Mercury	W — Visible through August 14
Venus	W
Mars	S — SW
Jupiter	W
Saturn	S — SW

Moon Phases

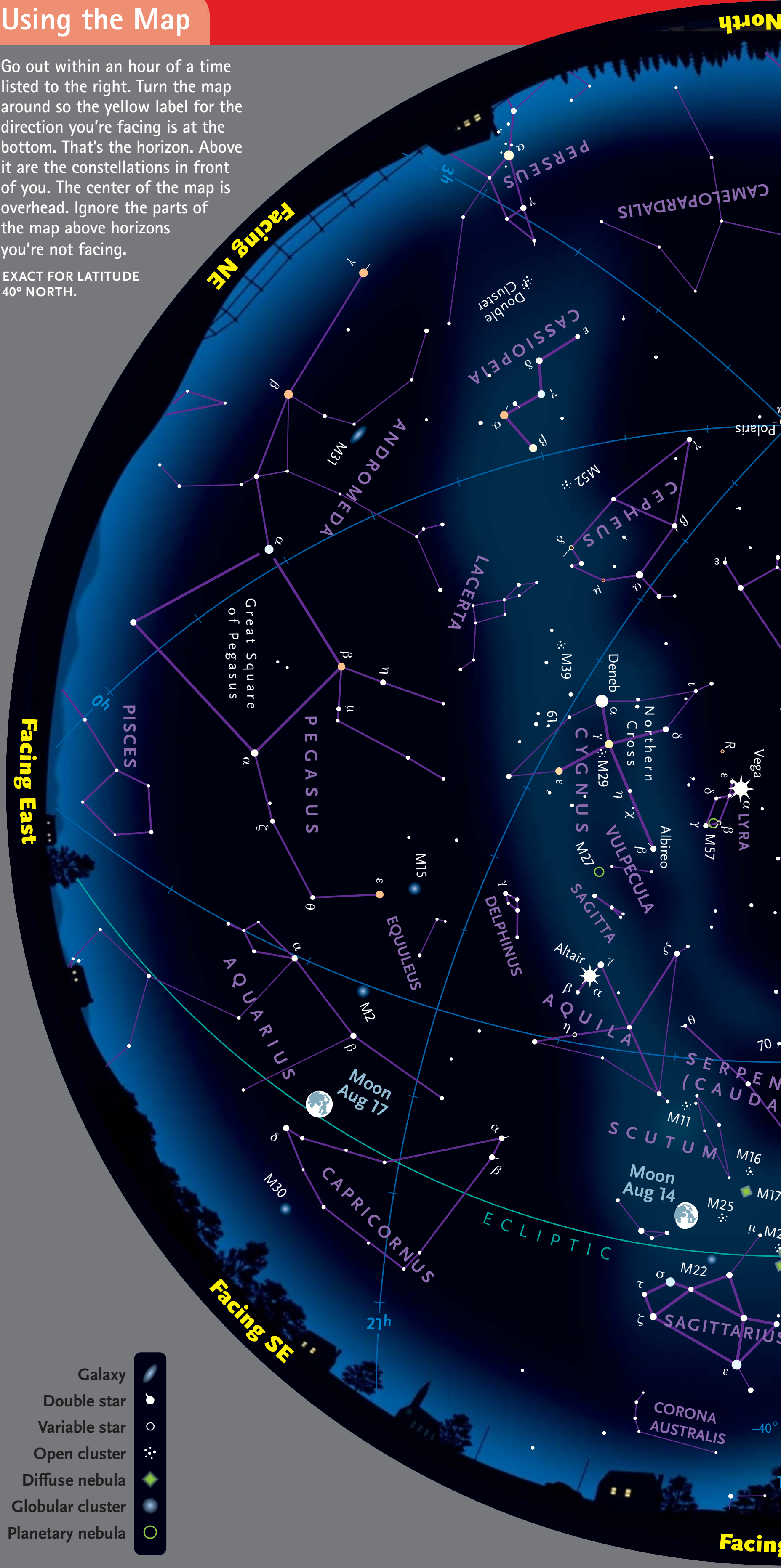
New August 2 4:44 p.m. EDT	First Qtr August 10 2:21 p.m. EDT
Full August 18 5:26 p.m. EDT	Last Qtr August 24 11:41 p.m. EDT

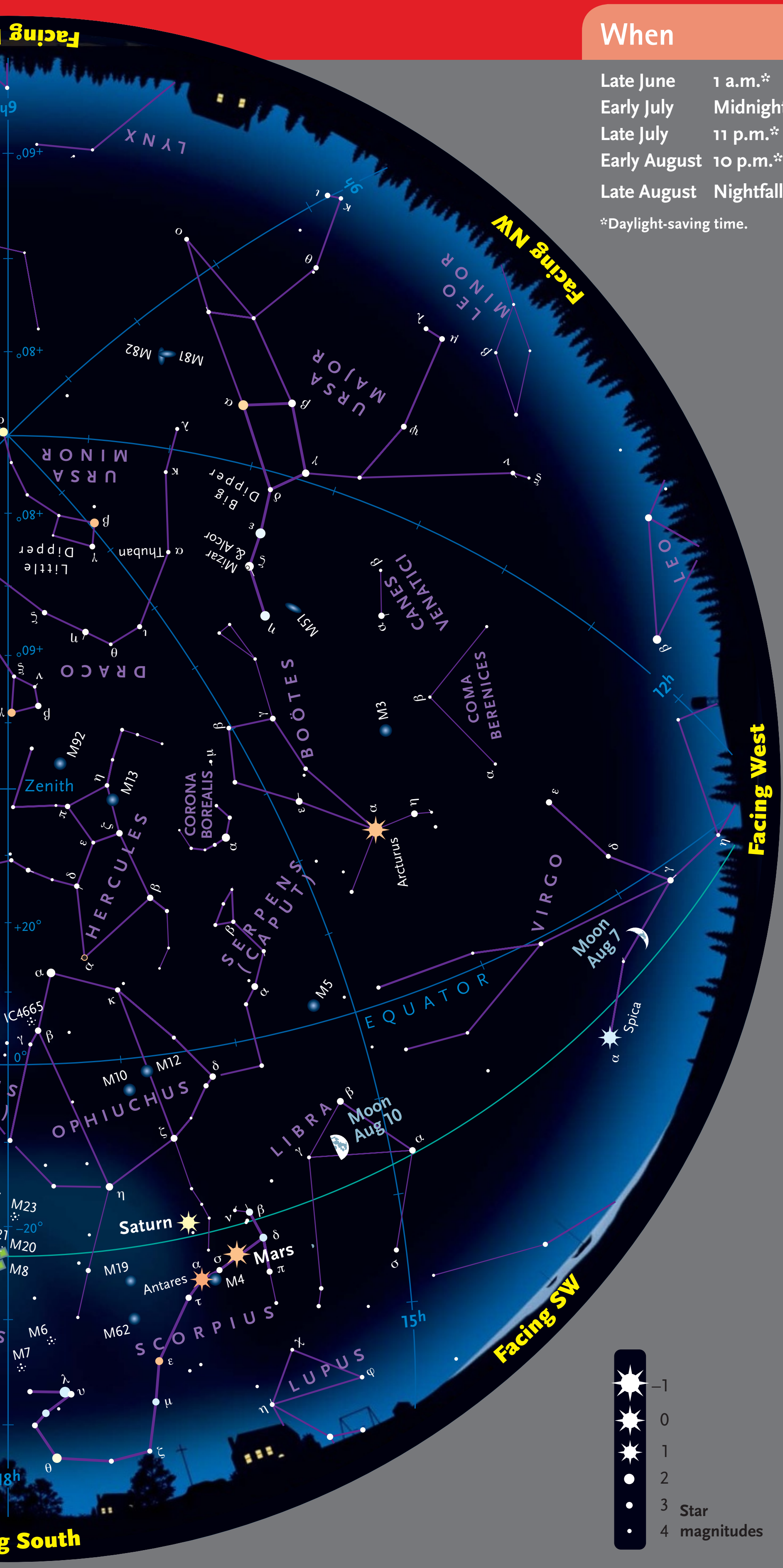
SUN	MON	TUE	WED	THU	FRI	SAT
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

Using the Map

Go out within an hour of a time listed to the right. Turn the map around so the yellow label for the direction you're facing is at the bottom. That's the horizon. Above it are the constellations in front of you. The center of the map is overhead. Ignore the parts of the map above horizons you're not facing.

EXACT FOR LATITUDE 40° NORTH.





When

Late June	1 a.m.*
Early July	Midnight*
Late July	11 p.m.*
Early August	10 p.m.*
Late August	Nightfall

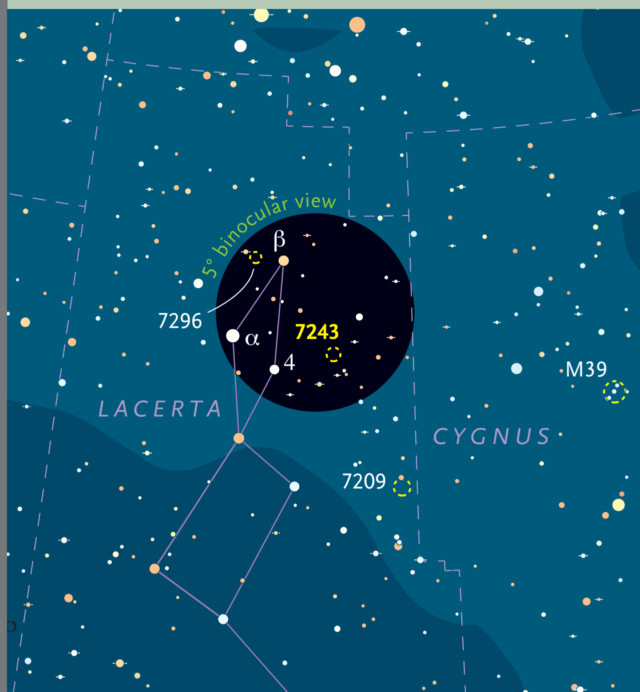
*Daylight-saving time.

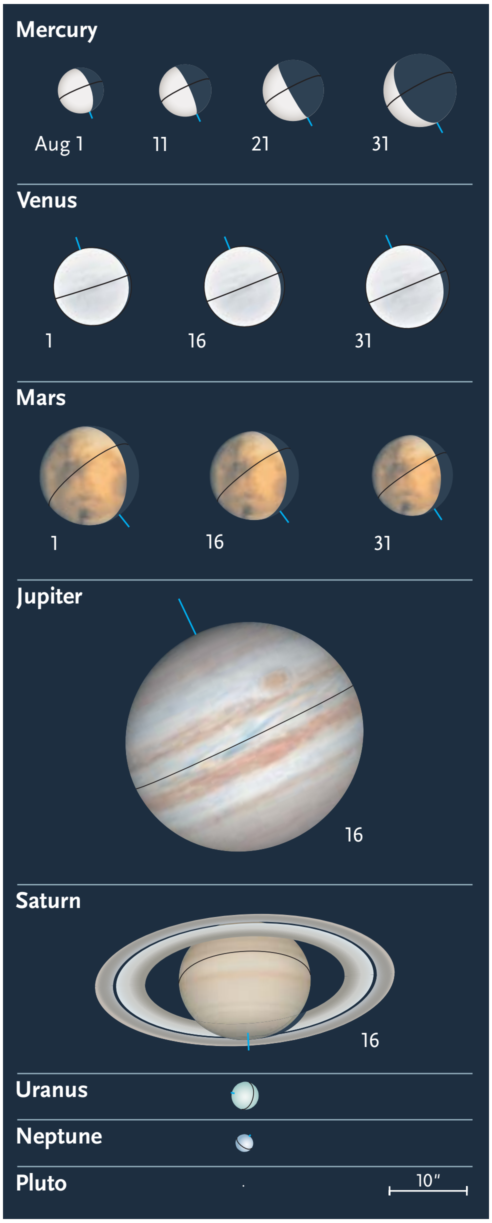
Lasso the Lizard

I am a connoisseur of a particular class of open clusters: those set in star fields so rich that the clusters seem to merge into the Milky Way. A favorite of mine in this genre is **NGC 7243** in the constellation Lacerta, the Lizard.

The cluster is a fairly easy catch about 1.5° west of 4 Lacertae. It's elongated from east to west and at 10× looks like a narrow, westward-pointing arrowhead. At 15× a dense swarm of unresolved stars gives the eastern half of NGC 7243 a nebulous glow, whereas the brighter stars in the western portion look more like a classic open cluster. To my eyes it appears as a miniature version of M8, the Lagoon Nebula in Sagittarius, only with the "nebula" and "cluster" portions reversed from east to west.

The cluster's neighborhood also makes for compelling viewing. NGC 7243 sits in a rich band of stars that trends from northeast to southwest, with the cluster's arrowhead shape cutting across the band almost at right angles. Although this stream of distant suns is richest in the cluster's immediate neighborhood — like foothills building to a mountain peak — it can be traced out for almost 10°. And it's book-ended by two additional open clusters, NGC 7209 on the southwest end and NGC 7296 at the northeast. If we imagine Beta (β) Lacertae as the head of the constellation's stick-figure, the swath of stars between NGC 7209 and NGC 7296 forms a leash running to the lizard's neck. Grab your binos and go for a walk! ✦



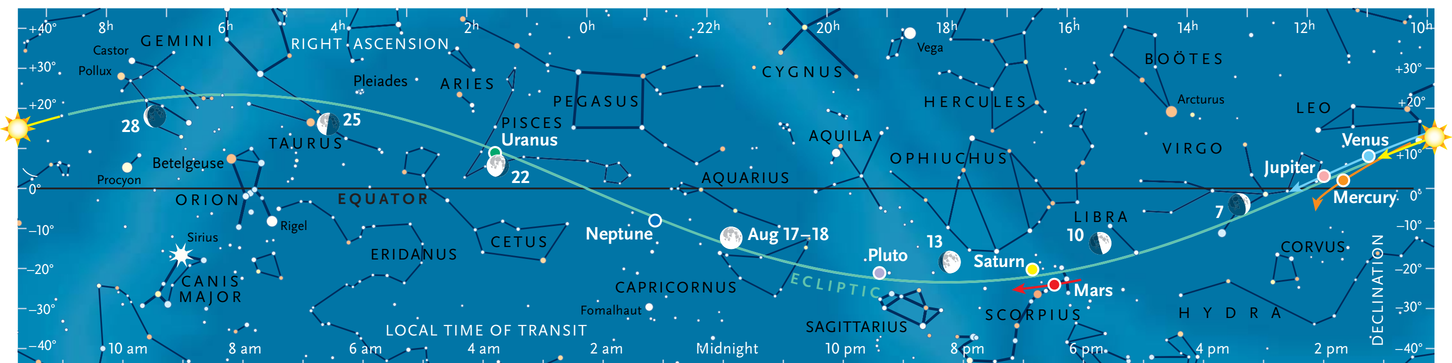


Sun and Planets, August 2016

	August	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$8^h\ 45.5^m$	+18° 01′	—	–26.8	31′ 31″	—	1.015
	31	$10^h\ 37.9^m$	+8° 39′	—	–26.8	31′ 41″	—	1.009
Mercury	1	$10^h\ 15.6^m$	+11° 27′	23° Ev	–0.2	5.9″	72%	1.130
	11	$11^h\ 04.2^m$	+4° 59′	27° Ev	+0.1	6.8″	59%	0.992
	21	$11^h\ 37.6^m$	–0° 28′	27° Ev	+0.4	7.9″	44%	0.847
	31	$11^h\ 49.2^m$	–3° 18′	21° Ev	+1.1	9.5″	24%	0.710
Venus	1	$9^h\ 47.5^m$	+14° 54′	15° Ev	–3.8	10.1″	96%	1.648
	11	$10^h\ 34.6^m$	+10° 32′	18° Ev	–3.8	10.3″	95%	1.614
	21	$11^h\ 20.3^m$	+5° 43′	21° Ev	–3.8	10.6″	94%	1.575
	31	$12^h\ 05.0^m$	+0° 38′	23° Ev	–3.8	10.9″	92%	1.533
Mars	1	$15^h\ 44.9^m$	–22° 46′	110° Ev	–0.8	13.0″	87%	0.722
	16	$16^h\ 11.8^m$	–24° 00′	102° Ev	–0.5	11.6″	86%	0.804
	31	$16^h\ 45.4^m$	–25° 05′	95° Ev	–0.3	10.5″	85%	0.889
Jupiter	1	$11^h\ 31.8^m$	+4° 17′	43° Ev	–1.7	32.1″	100%	6.146
	31	$11^h\ 53.6^m$	+1° 54′	20° Ev	–1.7	30.9″	100%	6.387
Saturn	1	$16^h\ 33.1^m$	–20° 16′	121° Ev	+0.3	17.5″	100%	9.479
	31	$16^h\ 33.6^m$	–20° 23′	92° Ev	+0.5	16.7″	100%	9.952
Uranus	16	$1^h\ 30.4^m$	+8° 47′	119° Mo	+5.8	3.6″	100%	19.441
Neptune	16	$22^h\ 50.7^m$	–8° 18′	162° Mo	+7.8	2.4″	100%	28.988
Pluto	16	$19^h\ 04.9^m$	–21° 18′	142° Ev	+14.2	0.1″	100%	32.355

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

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



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

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

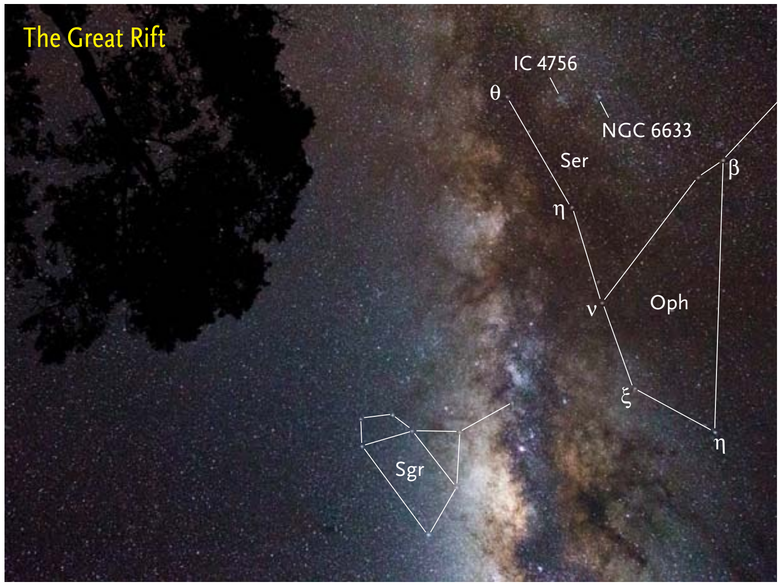
Fred Schaaf

Summertide Sailing

Search for treasure as you navigate the Milky Way river.

