Book Review: ENCYCLOPEDIC DEEP-SKY HANDBOOK p. 65

Test Report: 3 GREAT $200 TELESCOPES p. 54

Daytime Challenge: MOON OCCULTS VENUS p. 46

THE ESSENTIAL GUIDE TO ASTRONOMY

SKY & TELESCOPE

Dogs & Monsters: Winter Binocular Tour p. 32

DECEMBER 2015

100 Years of GENERAL RELATIVITY

How Einstein Changed Astronomy p. 18

The Search for Gravitational Waves p. 26

Explore the Moon's Mare Humorum p. 48

Moonless Nights for Geminid Meteors p. 44

Deep-Sky Wonders: An Audience with the Queen p. 50

US $5.99
CAN $6.99
12
0 74808 02207 6
Display until November 30, 2015

Visit SkyandTelescope.com

Download Our Free SkyWeek App

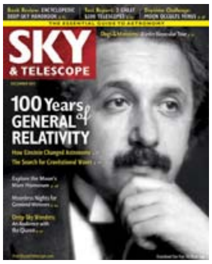
M24 region imaged by Tony Hallas using a Tele Vue-NP101is refractor.

Tony with his Tele Vue eyepiece collection awaits a night of great observing at his dark-sky site.


PL16803 image of Comet Lovejoy courtesy of Gerald Rhemann.


FLI has been manufacturing
KAF-16803 cameras since 2006.
(Sensor shown actual size)

SKY & TELESCOPE
December 2015 VOL. 130, NO. 6



On the cover: Albert Einstein's theory of gravity transformed modern astronomy. We're still unlocking its secrets.

PHOTO: E. O. HOPPE / WIKIMEDIA COMMONS

FEATURES

18 **Astronomy & the Future of General Relativity**

COVER STORY

Albert Einstein published his general theory of relativity 100 years ago this month. Astronomy took half of that time to catch up. Now it's running the show.
By Pedro Ferreira

26 **Gravitational Waves Hit Prime Time**

A century after Einstein predicted the existence of weak ripples in spacetime, scientists say they're on the verge of directly detecting these gravitational waves, thereby opening a revolutionary new window on the universe.
By Govert Schilling

32 **Binocular Holiday**

Take a guided tour of the Milky Way's top attractions.
By Mathew Wedel

©BIGSTOCKPHOTOS.COM / THEROMB. MAP INSERT: GREGG DINDERMAN

OBSERVING DECEMBER

S&T TEST REPORT

ALSO IN THIS ISSUE

There's more to find online @
SkyandTelescope.com

ONLINE MARKETPLACE
Browse personal used equipment and sell your own without paying a fee.
SkyandTelescope.com/marketplace

TIPS FOR BEGINNERS
New to astronomy? Here's everything you need to jump into the fun.
SkyandTelescope.com/letsgo

INTERACTIVE SKY CHART
Find out what the sky looks like for your time and place.
skychart.SkyandTelescope.com

ONLINE STORE
Shop our online store for globes, calendars, atlases, and more.
ShopatSky.com

BUILD COMMUNITY
Seeking fellow astronomy enthusiasts? Find local clubs, planetariums, and observatories in your area, or add your own organization to our listings.
SkyandTelescope.com/astronomy-clubs-organizations

ASTROPHOTO GALLERY
Enjoy readers' best images and upload your own.
SkyandTelescope.com/gallery

Find us on Facebook & Twitter

SKY & TELESCOPE (ISSN 0037-6604) is published monthly by Sky & Telescope, a division of F+W Media, Inc., 90 Sherman St., Cambridge, MA 02140-3264, USA. Phone: 800-253-0245 (customer service/subscriptions), 888-253-0230 (product orders), 617-864-7360 (all other calls). Fax: 617-864-6117. Website: SkyandTelescope.com. ©2015 F+W Media, Inc. All rights reserved. Periodicals postage paid at Boston, Massachusetts, and at additional mailing offices. Canada Post Publications Mail sales agreement #40029823. Canadian return address: 2744 Edna St., Windsor, ON, Canada N8Y 1V2. Canadian GST Reg. #R128921855. POSTMASTER: Send address changes to Sky & Telescope, PO Box 420235, Palm Coast, FL 32142-0235. Printed in the USA.