"And now the sun had set, and all the colours of the world and heaven had held a festival with him, and slipped one by one away before the imminent approach of night . . . the fireflies in the deeps of the forest were going up and down, and the great stars came gleaming out to look on the face of Yann.

. . . And so Yann bore us magnificently onwards, for he was elate with molten snow that the Poltiades had brought him from the Hills of Hap, and the Marn and Migris were swollen full with floods; and he bore us in his might past Kyph and Pir, and we saw the lights of Goolunza." — Lord Dunsany, "Idle Days on the Yann," 1912



Last month in this column, we began a long voyage south from Cygnus on the Heavenly River, the Milky Way. We can continue it in a luxuriously idle cruise, as if we were on a fantasy river like the Yann, described in a story written by one-time chess and pistol-shooting champion of Ireland, Edward John Moreton Drax Plunkett — Lord Dunsany.

Milky Way of the Rift and the two channels. Beginning in Cygnus, the vast tongue of dark interstellar dust clouds called the Great Rift splits the bright Milky Way lengthwise into two bright channels.

One sight of interest that shines right in the Great Rift — or rather in its foreground — is the Coathanger. A low-magnification telescopic view shows that this tiny asterism (not a true cluster, though it is often called Brocchi's Cluster) looks astonishingly like a coathanger made of stars. The Coathanger lies near Sagitta, the Arrow, about one-third of the way along the line from Altair to Vega in the small constellation Vulpecula, the Fox. Can you detect it with your unaided eye? In dark skies you should at least see it as a 1°, 3.6-magnitude patch or blip of brightness against the Rift's dark background. The main pattern of Sagitta — small though much bigger than the Coathanger — lies in the glow bordering the Rift.

What shines in or in front of the dimmer channel of Milky Way, the one that peters out in northern Ophiuchus? The intriguing area of Beta (β) Ophiuchi (Celbalrai) and the big naked-eye cluster IC 4665; the V-shaped Taurus Poniatovii asterism (a defunct constellation); and Barnard's Star.

But I like to point out the pair of lesser-known yet fascinating objects just "upstream" from this area. They're large naked-eye clusters — one of them huge — just 3° apart. The larger of the two, 52′-wide IC 4756, rests 4.5° west-northwest of the beautiful low-power double star Theta (θ) Serpentis (Alya), the most northerly star in the line of Serpens Cauda (the Serpent's Tail, which projects perfectly into the Great Rift). The smaller cluster, some 3° northwest of IC 4756, is NGC 6633. Though smaller than its neighbor, it's still quite big (27′ wide) and bright, shining at magnitude 4.2 — though like IC 4756, it's rather loosely structured. Use very low magnification on both when you turn your scope or binoculars on them.

We credit astronomy writer and editor Terence Dickinson with coining the name "the S-O Double Cluster" (Serpens-Ophiuchus Double Cluster) for this cluster pair (IC 4756 is in Serpens, NGC 6633 just over the border in Ophiuchus). The S-O Double Cluster is profoundly different than the famed Double Cluster in Perseus — but intriguing nonetheless, especially for naked-eye sailors of the Milky Way.

Yann or Anduin? The poet W. B. Yeats is said to have admired Dunsany's "Idle Days on the Yann." But which fantasy river is the Milky Way most like? Maybe the great north-south river of J. R. R. Tolkien's Middle-earth, the Anduin. But I'll make that comparison next month, when we finish our Milky Way trip with the richness of Scutum, southern Serpens, Sagittarius, and Scorpius. ✦

August's Double Convergences

Observe a series of planetary get-togethers this month.

Welcome to a short but wonderful burst of planetary conjunctions. Some occur very low in evening twilight — including an ultra-close meeting of planets Venus and Jupiter. But in addition to the groupings of Venus, Jupiter, and Mercury (and Regulus) very low in the west at dusk, we'll also see Mars make a weeks-long march in the south, moving from the head of Scorpius to pass right between Saturn and the Scorpion's heart, Mars-colored Antares.

DUSK

On August 1st, **Jupiter**, **Mercury**, Regulus, and **Venus** — in that order, from upper left to lower right — form a line nearly 27° long in the west after sunset. But look early in twilight and bring binoculars, because Venus is only about 4° high even just 20 minutes after the Sun goes down, as seen from latitude 40° north. Magnitude –0.1 Mercury gleams about 8° upper left of magnitude –3.9 Venus, which sets a bit more than 45 minutes after the Sun. Mercury sets approximately 15 minutes later, and Jupiter follows in another 45 minutes.

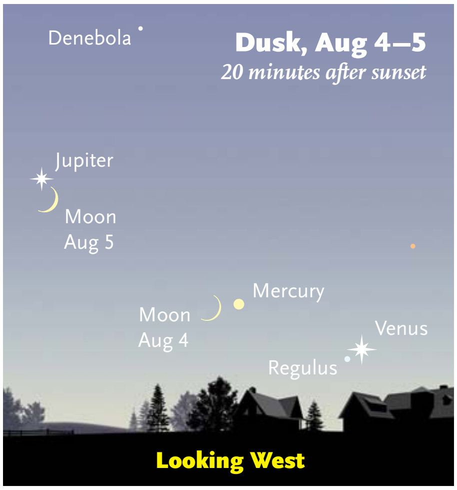
Unfortunately for viewers at mid-northern latitudes, Mercury doesn't appear any higher in the next few weeks, even as it reaches greatest elongation on August 16th. Venus, passing little more than 1° from Regulus on August 4th and 5th (use optical aid to view the pairing), edges just a bit higher as the weeks pass. Jupiter, however, moves noticeably lower in twilight each week, on its way to a grouping of Venus, Mercury, and Jupiter later in the month.

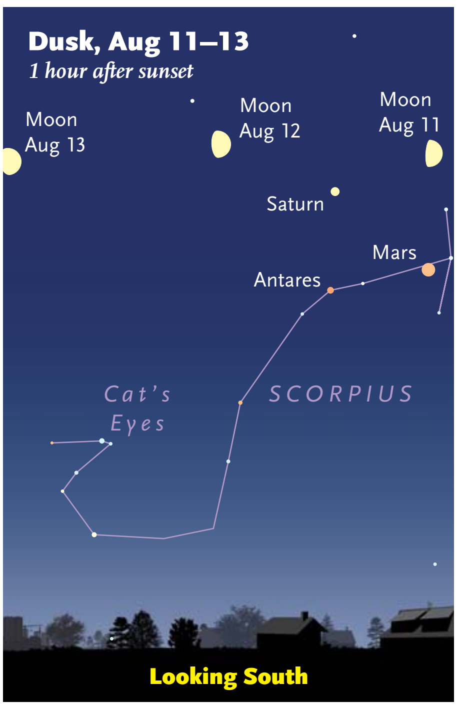
The spectacle of three planets passing each other in the second half of the month will present an observing challenge for viewers at mid-northern latitudes.

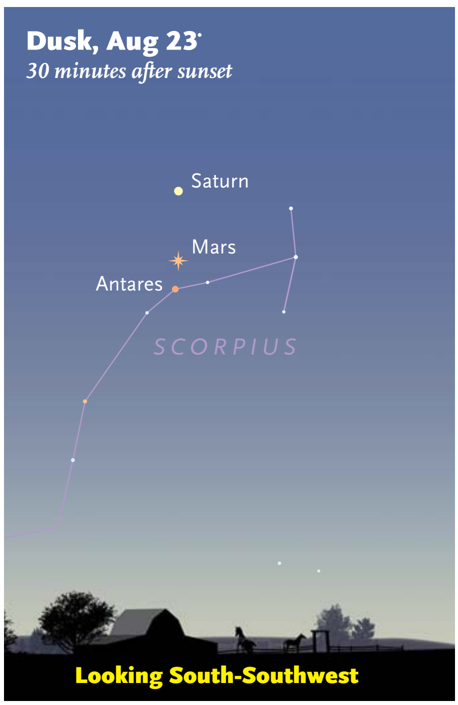
On August 19th Mercury, at a maximum altitude of 6° and dimmed to magnitude +0.3, shines its closest to Jupiter, which is about 4° above it. Venus is 8° right of Mercury, closer to the Sun. On August 28th Mercury, seriously faded to magnitude +0.8, comes its closest to Venus, hovering about 5° below and left of the brighter planet.

But the best conjunction for mid-northern viewers occurs on August 27th, when Venus and Jupiter draw as close as 0.1°, depending on your viewing location. From southern South America you can see this meeting in a dark sky, where the planets' lights will blend together when viewed with the naked eye. Use binoculars to pick up the duo as the Sun sets (but *do not* look at the Sun!). Telescopes will show the disks of the two planets together even in a fairly high-magnification field of view. Jupiter's dim disk measures about 31″ wide, the 92%-lit disk of Venus 11″ wide.

On this same big evening, the trio of Venus, Jupiter, and Mercury fit within their smallest circle of sky, just over 5° in diameter. Venus and Jupiter remain 2° apart or less from August 25th to 29th.



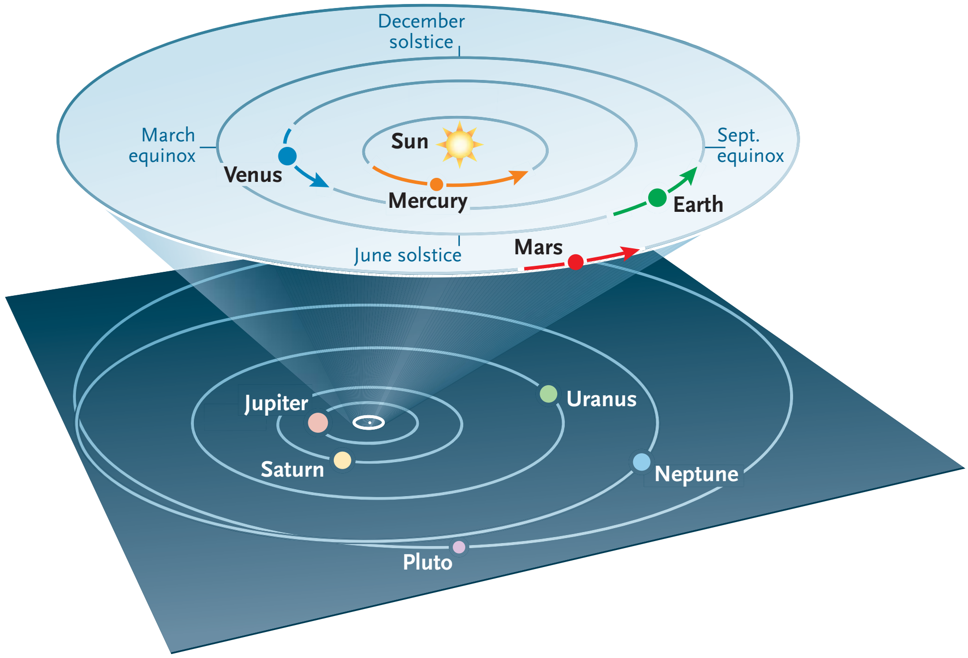




Fred Schaaf

ORBITS OF THE PLANETS

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



EVENING

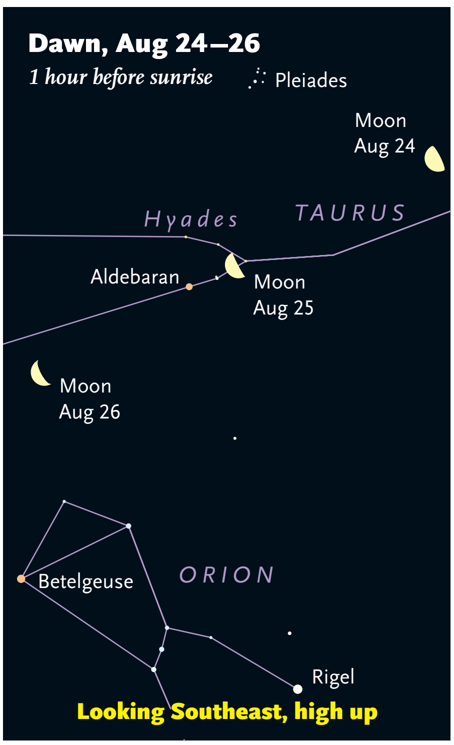
Mars and **Saturn**, together with Antares, put on a rare and beautiful show in August — and it's easy to see.

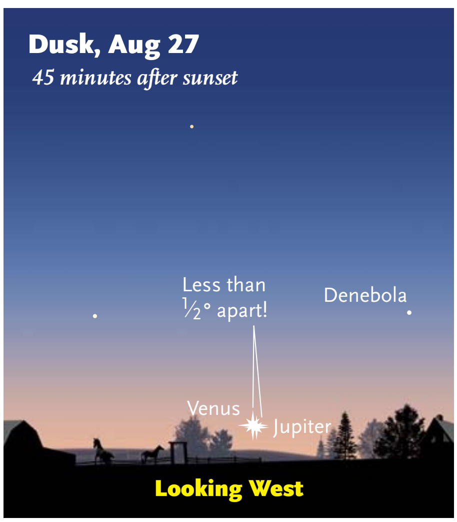
Mars spends the month dimming from magnitude –0.8 to –0.3 and shrinking from 13″ to 10½″ wide. But that's still big and bright enough to display well the campfire color of Mars to the naked eye and potentially some surface features in the telescope.

Saturn, though dimming from magnitude +0.3 to +0.5 over the course of August and getting a bit smaller, still shows its rings far open in telescopes. Both Mars and Saturn transit roughly around sunset, so get your scope on them right at dusk before they sink lower.

The real drama, however, comes from Mars's march into and through upper Scorpius. As August starts, Mars crosses from Libra to Scorpius and then, around August 9th, passes very close to the south of the bright and unpredictable variable star Delta (δ) Scorpii. The most amazing views come on the American evenings of August 23rd and 24th, when Mars travels between Saturn and Antares. On both evenings Mars appears less than 2° north of Antares and a bit more than 4° south of Saturn. Although Antares, at an average magnitude of +1.0, shines 1.4 magnitudes dimmer than Mars (less than a third as bright), their colors are comparable.

Mars zooms east, away from Saturn and Antares, as August ends. By August 31st, both planets set at approximately 11:30 p.m. daylight-saving time.





NIGHT

Pluto spends the month of August in the Sagittarius Teaspoon. The dwarf planet is observable with a large-aperture telescope most of the night but is highest in late evening; see the July issue, page 48, for a finder chart.

Neptune, in Aquarius, reaches opposition on September 2nd, so it's already visible almost all night. It's at its highest soon after midnight. See **skyandtelescope.com/urnep** for finder charts for both Neptune and **Uranus**, which rises a few hours after sunset in Pisces.

MOON PASSAGES

The slender crescent **Moon** poses very low near Venus, Mercury, and Jupiter at dusk on August 4th and a bit higher near Jupiter on the 5th. The gibbous Moon forms a large but dramatic equilateral triangle with Mars and Saturn at nightfall on August 11th. On August 25th, the Moon occults Aldebaran for much of the eastern and southern United States (including Hawai'i) and central America; see page 51. ✦

Perseids to Get a Jupiter Boost?

After the Moon sets, the Perseid meteors could be unusually rich.

The most-observed meteor shower is the annual Perseid display, active for several nights in prime vacation season. This year the Moon will be waxing gibbous on the predicted peak night, August 11–12. But the Moon will set around 1 a.m. for mid-northern observers, leaving the night dark for the three or four prime meteor-watching hours before dawn: this is when your side of the Earth faces most directly into the oncoming meteoroids.

In a normal year, you may see about 60 to 90 Perseids per hour on the peak night between midnight and dawn if you have an excellent dark sky. But the shower can vary a lot from year to year.

And this year's shower will probably be better than usual. There's even a chance that it could be spectacular.

Four hours, compressed. "I created a composite of all the meteors captured on August 13, 2015, from 12:30 to 4:30 a.m.," writes Brad Goldpaint from northern California. "The large mountain in the distance is Mount Shasta, and the glow from the base of the mountain is the city of Mount Shasta." The evening before, he recorded the starry sky and its reflection in the still lake in a 25-second exposure. The landscape is from a long exposure he shot at a very low ISO during deep twilight. He took dozens of sky exposures during the morning hours, subtracted out the 65 meteors that these recorded, and aligned them to their star backgrounds in the original sky image.

Joe Rao, *a seven-time Emmy-nominated broadcast meteorologist at News 12 in Westchester, N.Y., has been an assiduous amateur astronomer for nearly 50 years. He won the Astronomical League's Walter Scott Houston Award in 2009*

Joe Rao

An Enigmatic Enhancement

For the last several years, the Perseids have been quite normal. But in the late 1970s and early 1980s the shower turned unusually active. The 1980 display was one of the best in memory up to then; many observers reported seeing more than 120 per hour and occasionally up to 5 or 6 a minute. A reputable Japanese observer counted nearly 250 in one hour.

The Perseid meteoroids are dusty debris bits shed by the periodic comet 109P/Swift-Tuttle, which was discovered in the summer of 1862. Many experts in the 19th and 20th centuries calculated its orbital period to be 120 ±2 years, and summer 1981 was considered the "most probable" time for the comet to be recovered. Meteoroids tend to be thicker in the vicinity of their parent comet, so astronomers naturally assumed that the strong Perseid activity in 1980 was due to the impending arrival of Swift-Tuttle.

Yet the comet failed to appear during its anticipated 1979–1983 time frame. Perseid activity through the 1980s returned to normal, and many assumed that Comet Swift-Tuttle — which had evolved into a strikingly beautiful object after its 1862 discovery — had somehow slipped by undetected.

The late Brian G. Marsden, longtime director of the Minor Planet Center (MPC) at the Harvard-Smithsonian Center for Astrophysics, put forward an alternative solution: that Comet Swift-Tuttle was perhaps identical with a comet briefly seen in 1737. If so, it might still return. . . around 1992.

Few astronomers believed it. Hadn't the Perseids ramped up around just the right time? The legendary astronomy popularizer Sir Patrick Moore pooh-poohed the idea that Swift-Tuttle would reappear in 1992 and bet a colleague a bottle of whiskey that it wouldn't.

He lost. The comet indeed returned in the fall of 1992, validating Marsden's prediction. And the Perseids in the years around then were even more memorably abundant.

So what caused the high rates in 1980? It was probably a completely unrelated perturbing influence by the most massive planet: Jupiter.

The first to formally propose that Jupiter plays a role in Perseid activity were Esko Lyytinen of Finland and Tom Van Flandern of the U.S. Naval Observatory, in 2004. The comet passes a good 1.7 a.u. above Jupiter's orbit while moving inbound toward the Sun. But because the comet — and the meteoroid stream all along its orbit — have made hundreds of trips around the Sun over tens of thousands of years, slight periodic perturbations can add up.

Every 11.86 years (Jupiter's sidereal period), Jupiter passes under the broad rubble stream. Each time, its gravitational field shifts some of the comet dross about 0.01 a.u. closer to passing Earth's orbit. This segment of dusty debris takes about 16 more months to reach our path, whether Earth happens to be there or not. The long-term result: when Earth reaches the Perseid-intersecting part of its orbit in mid-August, occasionally an extra stream of Perseids will be passing through at the same time.

If this happens about every 12 years in sync with Jupiter's orbital period, we have a nice explanation for not only the strong 1980 display, but also the enhanced showers that were reported in 2004, 1968, 1945, and 1921.

What About 2016?

This would appear to be another of those "prime years." Russian meteor expert Mikhail Maslov, who has closely studied the evolution of the Perseid stream in space, predicts a "significant increase of Perseid background activity, with a zenithal hourly rate (ZHR) of 150–160." By comparison, last year's Perseid shower reached a peak ZHR of about 90, judging from the counts submitted to the International Meteor Organization (IMO) by observers worldwide.

The shower's predicted time of maximum is 12:40 UT August 12th. That's after sunrise for North America, but peak activity usually lasts about 24 hours.

Maslov points out that in addition, fresh debris trails shed by Swift-Tuttle in 1479 and 1862 ("fresh" implies dense and narrow) will likely encounter Earth and might also provide a brief enhancement of activity. Eastern Europe and western Asia are in the best position to watch for this, as it should happen during their early-morning hours when the Perseid radiant is highest.

Moreover, French meteor expert Jérémie Vaubaillon has calculated an older discrete trail of the comet's rubble dating back to 1079. He forecasts Earth passing closest to the middle of this trail at 4:56 UT August 12th, which would favor eastern North America on top of whatever else is happening. This might lead to a sudden outburst of bright meteors, but Vaubaillon cautions, "This 1079 trail [is] quite old, making the forecasting less certain. I certainly would look for it, but just keep in mind the uncertainties."

As always, the rates you actually see are less than the ZHR unless the radiant (in northern Perseus) is overhead and your sky is dark enough for magnitude-6.5 stars to be visible. Light pollution reduces the numbers, though the brightest ones will shine through. The meteors themselves flash into view anywhere in the sky, not necessarily near the radiant.

To do a meaningful meteor count by standard methods, so that your count can be integrated with others made all over the world for many days running, see **imo.net/visual/major**. There too you will find the required forms for submitting a report of your count.

Good luck and clear skies to all!

— Joe Rao

FOLLOW THE SHOWER ONLINE: As meteor observers report their counts to the IMO, you can watch this year's Perseid activity curve develop hour by hour at imo.net.

Resolve a Star's Disk Naked-Eye!

"Stars are points." You learned that as soon as you took up astronomy. They're so far away, with apparent diameters so tiny (not counting the Sun, of course), that they're indistinguishable from how mathematical point sources would look, even in the largest telescopes.

Well, most of the time. Various technologies and techniques can now get around that stricture to some extent. But for amateurs? Never!

Except in one instance: during a grazing lunar occultation of a bright red or orange star — in particular Aldebaran, the 1st-magnitude eye of Taurus.

Aldebaran is not only the brightest star that the Moon can ever occult, it's also one of the largest in apparent diameter: 20 milliarcseconds. If you're positioned to see the Moon's edge barely skim Aldebaran, you may witness it fading and reappearing less than instantaneously. Even with your naked eyes.

On Friday morning July 29th, observers in much of the southern U.S. as well as Mexico and Central America will be treated to a naked-eye reappearance of Aldebaran from behind the dark side of the waning crescent Moon. The crescent will be 23% sunlit. Observers near the *graze line* on the map at right have a chance to see a gradual occultation. For observers farther north, the Moon and Aldebaran will perform a near miss.

You'll need at least a small telescope if you're on the eastern side of the continent, or in southern or central Europe, because there the occultation happens in daylight. The farther west you are, the darker the sky will be. Right along the graze line, the map indicates where the graze happens in daytime, bright dawn, deep dawn, or night.

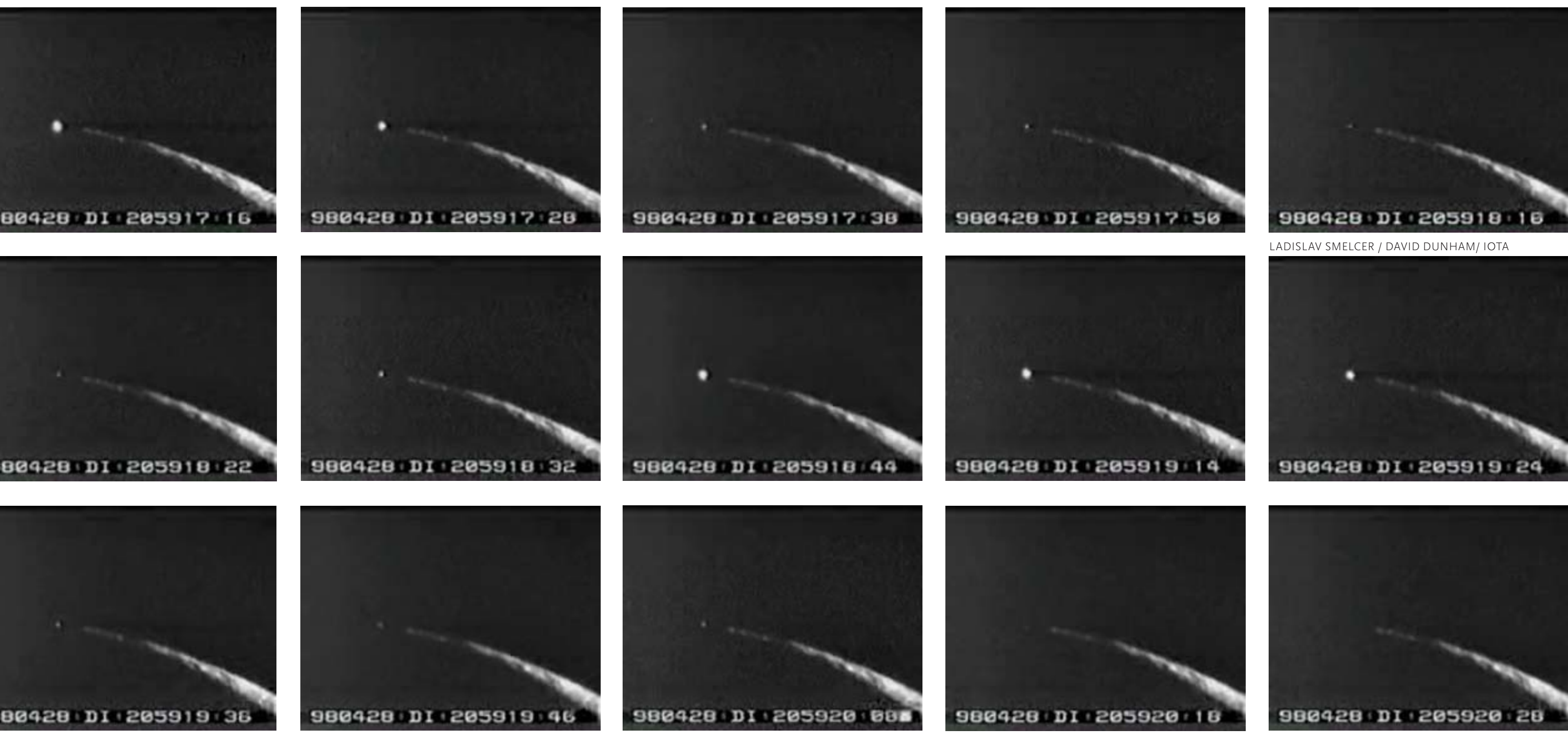
Where the occultation is total rather than grazing, you can also catch the star's disappearance on the Moon's bright limb. For this you'll need a telescope even at night, because without high magnification, the glare of the Moon's sunlit terrain hides even a 1st-magnitude star right next to it. Aldebaran's reappearance on the dark limb will be much easier — if you're watching at the right moment!

Here are some times:

At **Austin**, the *disappearance* is at 4:39 a.m. CDT, the *reappearance* at 5:19 a.m. CDT; **Atlanta**, *d.* 5:48 a.m., *r.* 6:40 a.m. EDT; **Miami**, *d.* 5:33 a.m., *r.* 6:43 a.m. EDT; **Pittsburgh**, *d.* 6:11 a.m., *r.* 6:44 a.m. EDT; **Washington, DC**, *d.* 6:05 a.m., *r.* 6:53 a.m. EDT; **Boston**, *d:* 6:20 a.m. EDT, *r.* 7:03 a.m. EDT.

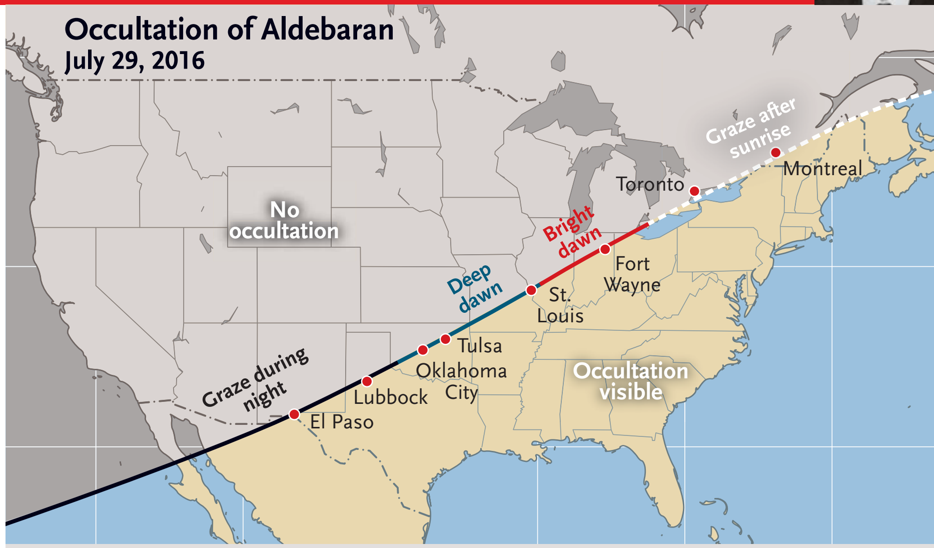
More precise times, and additional details including the altitudes of the Sun and the Moon, are listed for over 1,000 cities and towns in the predictions link at the end of this article.

When the Moon's limb grazed Aldebaran over Łódź, Poland on April 28, 1998, Ladislav Smelcer was there videorecording with an 11-inch Schmidt-Cassegrain scope. Here is every 5th frame of a 3-second clip from his movie. Aldebaran dims gradually, rebrightens partially, then fades out altogether. His setup inserted the date and local time into each frame; Universal Time is two hours earlier (so the UT minute is 18:59). Twenty-five other observers timed graze events visually, mostly by voice calls into tape recorders. In all, 142 contacts were timed.



LADISLAV SMELCER / DAVID DUNHAM/ IOTA

***David Dunham**, a founder of IOTA, has led the coordination of occultation timings since 1962. Write him at dunham@starpower.net.*



S&T: LEAH TISCIONE, DATA: IOTA

Observers in the southern and eastern US, the Caribbean, and most of Mexico can watch the Moon occult Aldebaran on the morning of July 29th. Along the graze line, you're likely to see gradual events due to the star's relatively large angular size. The graze occurs during night for Texas, dawn from Oklahoma to Lake Erie, and daytime northeast from there.

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 examine the precise graze path to street-level accuracy using the interactive Google Maps link in the special page we've set up for this event, also given at the end of the article.

Viewed from this narrow zone, the giant star should disappear and reappear multiple times as hills and valleys along the Moon's northern limb cover and expose it. Most of these events will appear non-instantaneous, even taking up to a full second, due to Aldebaran's angular size: 40 meters wide at the Moon's distance. Sometimes a sideways-speeding hill may cover only a part of the star's face, causing an incomplete partial occultation.

We can now predict these narrow zones very accurately, thanks to the laser altimeters on Japan's Kaguya and NASA's Lunar Reconnaissance Orbiter spacecraft. These mapped all of the Moon's topography to high accuracy. So now, you can choose your viewing location to within just a few meters in order to maximize the number of contact events you can view or record. See the web page for the event.

From the mid-1960s into the 1980s, observers with the International Occultation Timing Association (IOTA) recorded hundreds of grazes, mostly visually, to refine the lunar profile and star positions. Now that we know both of these parameters very well, such observations are less valuable to astronomers. So since the early 1990s, IOTA has concentrated its efforts more on asteroid occultations.

But lunar occultations do remain valuable to discover and resolve close double stars, especially when recorded with video. The Kepler-2 Project is currently looking for exoplanet transits of stars near the ecliptic. The Kepler team is very interested in which of their program stars might be close doubles, because stellar duplicity throws off the analysis of any sign of an exoplanet. Aldebaran isn't suitable for this particular work, but some of the Hyades stars to be occulted on the same night are. Again, see the web page.

Even though we don't expect to learn much new from it, the July 29th Aldebaran graze is probably the best of the current series for populous parts of North America. For that reason, IOTA will hold its annual meeting in nearby Stillwater, Oklahoma, the weekend after the Friday-night graze; details are in the link. Most attendees will try to observe the graze from northeast of Edmond, Oklahoma; some will be ready to travel if clouds threaten. You're welcome to join our expedition, the IOTA meeting, or both.

Hyades Stars

About two hours before Aldebaran reappears from behind the Moon's dark limb, the 4.8-magnitude Hyades star ZC 677 will do the same for much of the eastern US. Its graze line will run about 100 miles south of Aldebaran's and pass over Cincinnati, Ohio, and Ithaca, New York. Details are in the event link.

Also to be occulted for various parts of North America are several other stars, including the pair Theta^1 and Theta^2 Tauri, magnitudes 3.8 and 3.4, respectively. Detailed predictions for those two are in the predictions link.

A Blue-Sky Aldebaran Occultation on August 25th

One lunar month after the July 29th occultation, the Moon crosses Aldebaran again: during daytime on August 25th for much of the southwestern U.S.