December 2015 Digital Extra

BONUS WEB CONTENT

- **Gravitational Waves**
  Watch what gravitational radiation does to spacetime, and learn about observatories such as LIGO and LISA.
- **Telescope Reviews**
  Read classic reports on Orion's StarBlast and Astronomers Without Borders' OneSky telescope.
- **Stamps & Astronomy**
  See images of intriguing Soviet & Russian stamps.

Photo Gallery

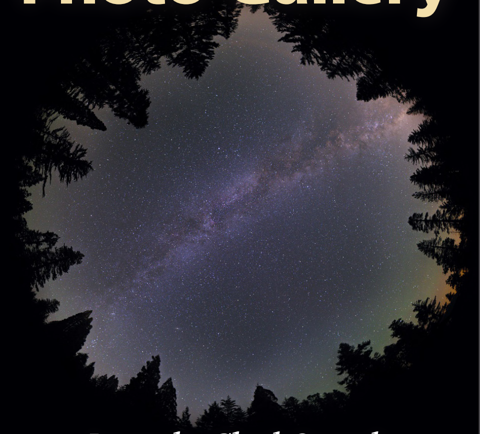


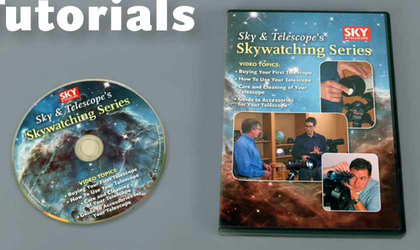
Image by Chad Quandt

EXPLORE OUR WEBSITE!

- **Stargazer's Corner**
  Catch the latest amateur escapades and undertakings in this special section.
- **Observing Eclipses**
  Prepare for eclipsesi n 2016 and 2017 with our online guides to watching and imaging.
- **Free eBook Library**
  We've put together a selection of resources on everything from Saturn to black holes.

TOUR THE SKY – ASTRONOMY PODCASTS

Telescope Tutorials

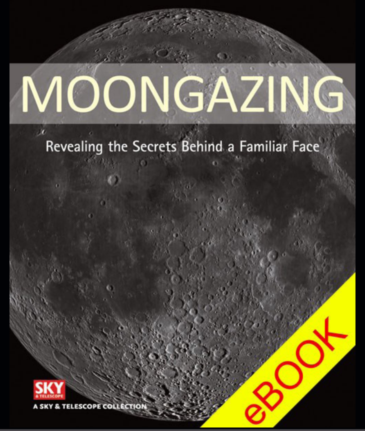


OBSERVING HIGHLIGHTS

Sign up for Newsletters and AstroAlerts

THIS WEEK'S Sky at a Glance

DOWNLOAD OUR APPS



DIGITAL BACK ISSUES:

September, October, and November

Find us on Facebook & Twitter

ONLINE PHOTO GALLERY

Pauline Acalin photographed the lunar eclipse on September 27th with her daughter in Joshua Tree, California.

Peter Tyson
Spectrum

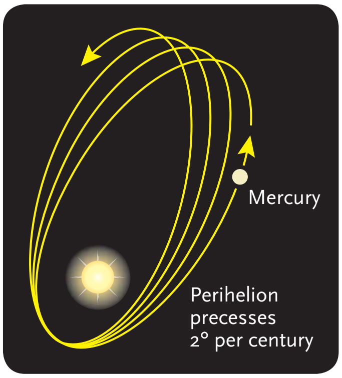
Einstein’s Coup

“HOW HELPFUL TO US here is astronomy’s pedantic accuracy, which I often used to ridicule secretly!” Thus wrote Albert Einstein to a fellow physicist on December 9, 1915, one week after he published his general theory of relativity.

As we celebrate the 100th anniversary of what Nobel laureate Paul Dirac deemed “probably the greatest scientific discovery ever made,” we amateurs and professionals in that field whose “pedantic accuracy” Einstein once scoffed at can savor a choice irony: That accuracy played a key role in both helping Einstein verify his field equations and furnishing him with one of the great eureka moments of his life. “I was beside myself with joy and excitement for days,” he later wrote about the aftermath of this moment.