This time the Moon will be last quarter. Once again, because the Moon is waning, the disappearance happens on the bright limb and the reappearance on the dark limb. Some times: at **Kansas City,** *disappearance* 12:56, *reappearance* 1:11 p.m. CDT; **Denver,** *d.* 11:43, *r.* 12:14 p.m. MDT; **Los Angeles,** *d.* 10:21, *r.* 11:26 a.m. PDT; **Berkeley,** *d.* 10:17, *r.* 11:15 a.m. PDT; **Honolulu,** *d.* 5:52, *r.* 7:17 a.m. HAST.

For More Information

• We at IOTA have set up a special web page for the July 29th event, with an interactive Google Map and much other information: **occultations.org/Aldebaran**.

• Detailed predictions for most of the events mentioned here 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: the disappearance, the reappearance, and the locations of cities. ✦

— David Dunham

Twin Basins with a Twist

Track down two big basins — one obvious and the other nearly invisible.

When looking through a telescope at the Moon, you see the cumulative effect of 4½ billion years of stuff happening. Some big features from long ago — for example, Montes Apenninus, the towering mountain chain created during the Imbrium basin's excavation 3.8 billion years ago — are still clearly visible. But other features, even sizeable ones, have vanished from view due to subsequent volcanism and impact erosion.

Fortunately, as I described in February's issue (p. 48), precision mapping of the pull of lunar gravity by the twin Gravity Recovery and Interior Laboratory (GRAIL) spacecraft can reveal subsurface evidence of hidden landforms. In particular, impact basins produce the largest gravity anomalies on the Moon, typically with a central gravity "high" or mascon (mass concentration), surrounded by a ring of gravity "lows." These appear as blues and reds, respectively, in the map below. The high in a basin's center results from the rise of dense mantle material under the basin and from dense mare lavas that partially fill its floor. The low corresponds to a thick annulus of less-dense crustal material.

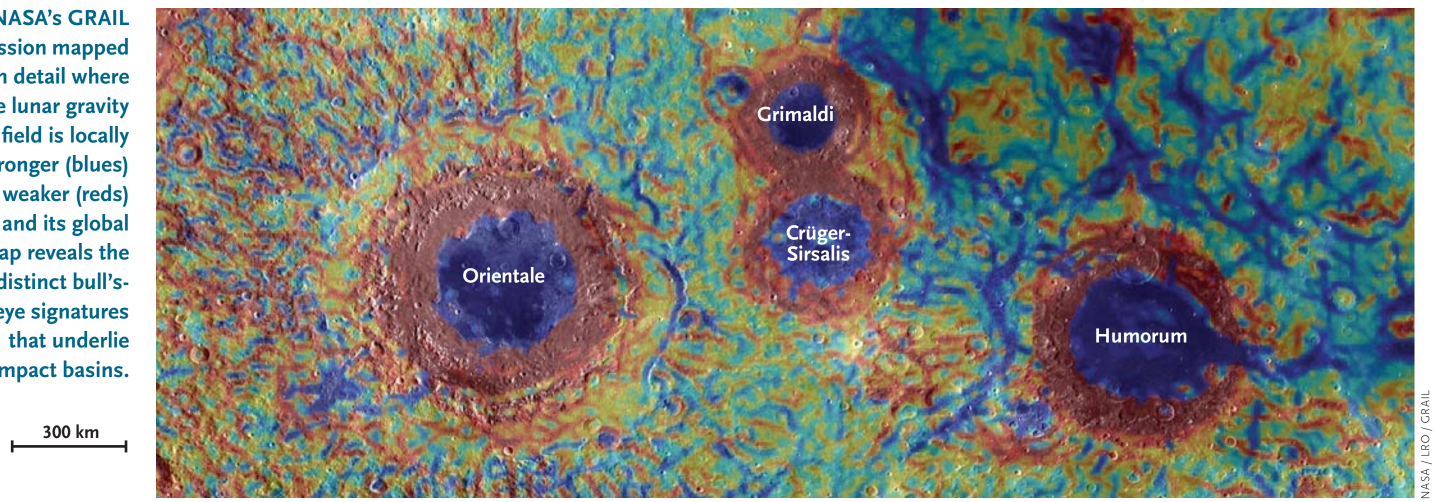
That's the pattern underlying the Orientale impact basin, which barely peeks around the Moon's western limb. Nearby are two smaller red-around-blue gravity signatures of basins. The northern bull's eye is associated with the **Grimaldi** basin, whose 220-km-wide mascon is about the same diameter as the distinct rim that surrounds its central plain of dark lava.

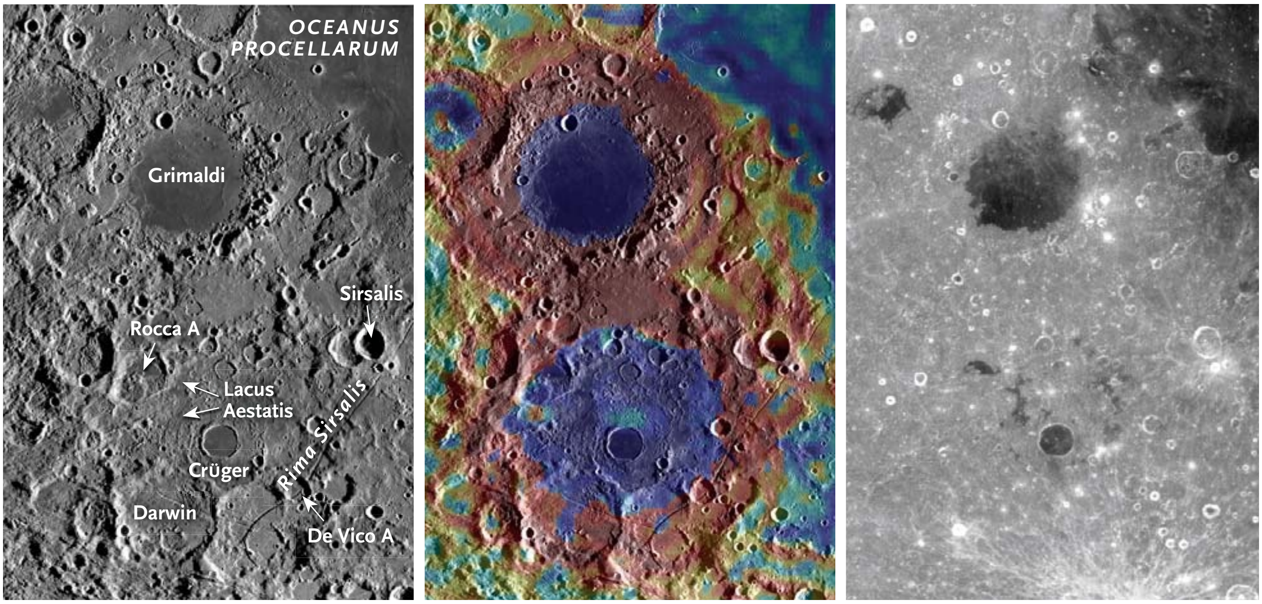
It's important to note that Grimaldi is not a crater but rather a basin (an impact site having two or more rims). Its large (460-km-wide) and more subtle outer rim is difficult to see in images, but its red coloration makes it stand out in a gravity map. Technically, Grimaldi's lava-covered floor could have been named Mare Grimaldis.

Immediately to its south is another gravity bull's eye of nearly the same size. It too must mark the site of a basin — and yet there's no obvious evidence for one on the surface. Lunar geologists call this hidden feature the Crüger-Sirsalis basin (CSB), named for two craters that it spans. **Crüger**, 46 km across, is the lava-floored crater near the basin's center, and **Sirsalis** is the brighter of two overlapping craters to the northeast. Based on their high-low gravity signature, CSB's phantom rims have diameters of about 240 and 400 km.

CSB's center is a patch of relatively flat terrain with few large craters. Usually the most visible parts of a basin are its rims, but none exist for CSB. Their disappearance is probably related to the location of the basin near the younger and larger Orientale basin. The latter's ejecta swept across this area, knocking down and covering preexisting terrain with torrents of debris. Grimaldi basin is about the same distance from Orientale, and yet more of its rim structure remains. Perhaps CSB predates Grimaldi, such that its surface features had already been degraded when the Orientale impact occurred. Interestingly, the centers of CSB and Grimaldi are both 1 to 1½ km

NASA's GRAIL mission mapped in detail where the lunar gravity field is locally stronger (blues) or weaker (reds) — and its global map reveals the distinct bull's-eye signatures that underlie impact basins.





The Crüger-Sirsalis impact basin, south of Grimaldi along the Moon's western limb, shows no rims. Yet its gravity signature (*center*) and telltale patches of mare lava seen near full Moon (*right*) confirm its reality.

NASA / LRO / GRAIL (3)

lower in elevation than the surrounding topography — so basin depressions can remain after their rims disappear.

This hidden basin explains why you'll see small patches of mare lava in Crüger, **Lacus Aestatis**, and nearby at full Moon. All of these flows lie within the inner rim of CSB, having leaked onto the surface because the crust is thin and penetrated by impact-induced faults that provided conduits from magma reservoirs below.

Gravity data also provide a clue to another mystery. **Rima Sirsalis** is a straight rille that has a surprisingly big bend near the crater De Vico A. GRAIL's map shows that the bend occurs exactly where the rille, if it had maintained a straight course, would have cut through the boundary between the basin mascon and the surrounding crustal rocks. So perhaps a sharp subsurface transition related to the basin created the rille's elbow.

If you want to take your personal exploration of the Moon beneath its surface, the Grimaldi and CSB areas are good places to learn. Look when the libration is favorable, as it will be during full Moon on August 18th and for a few days thereafter. Grimaldi's dark lavas are easy to spot, as are the surviving segments of the rim that encircles them.

Then look closely for a lower-lying zone of relatively smooth material just outside the basin's southern rim. This is a moat between the inner rim and the outer one, seen not as a circle of hills but rather marked by a decrease in elevation. The corresponding moat and outer rim are nearly invisible on the basin's northern side.

Now imagine what once must have existed at CSB. The center of this lost basin lies just north of easy-to-spot Crüger. Notice that this central area is relatively flat and sprinkled with hills of Orientale ejecta. Tens of meters beneath that lumpy surface might be a 240-km-wide plain of lava flows, some of which escaped to the surface at Crüger, Lacus Aestatis, and on the floor of **Rocca A** (northwest of Crüger). The large crater **Darwin** and other unnamed ruined craters occupy the space where the gravity map shows the red zone of low-density crust.

All these different data sets — gravity, topography, and imagery — peel back layers of the complex history of this corner of the Moon. The surface is just the starting point for understanding everything that's occurred. So take your time and imagine what might lie deeper down. ✦

The Moon • August 2016

Phases

NEW MOON
August 2, 20:45 UT

FIRST QUARTER
August 10, 18:21 UT

FULL MOON
August 18, 9:27 UT

LAST QUARTER
August 25, 3:41 UT

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

Distances

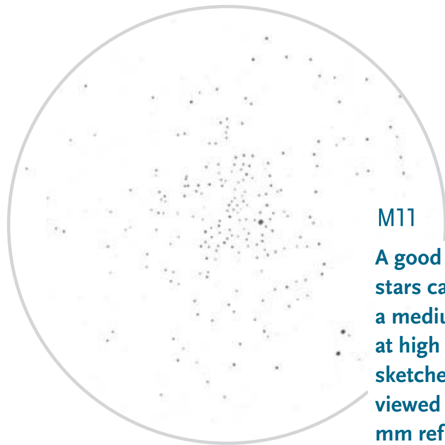
Apogee	August 10, 0^h UT
404,262 km	diam. 29′ 34″
Perigee	August 22, 1^h UT
367,050 km	diam. 32′ 34″

Favorable Librations

Mare Smythii	August 6
Cabeus (crater)	August 14
Hermite (crater)	August 24

Scutum's Gems

Part the misty vapors of the Milky Way to find these glorious objects.

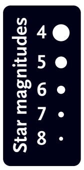


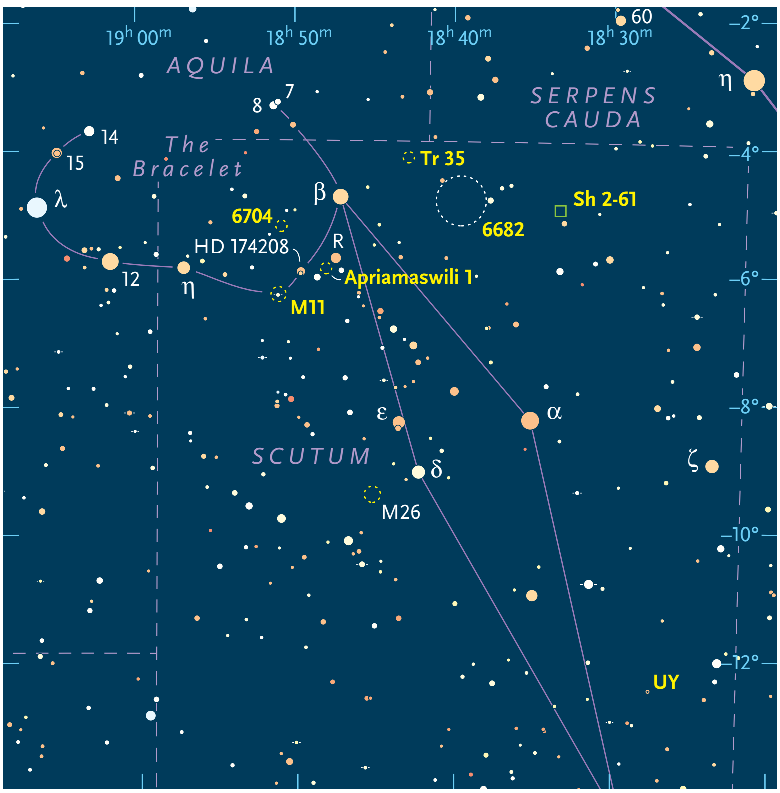
M11

A good number of M11's stars can be resolved with a medium-aperture scope at high power. The author sketched the cluster as viewed through her 130-mm refractor at 164×.

Without a doubt, the shining jewel of the constellation Scutum is the open cluster **Messier 11**, also known as the Wild Duck Cluster. German astronomer Gottfried Kirch discovered it on September 1, 1681. At first he was uncertain whether he was seeing a comet or a "nebulous star," but he dismissed the possibility of it being a comet when the object's position remained unchanged during succeeding nights. More than half a century later, British cleric and astronomer William Derham published his observations of nebulous stars, which he called "whitish Areæ, like a Collection of Misty Vapours: whence they have their Name." In the same memoir, Derham became the first observer to report that he found Kirch's object to be a cluster of stars.

Perhaps the historical description that resonates most with me is one recorded by John Herschel in his 1833 catalog: "A beautiful irregularly round cluster 10′ or 12′ diameter. The stars are all 11th magnitude except one 9th magnitude . . . [and] it is broken into 5 or 6 distinct groups with rifts or cracks between them. A glorious object." To me, M11 looks as though a crystalline star was dropped on the obsidian floor of the night, its many shattered fragments outshone by a small remnant of





NGC 6704 lies just over 1° north of open cluster M11. The Barnard 111 complex of dark, or *absorption*, nebulae stretches between and around the two clusters.

SCOTT ROSEN

its core. I've tried to portray M11 as seen through my 130-mm refractor at 164× (facing page), but the dusky fissures splitting its rafts of stars are best captured with your own eye. No image or sketch can truly do justice to this magnificent cluster.

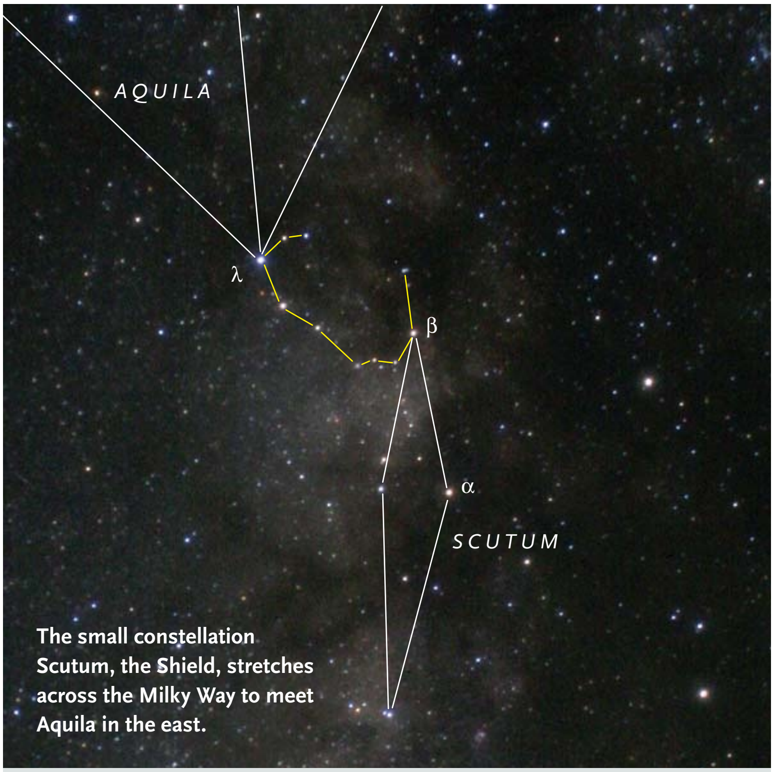
M11 is also the bauble decorating the **Bracelet**, an asterism that Arizona amateur Bill Dellinges noticed with 7×50 binoculars. Dellinges says that the Bracelet is one of those shapes that, once imagined, you can never again fail to see. Through my husband's 7×42 binoculars, it's easy to imagine an open-ended bracelet. It starts at 14 Aquilae and then curves through the stars 15, Lambda (λ), and 12. The Bracelet then crosses over into Scutum with Eta (η) Scuti and proceeds through the stars HD 174208 and Beta (β). Finally it returns to Aquila, ending at the star pair 7 and 8 Aquilae. All but three are magnitude 5.4 or brighter, so stargazers blessed with dark skies may be able to see most of the asterism with the unaided eye. When R Scuti is near maximum light, it adds another star to the bracelet.

A lesser gem on the bracelet is **Apriamaswili 1**, discovered by S. P. Apriamasvili of the Abastumani Observatory in 1964. The first spelling is the object's name as listed in the Simbad Astronomical Database, and the second is the author's name as you'll find on the discovery paper in the SAO/NASA Astrophysics Data System. Confusing matters further, some journal papers by the same astronomer are found under the name Apriamashvili. We owe these differences to various transliterations of a name written in Georgian script. The cluster is often called Basel 1, a later name bestowed in 1970.

Apriamaswili 1 is boxed up in a 35′ × 13′ trapezoid formed by four bright stars. My 130-mm scope at 48× shows a little knot of several faint stars and haze, which at 102× breaks up into 18 faint to very faint stars loosely tossed across 5′ of sky. Through my 10-inch reflector at 68×, the delicate cluster becomes a fairly conspicuous bunch of at least 20 stars, magnitude 11 and fainter. A magnification of 115× makes it clear that the group has an irregular shape, as well as indefinite borders. Stragglers seem to expand the group to 7′ and 30 stars.

Let's turn our attention to the open cluster **NGC 6704**, discovered by the outstanding German astronomer and comet-hunter Friedrich August Theodor Winnecke with his 3-inch Mertz comet seeker in 1854. Through the small refractor he saw it as a faint nebula, but when he later viewed it with the 9.6-inch refractor at the observatory in Berlin, he found that it was a coarse cluster of stars.

NGC 6704 sits 1.1° north of M11 within a ½° oval of stars, 8.6 magnitude and fainter. The cluster looks like a granular haze through the 130-mm refractor at 48×, while at 164× it displays about 15 faint to very faint stars over a patchy mist of unresolved stars. It's roughly 5′ across and more concentrated in the center. My 10-inch reflector at 166× plucks out 40 stars gathered into an odd shape covering 6′. A dense clump of stars dominates the center, with a sparse scattering of stars to its south, as though some trickled out of the main mass. A starry band reaches westward from the clump, and from its end, a sweeping



The small constellation Scutum, the Shield, stretches across the Milky Way to meet Aquila in the east.

PK CHEN

The Jeweled Shield

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Messier 11	Open cluster	5.8	11′	18^h 51.1^m	–06° 16′
Bracelet	Asterism	—	4.8° × 2.6°	18^h 56.5^m	–04° 39′
Apriamaswili 1	Open cluster	8.9	5.5′	18^h 48.1^m	–05° 51′
NGC 6704	Open cluster	9.2	5.0′	18^h 50.8^m	–05° 12′
Trumpler 35	Open cluster	9.2	6.0′	18^h 43.0^m	–04° 14′
NGC 6682	Star cloud	—	47′	18^h 39.6^m	–04° 46′
Sharpless 2-61	Emission nebula	—	2.0′	18^h 33.4^m	–04° 58′
UY Scuti	Red supergiant	8.6–10.5	—	18^h 27.6^m	–12° 28′

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.

POSS-II / CALTECH / STSCI / PALOMAR OBSERVATORY

The nearly inscrutable emission nebula Sharpless 2-61 rests at the center of this 30×15 arcminute field. Sh 2-61 is a compact H II region ionized by a multiple star system.

curve of moderately bright stars arcs around to the north, evocative of the graceful arm of a spiral galaxy.

Hopping 1.2° west-northwest from Beta Scuti takes us to the open cluster **Trumpler 35**, which stands out rather well as a patch of haze sprinkled with fairly faint to very faint stars when viewed through my 130-mm scope at 48×. At 102× I see at least 20 stars in a 6′ group, the brightest ones forming an arc that's concave toward the northeast. The 10-inch scope reveals about 35 stars, 12th magnitude and fainter, many in radial chains that stretch the group to 8′ across its longest dimension.

If we slip 1° west-southwest from Trumpler 35, we'll encounter an absorption hole — a thinning of interstellar material that absorbs light from background stars. Here we see the star cloud **NGC 6682**, a pileup of remote suns beheld through this relatively clear window. The 130-mm refractor at 28× nicely shows off this ¾°-wide enhanced splotch of Milky Way peppered with faint stars. Two bright stars, magnitude 7 and 8, rest just off the west and northeast edges, respectively.

The emission nebulae **Sharpless 2-61** resides 1.1° west of the 7th-magnitude star near NGC 6682's edge. In my 130-mm scope at 102×, it's a small, faint glow with a dim star embedded. Nebula filters don't significantly improve the view. With the 10-inch scope at 166× the nebula spans about 1½′. The star sits north of the nebula's center, and a few fainter stars are superimposed. The embedded star is actually a multiple system with several tightly spaced components that likely belong to a youthful star cluster enshrouded by its nebula.

For our final visit, let's plunge much farther south to the semi-regular variable star **UY Scuti**, a pulsating red supergiant with a period of roughly 750 days and a visual-magnitude range of 8.6 to 10.5. However, that's not where its attraction lies. UY Sct is a leading candidate for the title of largest known star, even though uncertainties in size determinations for red supergiants are great enough to blur the ranking among them. In the June 2013 issue of *Astronomy & Astrophysics*, Belén Arroyo Torres and colleagues determined the mean radius of the star to be 1,708 (plus or minus 192) times the radius of our Sun. If you replaced our Sun with UY Sct, the star's outer surface would extend more than halfway between the orbits of Jupiter and Saturn.

Red supergiants are quite distended, and UY Sct weighs in somewhere between 25 and 40 times the mass of our Sun. The star is sometimes referred to as a *hypergiant*, but this is a misnomer. Technically, hypergiant stars have a luminosity class of 0, while UY Sct is Ia, the highest luminosity class for supergiants.

When I looked at UY Sct with my 130-mm refractor at 37×, it was near maximum brightness and smoldered with a deep red-orange hue. It reddens more as it dims, but you may need a larger scope to detect the color. I'd like to thank fellow astronomy club member Greg Nowell for bringing this fascinating star to my attention. ✦

Rod Mollise

Space-Walking with the Meade MWAs

These new 100° eyepieces offer users vast fields and good ergonomics.

ROD MOLLISE

The Mega Wide Eyepieces each feature a vast apparent field of view in a comfortable housing that does not interfere with your eye placement.

I'M ADDICTED TO that "space walking" experience — observing the sky through ultra-wide-angle eyepieces with large apparent fields of view (AFOV). When I'm using a large AFOV eyepiece, it's like I'm floating in space with no telescope between me and the sky. The field circle in the eyepiece is huge and the view much more absorbing than in an ocular with a narrower apparent field. Expressed in degrees, AFOV also determines how much actual sky, how much "true field," is shown.

I began my love affair with large AFOV oculars in the early 1990s after I got a look through a Tele Vue Nagler eyepiece. Its 82° apparent field forever spoiled my 55° Plössls for me. About seven years ago, things got even more serious when 100° eyepiece designs entered the market. Suddenly, the 82° eyepieces I loved didn't seem as

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WHAT WE DON'T LIKE:

Rubber eyecups wouldn't stay put

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special anymore. So, did I go out and replace all my oculars with 100° wonders? No. There was a problem: cost.

Ultra-wide eyepieces were priced at $600 and up, which kept my inventory down to two. That could change now, however, with the introduction of the modestly priced Series 5000 Mega Wide Angle (MWA) eyepieces from Meade.

General Overview

The MWA series consists of four eyepieces with focal lengths of 21, 15, 10, and 5 mm. While it would be nice to have an ocular with a longer focal length than 21 mm, it's not as necessary with 100° eyepieces as with narrower ones. The 21-mm covers a large true field and is actually a better performer in light pollution than a lower-magnification eyepiece, tending to spread out background sky glow.

When using multiple eyepieces, optics are only part of the story. Equally important are their mechanical characteristics, not just for durability's sake, but for ergonomics. If it's difficult to properly position your eye at the eyepiece, it doesn't matter how good the glass is. The MWAs look modern, but unlike some oculars, their barrels don't get in the way of proper eye placement.

The Mega Wides are equipped with rubber grip rings and feel good in your hand. Their finish is outstanding, and removing the caps from the eye and field lenses reveals perfect-looking greenish lens coatings (they are fully multi-coated). All visible interior surfaces, particularly the eye lens and field lens areas, are well-blackened to reduce light scatter. Each eyepiece is threaded to accept standard filters.

Was there anything I didn't like about the MWAs' mechanics? Their rubber eyecups tended to become detached. When I folded an eyecup up to block stray light, it would often pop off and I'd lose it in the grass on a dark observing field. But this is a minor quibble.

The first thing I did after the MWAs arrived was to check their two most important specifications, eye relief and apparent field. While Meade publishes these specifications in their promotional literature, my motto is "trust but verify."

Eye relief is the distance you need to position your eye from an eyepiece to take in the entire field of view. Meade gives eye relief figures of 20 mm for the 21- and 15-mm eyepieces, 19.7 mm for the 10-mm, and 13 mm for the 5-mm ocular, and my measurements confirmed they were correct. Even 20 mm is not much eye relief for those who wear glasses while observing, but it's still fairly generous for ultra-wide-field oculars.

To roughly determine the MWAs' apparent fields, I timed how long it took a star near the celestial equator to cross the field in an undriven scope. I then converted that figure to AFOV. The three oculars with longer focal lengths were close to Meade's 100° specification. Only the 5-mm came up a little short at about 94°.

I also checked for pincushion and barrel distortion, though slewing around dense star fields, which revealed little evidence of either problem to my eyes.

Meade also claims the MWA series are parfocal, meaning that they reach focus at the same point. That's

ROD MOLLISE

Internal reflections were well controlled in each of the MWA eyepieces, though the 21-mm required more care when positioning your eye to avoid "kidney-bean" blackouts of parts of the field.

not *quite* true in practice. The 21- and the 15-mm models are 2-inch eyepieces and are indeed parfocal with each other, as were the 10- and 15-mm eyepieces. But the 10- and 5-mm eyepieces have 1¼-inch barrels and must be used in an adapter, which usually places them farther out in the telescope's focuser. As such, they don't focus at the same place as the 2-inch eyepieces.

21-mm

This seven-element eyepiece is the most physically imposing of the MWAs, and is something of a handful at 1.68 pounds. In performance, the 21-mm was paradoxically the most and least impressive of the set. Its huge field was breathtaking, but stars more than 80% of the way to the edge of the eyepiece looked misshapen in my f/5 Dobsonian reflector.

Much of this was due to the star-distorting coma inherent in a short-focal-ratio telescope. When I added a coma corrector, star appearance improved considerably across the field, but some residual astigmatism in the eyepiece design meant stars toward the edge were still not perfect. Unsurprisingly, edge-of-field stars looked better in my f/10 Schmidt-Cassegrain telescope.

I found it important to keep my eye close to the eyepiece's optical axis. Move it to one side and performance was poorer. I'd get "kidney-beaning," bean-shaped dark patches in the field of view, and also some spurious color on bright objects. In practice, it was not hard to position my eye properly and soon became second nature.

15-mm

S&T: SEAN WALKER (4)

While it doesn't offer the space-spanning views of the 21-mm, the 1.4-lb., 15-mm MWA shows a nice wide swath of sky and its shorter focal length is less demanding of the optical design. Stars at the field edge were respectably round, both due to coma being less prominent because of the 15's lower astigmatism and its higher magnification. Eye placement was also less critical than with the 21-mm. Despite the presence of eight lens elements (which could dim the view by absorbing some light), objects seemed just as bright as in other 15-mm eyepieces with fewer lenses.

10-mm

Like the 15-mm, the 10-mm is perhaps a better balance of field size and optical quality than the 21-mm. Stars were small and well shaped at the field edge in my Schmidt-Cassegrain, which made star clusters look great. The 10-mm became my "glob buster," making short work of smaller globular star clusters like M92 in Hercules, delivering plenty of tiny stars on a dark background. This one weighs in at a fairly modest 14.7 ounces, and, like the 15-mm, incorporates eight lens elements.

5-mm

While the 5-mm came up a little short in the AFOV figure, it acquitted itself well in every other regard. Stars were better at the field edge than in any of the other MWAs. Perhaps the greatest compliment I can pay this ocular is to call it a good planetary eyepiece. Saturn was beautiful in my Dobsonian at 250×, and its wide field meant I didn't have to continually nudge the scope along to track. This nine-lens-element eyepiece weighs only 11.8 ounces and handles like a normal eyepiece.

I thoroughly enjoyed observing with the MWAs, but beyond the fun, there were a few surprises. The biggest was how well they stacked up to my premium 100° oculars in use. Stars at the edge of the field were not as good as in premium oculars, but even with the large, low-power field of the 21-mm that rarely bothered me. I was concentrating on the eyepiece center most of the time, and only bright "problem" stars on the edge of the field normally caught my attention. Still, when directly compared with the more expensive eyepieces, the MWAs presented a slightly softer view overall.

After my testing was done, I just had a ball spacewalking with the Mega Wides. The MWAs are good performers by any standard, and the fact that they don't break the bank to deliver means I can't help but be enthusiastic about them. ✦

S&T Contributing Editor ***Rod Mollise*** *loves the view through a quality eyepiece.*

▸ **LIGHTWEIGHT DOME** Canadian Telescopes introduces the NexDome Observatory (starting at $1,795 for the dome only). This 2.2-meter (8-foot) dome is manufactured from multiple layers of impact-resistant ABS material that retains its shape under a wide range of temperatures. An additional, outer layer of Solarkote protects the structure from ultraviolet deterioration. The Nex-Dome rides on two sets of wheels that prevent shifting and ensure smooth rotation while securing the dome during high winds. Its modular design allows a single person to assemble the dome in just a few hours with common household tools. See the manufacturer's website for additional options.

Canadian Telescopes
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604-336-3821; nexdome.com

THE BIG Q The latest astrograph from Takahashi is now available in North America. The Takahashi FSQ-130ED ($12,795) is billed as a flat-field astrograph that can accommodate the largest detectors on the market today. This 130-mm f/5 refractor incorporates five objective elements, three of which are manufactured from extra-dispersion glass to produce pinpoint stars across a large, 110-mm image circle. The FSQ-130ED's 5-inch focuser is designed to handle heavy cameras and accessories, and includes a camera-angle adjuster that lets you rotate your camera without losing focus. The telescope weighs 12.2 kg (26.9 lb.) and measures just 21.26 inches with the lens shade retracted.

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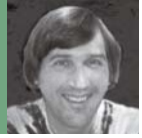


The Future is Fast

Phill Oltmann's 32″ f/2.4 scope raises — and lowers — the bar.

Phill Oltmann with his 32-inch f/2.4 scope. The scope stays put while the observatory rolls away from it, using the same motor that powered the polishing process.

I HAVE SEEN THE FUTURE, and it is fast. It's also vast. Thirty-two inches in diameter, to be precise, and less than *seven feet* high at the eyepiece.

Modern telescope making seems to be a rush toward ever greater apertures at ever shorter focal lengths. Alberta, Canada ATMer Phill Oltmann has pushed those parameters about as far as I've ever seen. Inspired by Mike Lockwood's 20″ f/3, Phill decided to see how large and fast he could go. He had already made a 20″ f/4 and realized that if he used the same tools to generate the same curve, he could make a 32″ mirror at f/2.5.

He ordered a blank from Newport Glass and had them pre-generate the rough curve, removing nearly 13/16″ of glass from the 2.5″ blank's center. He began grinding with 60-grit to remove the striations from the curve generator, then graduated to finer and finer grits as with any other mirror. He did all the grinding by hand with the 16″ granite grinding tool he'd used on his 20″.

For polishing he built a 24″ dental plaster tool and motorized the mirror on a spindle. The mirror rested on the same 18-point cell used in the final telescope, to ensure adequate support. An overhead arm held the tool in place and differential friction made the tool rotate while polishing. Phill varied the tool's offset every 15 to 20 minutes to avoid creating zones.

Grinding and polishing took only two months, but parabolizing took one and a half years! Phill could only work on it during the summer, and he could only put in about three hours a day, using tools of 12″, 10″, and 6″ diameter pushed by hand. He used Ronchi and Foucault tests, going exclusively with the Foucault test and a 19-slot Couder screen as he approached his desired parabola.

During the parabolizing phase he learned that the amount of glass removed when transitioning from a spheroid to a paraboloid increases exponentially with decreasing f-ratio. Canadian optician Peter Cerovolo began parabolizing one of his fast scopes during fine grinding, and Phill says, "Considering the extreme amount of work I did figuring the mirror, that's what I will do in the future — if ever I lose my mind and try another such project."