That accuracy concerned the orbit of the planet Mercury. Astronomers had long known that Mercury’s perihelion — its point of closest approach to the Sun — shifted slightly in a way that Newton’s theory of gravitation couldn’t account for. Nor could Einstein, even just weeks before publishing his theory on December 2nd, get his own theory to account for it either.

But in mid-November he made a thrilling discovery. Einstein decided to check if his still-unfinished equations would yield the same result about Mercury’s precession as astronomers had measured. They did! In short, they predicted that Mercury’s perihelion should shift by about 43 arcseconds per century.



S&T: GREGG DINDERMAN

Astronomers could explain all but 43″ of Mercury’s 2° orbital anomaly. Then came Einstein.

“My boldest dreams have now come true,” Einstein confided to his best friend, Michele Besso, on December 10th. Among other solutions he’d just reached, he told Besso, was his verification of Mercury’s perihelion motion, which he called “wonderfully precise.”

Thus “pedantic accuracy” had become “wonderfully precise.” (Thanks, Albert.)

There’s another irony: Astronomy, which for decades had little to do with general relativity, now leads the way in new science arising from or related to the theory. As Pedro Ferreira explains starting on page 18, “We are entering a new golden age in general relativity” and “it is the astronomers who are now driving its progress.” This includes the search for gravitational waves. As Govert Schilling describes in his article on page 26, a century after Einstein predicted the existence of these weak ripples in spacetime, scientists may be close to detecting them directly.

Gravitational-wave astronomy, once truly under way, would shed light on everything from the Big Bang and galaxy mergers to supernova explosions and gamma-ray bursts, Schilling notes. “Who,” he asks, “would have imagined that back in 1915?”

Well, one person does come to mind. ✦

Peter

Editor in Chief

SKY & TELESCOPE
Founded in 1941
by Charles A. Federer, Jr.
and Helen Spence Federer
The Essential Guide to Astronomy

EDITORIAL
Editor in Chief **Peter Tyson**
Senior Editors **J. Kelly Beatty, Alan M. MacRobert**
Equipment Editor **Sean Walker**
Science Editor **Camille M. Carlisle**
Web Editor **Monica Young**
Observing Editor **Susan N. Johnson-Roehr**

Senior Contributing Editors **Robert Naeye, Roger W. Sinnott**

Contributing Editors **Jim Bell, Trudy Bell, John E. Bortle, Greg Bryant, Thomas A. Dobbins, Alan Dyer, Tom Field, Tony Flanders, Sue French, Steve Gottlieb, David Grinspoon, Ken Hewitt-White, Johnny Horne, Emily Lakdawalla, Jerry Lodriguss, Rod Mollise, Donald W. Olson, Joe Rao, Dean Regas, Fred Schaaf, Govert Schilling, Gary Seronik, William Sheehan, Mike Simmons, Alan Whitman, Charles A. Wood, Robert Zimmerman**

Contributing Photographers **P. K. Chen, Akira Fujii, Robert Gendler, Babak Tafreshi**

ART & DESIGN
Design Director **Patricia Gillis-Coppola**
Illustration Director **Gregg Dinderman**
Illustrator **Leah Tiscione**

PUBLISHING AND MARKETING
Advertising Sales Director **Peter D. Hardy, Jr.**
Digital Ad Services Manager **Lester J. Stockman**
IT Manager **Denise Donnarumma**
Consumer Marketing **Joseph Izzo**

F+W, A CONTENT + ECOMMERCE COMPANY
Chairman & CEO **David Nussbaum**
CFO & COO **James Ogle**
VP / Group Publisher **Phil Sexton**
Chief Digital Officer **Chad Phelps**
Senior VP / Operations **Phil Graham**
VP Communications **Stacie Berger**
Director of Magazine Marketing & Fulfillment **Mark Fleetwood**

Editorial Correspondence (including permissions, partnerships, and content licensing)**:** *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, USA. Phone: 617-864-7360. Fax: 617-864-6117. E-mail: editors@SkyandTelescope.com. Website: SkyandTelescope.com. Unsolicited proposals, manuscripts, photographs, and electronic images are welcome, but a stamped, self-addressed envelope must be provided to guarantee their return; see our guidelines for contributors at SkyandTelescope.com.