One downside to large, fast telescopes: the secondary mirror has to be big. Phill's is 8.5″ on the minor axis. There's a hidden bonus, though: the extra length taken up by the secondary cage diameter shortens the scope's height. This scope wound up being shorter than his 20″! As Phill says, "It's nice to have only one step up a ladder."

He patterned the scope's OTA on David Kriege and Richard Berry's book, *The Dobsonian Telescope*, so it has a distinct "Obsession" look to it. It's an Obsession seen in a funhouse mirror, though, with trusses less than three feet long.

Parabolizing was done by hand with 12″, 10″, and 6″ tools, using mostly half-diameter strokes.

PHILL OLTMANN (2)

PHILL OLTMANN

The f/2.4 mirror is so deep, friends called it "the soup bowl." Phill proves them right in the photo above.

So after constructing this amazing squat beast, how does it perform? In a word: beautifully! I had the privilege to look through this scope during a vacation to the Arizona/New Mexico area where Phill spends his winters, and I can attest that the view is nothing short of spectacular. Thanks to a 3″ Paracorr, the stars are pinpoints from edge to edge of the field, a field that's an impressive degree across in a 17-mm Ethos eyepiece. And the image is just as bright as you'd expect for a 32″ mirror. After looking at the Orion Nebula with it, I just about fell over.

It wouldn't have been much of a fall. That's the beauty of this scope. As Phill says, it provides "all the amenities of a big scope with only one step up a ladder. Truly, the super-fast Dobsonian is the next stage of evolution in visual observation and aperture fever."

I couldn't agree more.

Phill Oltmann would like to dedicate this article to the memory of his friend and mirror-making mentor, Barry Arnold. Phill can be contacted at **dr.philloltmann@yahoo.com.** ✦

In his years grinding mirrors, ***Jerry Oltion*** *has gone as fast as f/3.8, which is rapidly becoming passé.*

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

Processing with PixInsight

Follow this workflow to get more out of your deep-sky astrophotos.

FROM SCOPE TO PRINT *PixInsight* **is an all-encompassing astronomical image-processing program that runs on all major computer platforms. It includes everything you'll need to create stunning results ready to print, like this photo of IC 417 above. The author supplied all photos with this article.**

Ron Brecher

"One size fits all" is a rarely used term in astrophotography. Astro-imagers shoot all types of deep-sky objects in a variety of ways: wide field or high magnification, color or monochrome, natural or representative-color narrowband. We often use different telescopes, cameras, software, and processing techniques to achieve beautiful results. And although I've used a variety of equipment over the years, I've settled on one program to work up all of my deep-sky images from start to finish: *PixInsight* (**pixinsight.com**).

PixInsight is perhaps the only software that can handle everything from basic image calibration to advanced processing. It reads and writes virtually every image file format and has effective tools for just about anything you'd want to make your images stand out from the crowd. But it is a complex program that can be intimidating to a beginner.

I found that adopting a standard workflow helped me to become familiar with this powerful software and to streamline my own processing routine to get the best results from those rare clear nights. Here's how I do it.

Processing Flow

To begin, there are several ways to access *PixInsight*'s processes and scripts. The easiest is using the pull-down menu along the top of the screen. You can find all processes under Process > All Processes. To its right, the Script menu contains a standard set of scripts, organized in groups (Utilities, Image Analysis, Batch Processing, and more). You can download other scripts, or record your own to further streamline your workflow.

My typical processing routine involves 5 main steps:

1. Reducing my data to a single master for each filter.
2. Linear processing of the color and luminance (unfiltered monochrome) stacked separately. This includes combining the red, green, and blue files into a color image and enhancing it with Hydrogen-alpha (Hα) data, if shot.
3. Nonlinear stretching.
4. Combining the luminance and color data.
5. Final tweaks to the photo to prepare it for publishing or printing.

Following this general outline has helped raise the quality of the images I produce and also keeps me from skipping important processes. With a few minor modifications, this workflow can be used for image files generated by any type of camera, including DSLR and one-shot color CCD images.

Data Reduction

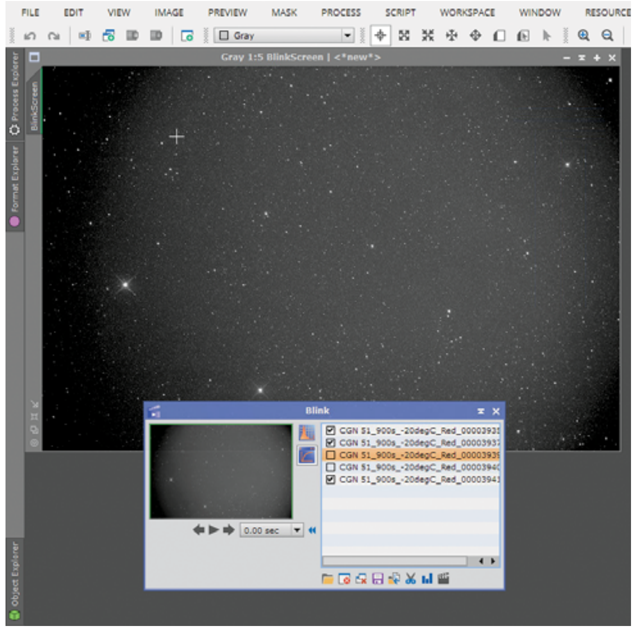
A night of CCD imaging can generate dozens of files, not to mention many calibration frames — the bias frames, dark frames, and flat-field images used to clean up the "light" (target) exposures. Data reduction is the process of making single "master" images from the many raw files I record of my chosen target. It involves selecting the best frames and then calibrating, aligning, and combining them into a final (though still unprocessed) result. Because I use a monochrome camera with color and narrowband filters, I often shoot through 3 to 5 filters to produce a color image (red, green, and blue, and sometimes luminance and Hα).

The first tool in my image-processing workflow is the Blink process, which lets me inspect each image and discard any that appear to be of poor quality (images with clouds, poor tracking, and so on). *PixInsight*'s SubframeSelector script (Script > Batch Processing > SubframeSelector) can automatically evaluate images and sort them into "approved" or "rejected" groups using quality criteria you can modify. When evaluating image quality, I use this opportunity to identify the best one to use as a reference when aligning images.

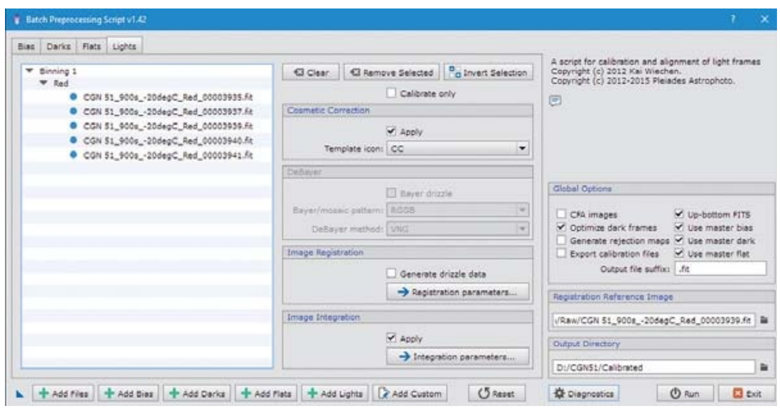
With my best frames in hand, I then apply the BatchPreprocessing (BPP) script. BPP is how I gather my calibration frames and generate "masters" from each group, and then apply these to my images. This script also performs additional functions, such as debayering one-shot color images or correcting hot and cold pixels with the CosmeticCorrection processes (both found in the Light tab). Once everything is loaded and ready, I choose where to save my calibrated files in the Output Directory section and click the Run button in the bottom right.

When BPP is complete, I'll open all the calibrated images taken with all my filters and align them all using the ImageRegistration > StarAlignment process. Be sure to select the reference image you identified earlier as your alignment target.

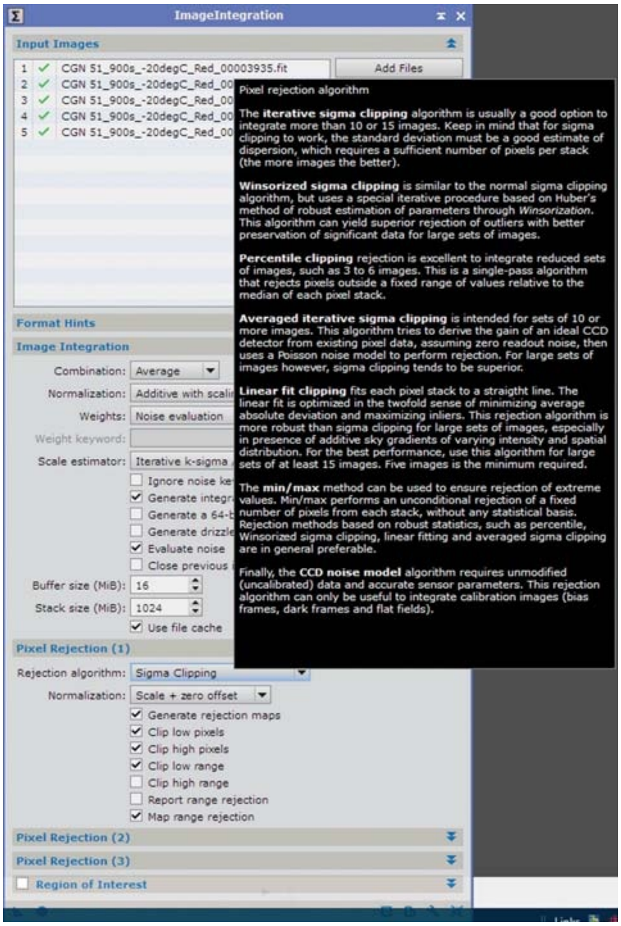
Now it's time to combine all my sub-exposures using the ImageIntegration process (found at Process > ImageIntegration > ImageIntegration), selecting one single-filter group at a time. *PixInsight* includes four integration processes, but ImageIntegration is the workhorse. I choose the best combination method for each filter's



QUALITY CONTROL **The Blink process lets you quickly inspect your images and reject any with clouds or poor tracking.**



DATA REDUCTION **Image calibration can be automated in *PixInsight* using the BatchPreprocessing script.**



STACKING The ImageIntegration process generates a master frame from a group of calibrated and aligned images. Hovering over a selection (in this case the Rejection algorithm) displays helpful tips about the options available.

data set, depending on how many sub-exposures I'm combining. The program will open a description of each method when the cursor is hovered over each option for a few seconds. Once I've loaded the tool with the images to be combined, I apply the process by clicking the blue circle at the bottom left of the window.

In a few moments, the data reduction is complete, producing a single stacked result. I'll save this file and then repeat the process for each filter group.

Linear Image Processing

After data reduction is complete, I'll open up each of my stacked results. These images will appear very dark, with only a handful of stars visible. This is because most deep-sky objects are much fainter than starlight, so they get recorded at the shadow region of the histogram. We can "stretch" the display in *PixInsight* using the ScreenTransferFunction process to better display the shadow regions, which doesn't modify the actual data.

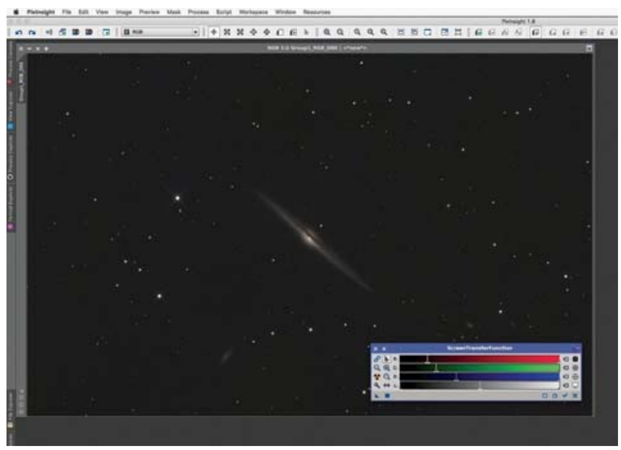
Before performing any additional processing, I'll inspect the images carefully for any leftover hot and cold pixels. If only a few spots need cleaning up, I'll use the clone stamp tool found at Process > Painting > Clone-Stamp; if I find many, I'll apply the CosmeticCorrection process again. Next, I'll crop out any non-overlapping edges in my images using the DynamicCrop process. This tool crops each image exactly the same, to remove areas that could interfere with later processing steps.

My next action is to address any light-pollution gradients in the images. Gradients can severely limit the quality of the final picture, particularly in a color image. Fortunately, there are two excellent tools in *PixInsight* to fix these problems: AutomaticBackgroundExtraction (ABE) and DynamicBackgroundExtraction (DBE). Both work well on individual files or a color image. (See *S&T*: Sep. 2014, p. 68, for a detailed article on using these powerful functions.)

Now I'll combine my individual red, green, and blue images into a color result using Process > ChannelManagement > ChannelCombination. This tool should automatically assign your filtered images to their respective channels, but if not, they can be selected manually. Click the blue "Apply Global" circle at the bottom left of the window and in a moment your color-combined image will appear. Be sure to save the result.

Often the color image will appear to have a strong bias toward one color. This can be corrected using the ColorCalibration process, but in difficult cases, applying the BackgroundNeutralization process first can help. Both often work well without any changes to their default settings.

At this point, I'll add any Hα data to the color image if available. Many experienced imagers struggle with blending Hα into a color image. Fortunately, *PixInsight* has an excellent script for the job. The NBRGBCombination script (under Script > Utilities) is very easy to use and produces a rich, natural-looking red color in emission nebulae without affecting star colors. With the



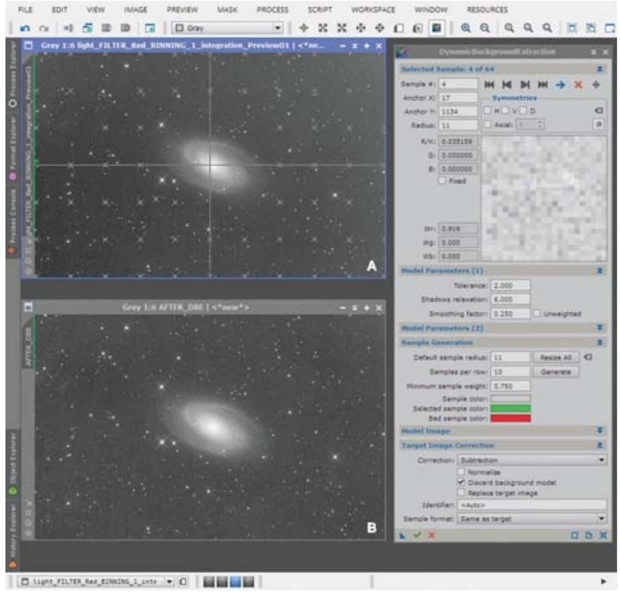
SCREEN STRETCH Use the ScreenTransferFunction process to display an image while continuing to work with it in its unstretched (linear) state.

script open, I'll select my color image in the RGB Source Image section and the Hα image in the Narrowband for R channel (eg Ha). Because Hα also emits at blue wavelengths, adding some hydrogen-alpha signal to the blue channel can make for a more natural-looking result, though reduce the Scale setting in the blue channel to about 0.02 and click Apply. It's usually necessary to re-balance the color on the blended image.

With my color data assembled, it's time to address the luminance channel. I often shoot an unfiltered luminance image, which has the benefit of recording faint details with a very high signal-to-noise ratio compared to the color data. This can then be added to the color picture to produce a very smooth, detailed result. The strong signal recorded in my luminance data can then be deconvolved to reduce blurring due to atmospheric turbulence. Deconvolution is a complex mathematical process that reverses some of the degradation and enhances small-scale details in the image. Getting it right takes a fair amount of experimentation (and will be detailed in an upcoming issue).

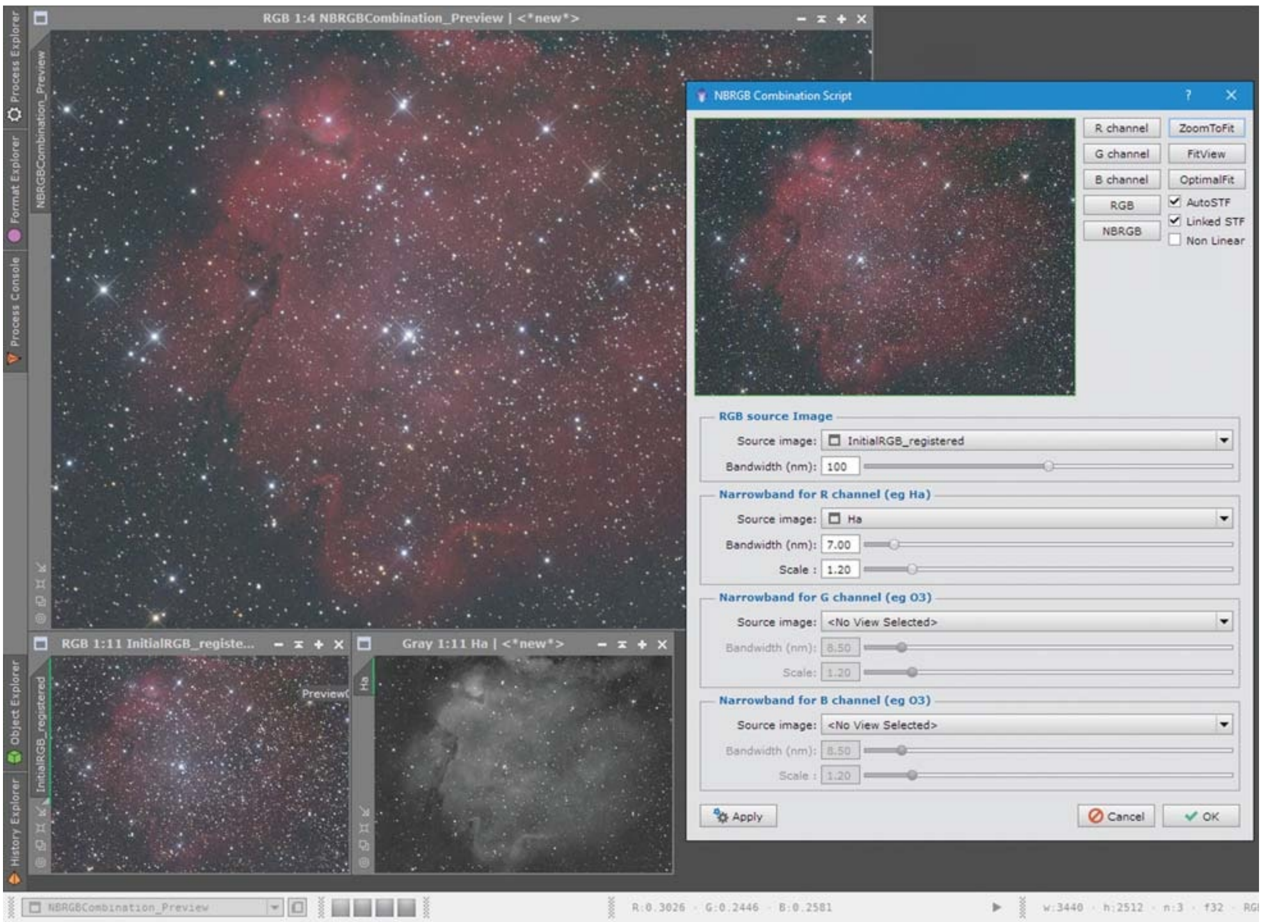
Noise Reduction

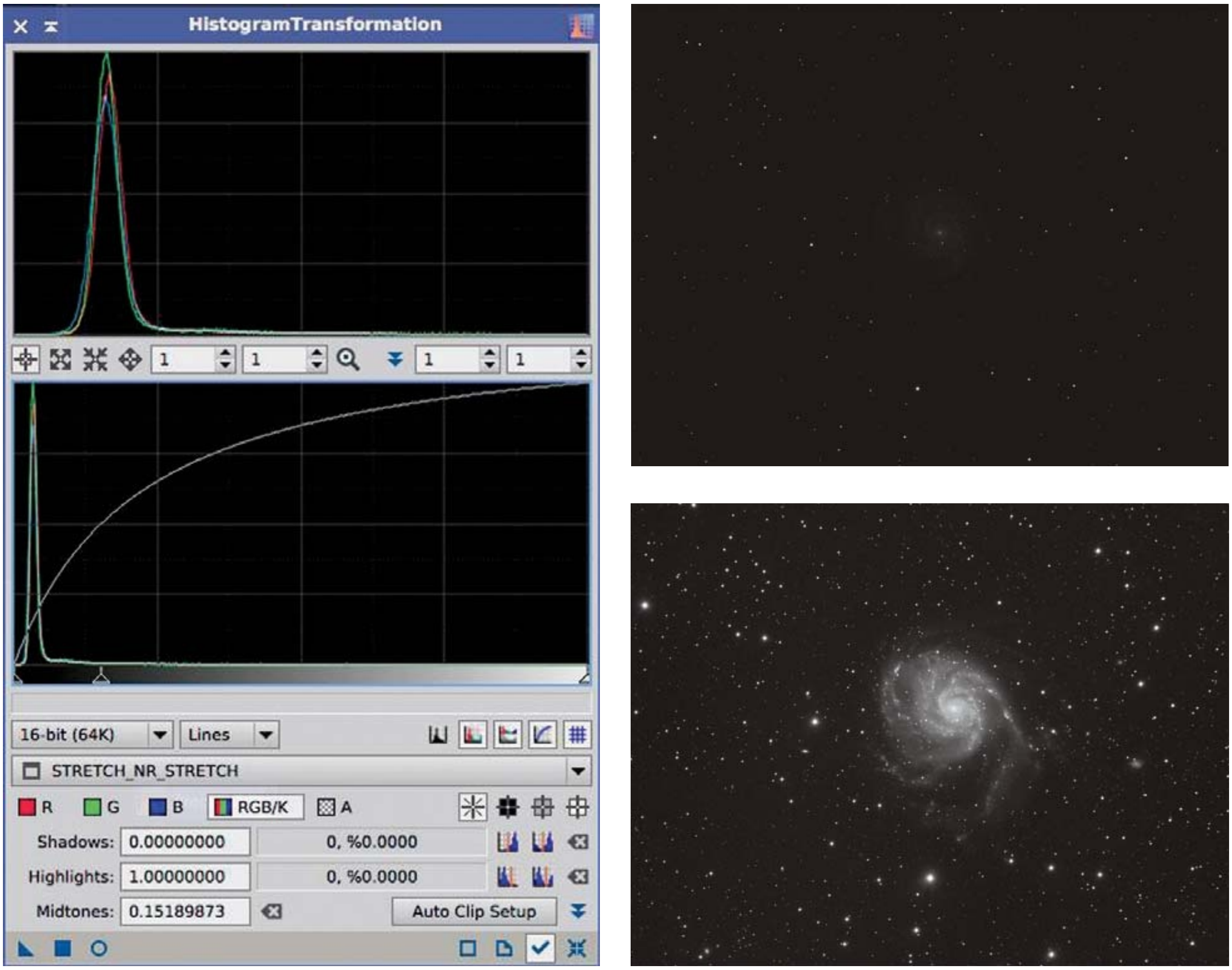
My next step is to address noise in the image using the MultiscaleLinearTransform (MLT) process. This tool can



GRADIENT KILLER Samples are placed on an image of M81 to remove a light-pollution gradient using the DynamicBackgroundExtraction process.

ADDING NARROWBAND *PixInsight* makes it easy to enhance a color image with hydrogen-alpha data using the NBRGBCombination script.





GOING NON-LINEAR Once you've cleaned up and deconvolved the image, it needs to be permanently stretched using the HistogramTransformation process. Move the middle caret toward the left to bring out the mid-range of the data, and then move the left caret toward the right to darken the background.

isolate small-, medium-, and large-scale noise kernels, allowing noise reduction to be targeted only in the areas where it's needed. I always apply MLT to both my color and luminance images, usually with the same settings for both. For each Layer from 1 to 4, I adjust the Threshold and Amount sliders to get the desired result. Try a Threshold of 3 and Amount of 0.5 for Layer 1, and lower values for each subsequent layer up to Layer 4 (noise reduction cannot be applied to the R, or residual, layer). The built-in masking feature should be activated to protect stars and other high-signal areas. The default mask settings usually work well.

Now it's time to stretch the image and make it nonlinear. There are a few different ways to do this in *PixInsight*, but I prefer the HistogramTransformation process. Clicking the blue circle at the bottom left of the tool's window activates the Real-Time Preview mode. Before making any adjustments, I reset the Screen TransferFunction so the Real-Time Preview displays an accurate preview of the results of stretching. Next, I'll slide the middle caret toward the left. This boosts the midtones of the image, though it also increases the background levels. I'll fix this by moving the left caret toward the right, which controls the black point in the image. To preserve significant data, I never adjust the white point, as doing that tends to bloat and overexpose the stars. Similarly, I only move the black point enough to darken the background without clipping out any faint details in the image.

Working with Nonlinear Images

With my image stretched after basic cleanup, it's time to be a little more artistic. This is where I can sharpen the luminance image, perform additional noise reduction, add it to the color data, and adjust the contrast and saturation. I prefer to work mostly on the Luminance channel and then blend it into the color image near the end.

At this point I want to selectively process regions the image. This is where Masks come in. Masks are extremely important when processing nonlinear images in *PixInsight*. These are black-and-white images that I overlay on the picture I'm working on, allowing processes to modify only the parts of the image I choose.

The program offers two main ways to make masks: RangeMask is used for selecting a range of brightnesses and can make masks that include stars and extended objects like galaxies. As its name implies, the StarMask process generates masks that isolate the stars. Both of these tools are intuitive to use, and tool tips are available to help you set each slider. In some cases, the luminance channel of a color image can make an excellent mask. Luminance can be extracted from a tricolor image using the ChannelExtraction command in Lab mode. A copy of a greyscale image can also make a good mask. Any image can be copied by dragging the view identifier tab at upper left of the image window to an empty spot on the *PixInsight* workspace. More complex masks can be created from simple masks using PixelMath, and there are some mask-related scripts, like ColorMask, that are sometimes helpful. Once I've made a mask, I'll use the selections in the Mask menu on the main toolbar to select, invert, or remove it.

Although I performed some noise reduction before stretching, an additional application is often necessary at this stage. I prefer to use the TGVDenoise process on nonlinear files. I tend to apply it only to the darkest areas of the luminance image, using a mask to protect stars and other structures. After applying noise reduction, the image can be stretched again by moving the black and mid-point carets — again taking care not to clip any significant data.

I can now combine the luminance with the color image using the LRGBCombination process. The best results are usually obtained when the two images being combined have a similar brightness. LinearFit, found in the ColorCalibration menu, can be applied with default settings to match the brightness of two images. Just specify the source image and drag the triangle (New Instance) icon to the target image.

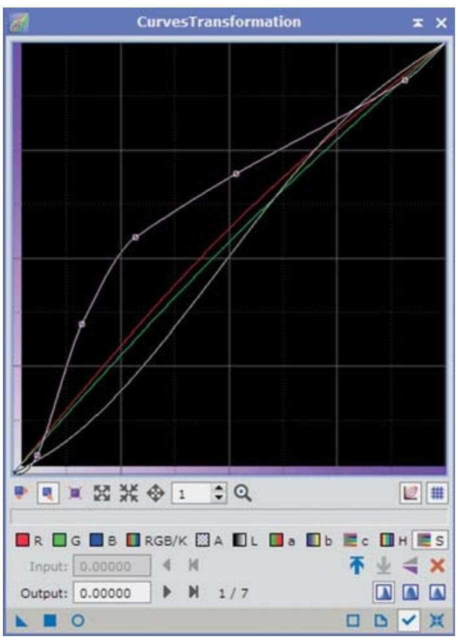
After my LRGB image is created, I might use the CurvesTransformation process to adjust contrast, brightness, and color saturation. Additional tweaks such as sharpening are performed using UnsharpMask, and I might also employ ExponentialTransormation to bring up faint features. The use of masks is advised for all of these steps, with only the final contrast and saturation tweaks on the unmasked image.

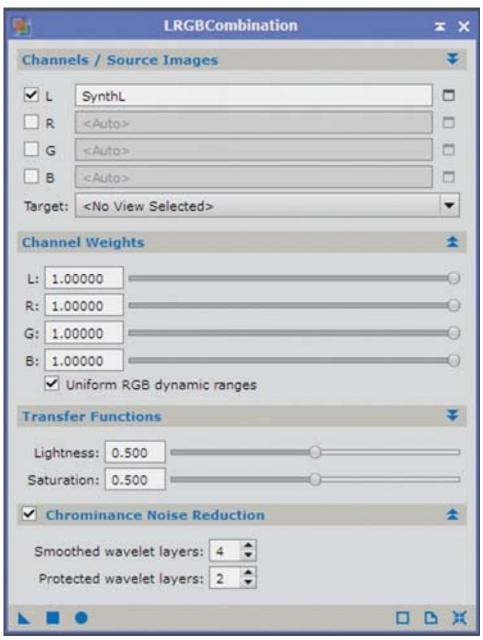
Sharing Online and in Print

Once my image is ready, I'll upload it to my website — and, of course, send it to *Sky & Telescope*. I'd strongly advise serious imagers to invest in a color-managed workflow so that others see your images the same way you do. It's best to use a hardware monitor calibration device such as the Spyder tools available from **datacolor.com**. With a calibrated monitor and *PixInsight*'s color management and proofing tools enabled and properly configured, my images look as good in print as they do online. All the settings and history of your project, including masks, processes, workspaces, and more, can be saved for reference at a later date (File > Save Project).

A final tip — find some constructive and friendly critics on various online imaging forums. Many there know what it takes to make a compelling astrophoto, and they might give you just the idea you need to make a great picture even better. ✦

Ron Brecher images deep-sky objects from his home observatory in Guelph, Ontario. Visit his website at ***astrodoc.ca****.*





FINAL CURVES
Far left: **The Curves process allows you to simultaneously adjust the brightness and contrast of the image (white), and the saturation (pink), as well as the individual color channels.**

ADDING LUMINANCE
Left: **Use the LRGBCombination process to replace the brightness of an RGB image with Luminance data processed separately. The contribution of each to the final result is controlled with the Transfer Functions sliders, and noise reduction can be applied to the color image, all in one process.**

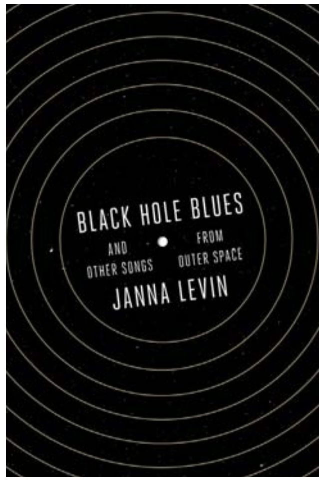
Big Science, Small Science

Black Hole Blues and Other Songs from Outer Space

Janna Levin
Alfred A. Knopf
256 pages, ISBN 9780307958198,
$26.95, hardcover

BLACK HOLE BLUES, Janna Levin's new book on LIGO (Laser Interferometer Gravitational-Wave Observatory) and the search for gravitational waves, builds on a deep literature analyzing "big science" — big-facility projects that employ large numbers of scientists and staff from various institutions, all supported by massive budgets. In its current state, LIGO epitomizes big science: the detection of gravitational waves required multiple teams at multiple institutions to develop multiple instruments at multiple sites over multiple decades. But as Levin shows, the early work in the field of gravitational waves resembled more closely "small science," with research conducted by individuals or small teams bound to a single university or institution. In a small science setting, the scientists functioned semi-autonomously and so were able to respond to data and ideas with as much or as little flexibility as they saw fit.

In *Black Hole Blues,* Levin documents LIGO's transformation from small to big, chronicling particularly well the growing pains during its development from a few ideas at individual labs to one of the largest projects ever funded by the National Science Foundation. She tells LIGO's story through biography and anecdotes, many of which were related to her during interviews with several of the primary actors from the project's early years. These include Rainier Weiss and Kip Thorne, two of the three physicists referred to as LIGO's *troika* (as explained late in the book, out of necessity Levin relies on an oral history recorded in 1997 for most of her discussion of the third physicist in the *troika,* Ron Drever). Personality as much as practicality shaped the founding years of LIGO, and as the search for gravitational waves stretched over years and even decades, succeeding generations of scientists and administrators inherited a project formed by the competing approaches of these three physicists.



While descriptions of the work at and the facilities of LIGO are scattered throughout the book, most of the chapters in *Black Hole Blues* are framed around individual voices — those of Weiss, Thorne, and Drever, but also of physicist Joe Weber and astronomer Jocelyn Bell Burnell, as well as LIGO administrator Rochus "Robbie" Vogt. Levin is at her best when she comes closest to ethnography. The ideas and motivations of the *troika* and collaborators ring through distinctly, despite her mediating prose. In fact, as I read, I found myself becoming more invested in the lives of the individual actors than in the project itself. Admittedly, I knew going in that Advanced LIGO (a series of upgrades moved LIGO's instruments from "initial" to "advanced" via an "enhanced" state) had successfully detected gravitational waves on September 14, 2015. I was much less sure about the outcome for the people who started the project, however. As it turns out, I had good cause to be worried about a few of the book's protagonists.

Black Hole Blues should appeal to anyone interested in the workings of big science, whatever the field — physics, astronomy, molecular biology. The workings of these massive research projects, the balancing of demands made by the various stakeholders, from scientists to adminstrators, are not often seen by the public, simply because it's hard to get a bird's-eye view of such large endeavors. While there are better and deeper explanations of gravitational waves already written, Levin gives her readers a satisfying look at how big science starts, develops, and — in the end — succeeds. ✦

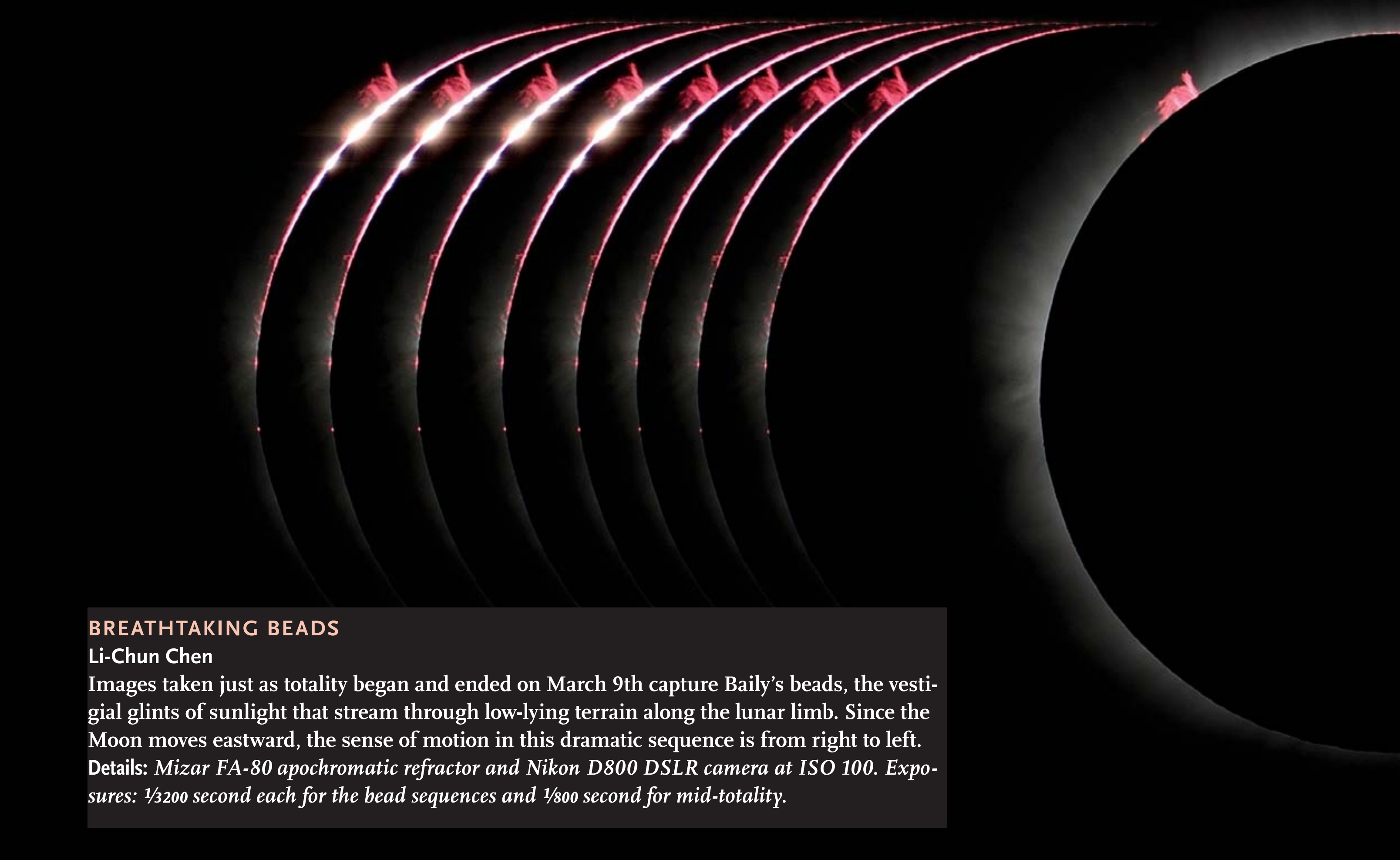
*Observing Editor **S. N. Johnson-Roehr** divides her time between staring at the sky and staring at the pages of a book.*

CORONA OF MANY COLORS

Wolfgang Strickling

The total solar eclipse on March 9th drew many photographers to the track of totality in Indonesia. This dramatic view results from using a handheld polarizing filter oriented 0° with respect to celestial north for the red channel, 60° for green, and 120° for blue. This polarization arises from scattering of radiation by free electrons.

Details: *Canon EOS 850D DSLR camera at ISO 100 with 500-mm mirror lens. Exposures: 1⁄30 and ½ second.*



BREATHTAKING BEADS

Li-Chun Chen

Images taken just as totality began and ended on March 9th capture Baily's beads, the vestigial glints of sunlight that stream through low-lying terrain along the lunar limb. Since the Moon moves eastward, the sense of motion in this dramatic sequence is from right to left.
Details: *Mizar FA-80 apochromatic refractor and Nikon D800 DSLR camera at ISO 100. Exposures: 1⁄3200 second each for the bead sequences and 1⁄800 second for mid-totality.*

◄ **MAGICAL MOUNT RAINIER**

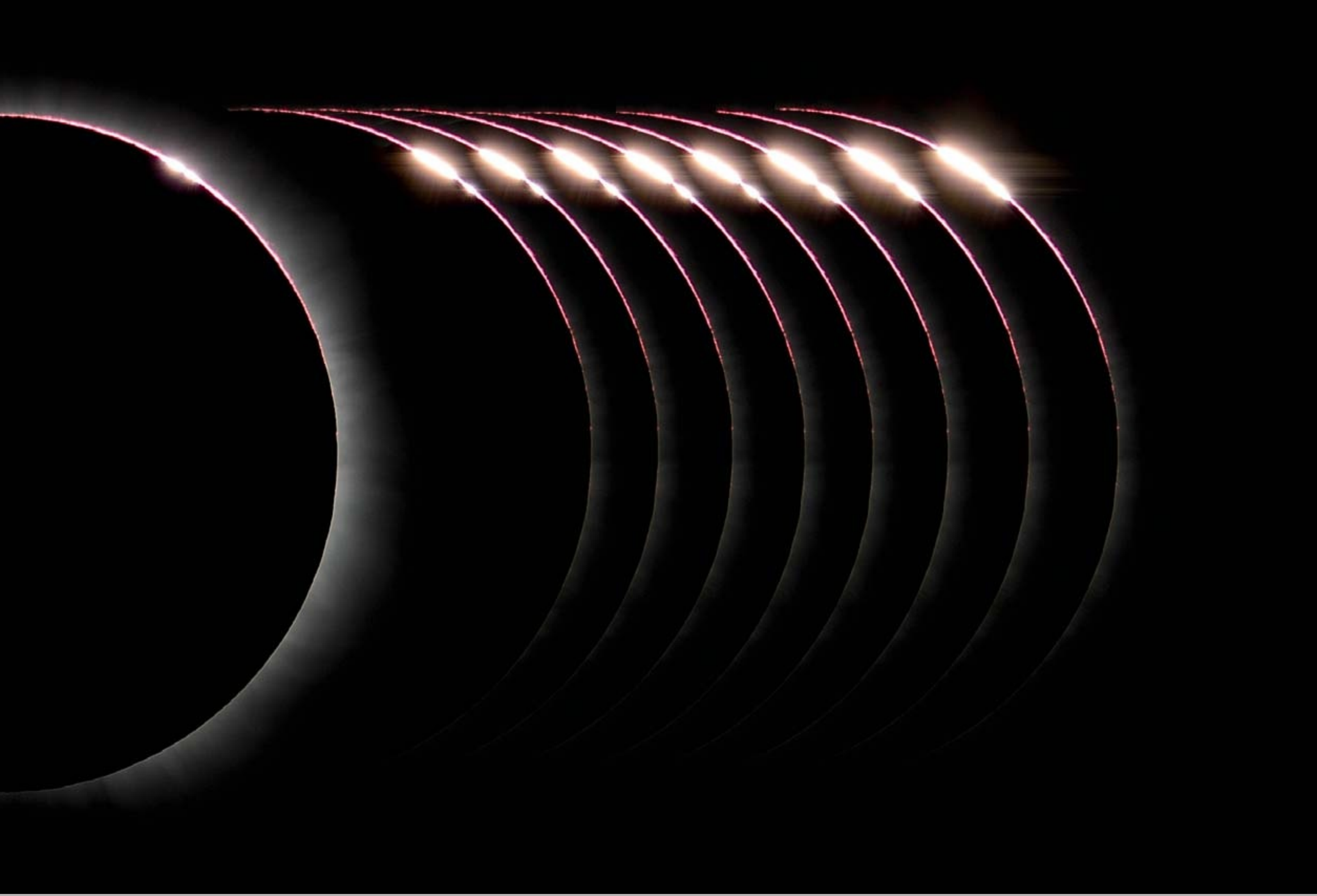
Matthew Dieterich

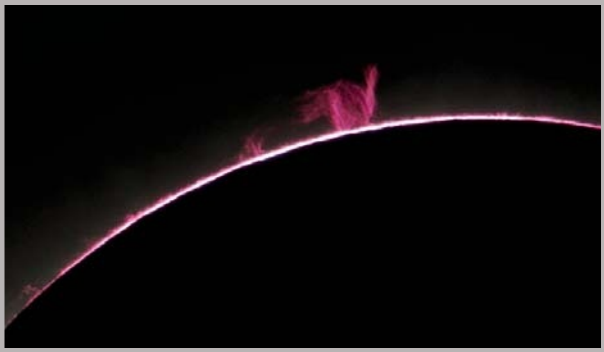
An aurora's pink glow, a sky filled with trailed stars, snow-capped Mount Rainier, and Reflection Lake create a picture-perfect combination good enough to be chosen for a stamp celebrating the U.S. National Park's centennial.
Details: *Nikon D750 DSLR camera at ISO 5000 and 24-mm lens. Total exposure: 27 minutes over 2 hours.*

► **DELICATE DETAILS**

Brian Peterson

Sharpless 170, about 6,500 light-years distant in Cassiopeia, is a faint cloud of ionized hydrogen energized by a hot central star.
Details: *Hyperion 12.5-inch f/8 astrograph and SBIG STL-11000 CCD camera used with Hα and RGB filters. Total exposure: 10½ hours.*





▲ **POLAR PROMINENCE**

Han-Chang Weng

Prominences often come into view when the Moon completely covers the Sun. But this one, seen during March's total eclipse, rose 65,000 km above the Sun's north pole and remained visible throughout totality.

Details: *Takahashi FSQ-106ED astrograph and Nikon D800 DSLR camera at ISO 400. Exposure: 1⁄8000 second.*

▶ **HEART OF THE SUN**

Mohammad Talafha

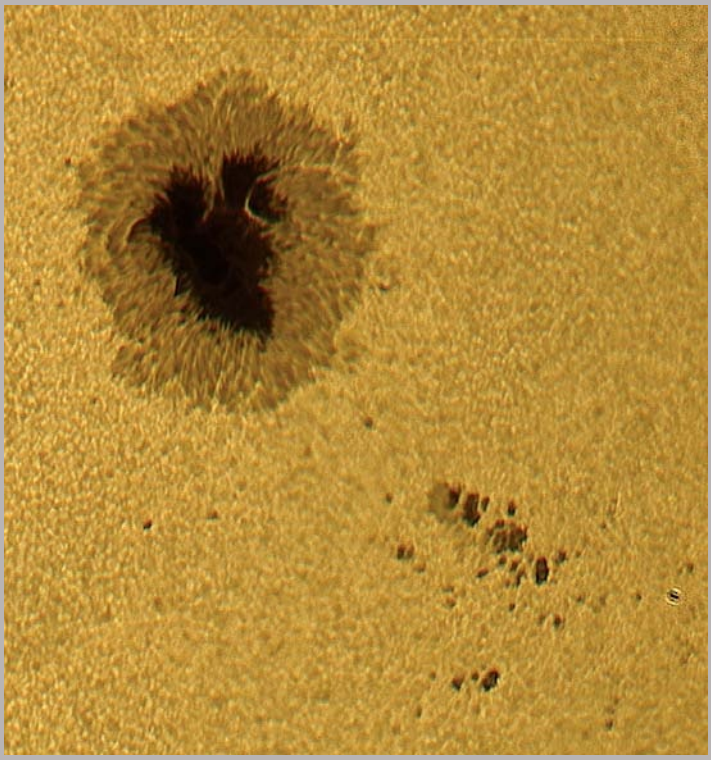
Members of the UAE's Sharjah Center for Astronomy and Space Sciences took advantage of exceptional seeing on April 12, 2016, to record Active Region 2925, whose heart-shaped umbra was three times Earth's size.
Details: *Baader 180-mm apochromatic refractor with white-light solar filter and GigE DFK 33G274 CCD video camera.*

▼ **COMPLEXITY IN CORONA AUSTRALIS**

Brett Soames & Ron Brecher

Located just south of Sagittarius, Corona Australis is often overlooked by observers. But its dusty molecular cloud is one of the closest star-forming regions. NGC 6541, the globular cluster at right, is 13 billion years old.
Details: *Takahashi FSQ-106N astrograph and SBIG STL-11000M CCD camera with Astrodon Gen2 LRGB filters. Total exposure: 8½ hours.*

Gallery showcases the finest astronomical images submitted to us by our readers. Send your best shots to gallery@SkyandTelescope.com. See SkyandTelescope.com/aboutsky/guidelines.



▲ **ECLIPSE OVER TERNATE**
Babak Tafreshi
The small Indonesian island of Ternate proved popular with eclipse chasers last March. A patchwork of clouds adds to the drama as the Moon's shadow races across the volcano-dotted landscape.
Details: *Nikon D810A DSLR camera at ISO 1600 and 35-mm lens. Exposure: 1⁄60 second.*

◄ **SOLAR CORONA'S MAGNETIC THREADS**
Mikhail Semenov, Andrey Oleshko, Aleksandr Yuferev
A painstaking 123-image composite reveals exquisite coronal details during the total solar eclipse on March 9, 2016. Note the ghostly features on the Moon, its landscape lit up by a full Earth.
Details: *Sky-Watcher BK 80ED refractor with Canon EOS 650D camera (ISO 200, 400, 800); Canon EOS 550D camera (ISO 400, 800) with 200-to-400-mm zoom lens at 200 mm. Exposures: 1⁄4000 to 1 second.* ✦

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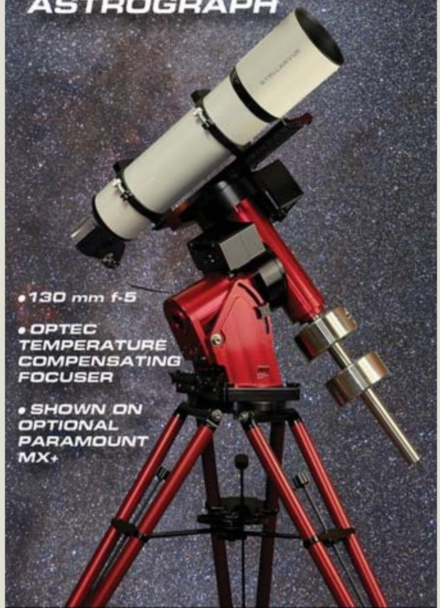


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Astronomers are studying gravity's minute distortions on galaxy images to see the invisible — dark matter.

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The Go To War

Despite recent stirrings, it's over, and happily so — the benefits of Go To are legion.

I THOUGHT THE "Go To War," the long-running debate about whether "real" amateur astronomers use telescopes that point automatically at sky objects, was over. But this sometimes-heated controversy seems to be flaring up again in online forums where amateurs gather and at the clubs I visit. Me? I'm all for computerized scopes, since they're one of the few things attracting new blood into our avocation.

I didn't always feel this way. I first got my hands on the technology more than 20 years ago, in late 1992 to be exact. A fellow club member invested his entire IRS refund in a Meade LX200, the first affordable Go To Schmidt-Cassegrain, and one evening he brought it to our club's dark site, where I was cruising along with my 6-inch Dobsonian. "Ha," I thought, "that thing'll never work. Get a horse!"

How wrong I was. My buddy invited me to give the Go To a try. Punched in "M13." There it was looking beautiful in the eyepiece. M5? Yep. M8, M20, M92, and all the rest of the summer wonders succumbed to the LX200 as quickly as I could push its buttons.

That left only the question of whether amateur astronomers *should* use Go To. Early on, when the subject came up at club meetings, I sided with the curmudgeons complaining about the "coffee grinder" scopes, with their whirring motors, that were springing up like weeds on our observing fields. You had to be able to navigate the sky to be an amateur astronomer. Familiarity with the stars is central to our avocation.

While I believed, and still believe, learning the sky is beneficial for a number of reasons — especially the feeling of accomplishment it brings — I've decided that's not what makes you an amateur astronomer. Instead, knowing something about the objects you observe is far more important than just knowing how to locate them.

S&T: LEAH TISCIONE

Once I admitted this realization to myself, I began to see the good the new telescopes could do for our hobby. Plenty of people enter astronomy, become enthusiastic about it, and then drop out. Once they get past the Moon, bright planets, and a vivid deep-sky object or two, they run out of interesting things to observe. They haven't yet mastered locating objects with a star chart and finderscope and get bored. Go To changes all that. With just a little help and instruction, novices can see dozens of celestial treasures from the get-go.

Something else convinced me Go To is a good thing: the way the blasé faces of teenagers at our club's public outreach sessions lit up at the sight of computerized telescopes. And they *really* lit up when one member sent her scope to targets wirelessly with a smartphone. Kids like computers and phones, and if that's a hook to get them into astronomy — where they'll find that computers are just the tip of the iceberg, coolness-wise — so be it.

Actually, I don't know why I'm worried whether the Go To debate might be creating divisions among us again. It's clear the war is over. Go To is here to stay. Don't like it? Don't use it. If you enjoy hunting for objects, by all means hunt. But stay focused on product, the enjoyment of the sky, rather than process, the type of tool we use to reach night-sky nirvana. ✦

*Contributing Editor **Rod Mollise** has two other articles in this issue: "Visual Filters for Deep-Sky Observing" (page 28) and "Spacewalking with the Meade MWAs" (page 58).*