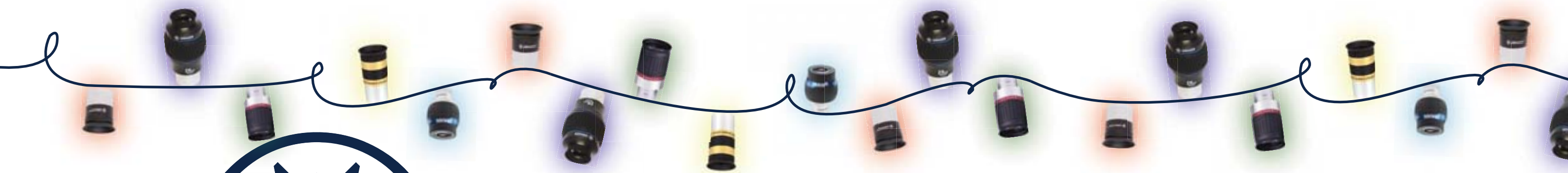
Advertising Information: Peter D. Hardy, Jr., 617-864-7360, ext. 22133. Fax: 617-864-6117. E-mail: peterh@SkyandTelescope.com
Web: SkyandTelescope.com/advertising

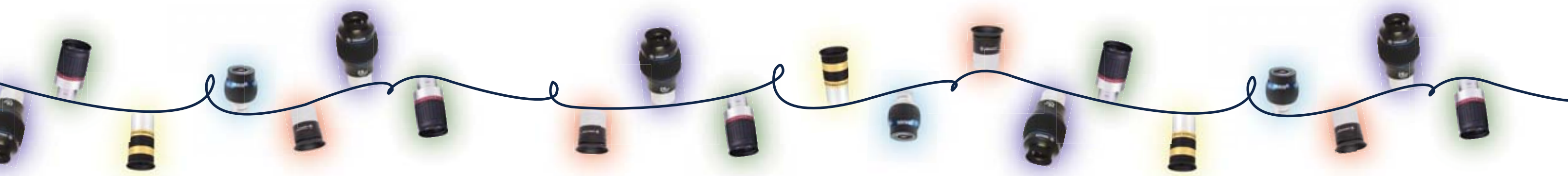
Customer Service: Magazine customer service and change-of-address notices: skyandtelescope@emailcustomerservice.com
Phone toll free U.S. and Canada: 800-253-0245.
Outside the U.S. and Canada: 970-658-2938.
Product customer service: skyprodservice@SkyandTelescope.com
Phone toll free: 888-253-0230.

Subscription Rates: U.S. and possessions: $42.95 per year (12 issues); Canada: $49.95 (including GST); all other countries: $61.95, by expedited delivery. All prices are in U.S. dollars.

Newsstand and Retail Distribution: Curtis Circulation Co., 730 River Rd., New Milford, NJ 07646-3048, USA. Phone: 201-634-7400.


iOptron
SkyTracker ™





S&T: GARY SERONIK

When you look at the full Moon, do you see the visage of a man — or a woman in profile?

Faces on the Moon

Several of the objects listed in Alan MacRobert's article about picking out lunar details by eye (*S&T:* May 2015, p. 50) I associate not with the "Man in the Moon" but rather with the "Woman in the Moon." Her eye is Mare Vaporum, the back of her mouth is Sinus Medii, and the Plinius region forms the base of the front lobe of her hair. Pickering's feature 11, the dark spot known as Palus Putredinis at the foot of Apennines, is not too hard to make out if you imagine it in front of this same lobe of hair. It is also near the landing area for Apollo 15.

Bill Shackelford
Bangor, Maine

While studying lunar topography derived from the laser altimeter on NASA's Lunar Reconnaissance Orbiter (**http://is.gd/LOLA_map**), I happened to spot a peculiar feature on the floor of Apollonius (at right). This crater is just south of Mare Crisium at 5° north, 61° east. The resemblance to a "smiley face" is strong — it reminds me of the no-longer-controversial "Face on Mars" seen by the Viking orbiters.

Anthony Mallama
Bowie, Maryland

Sidewalk Déjà Vu

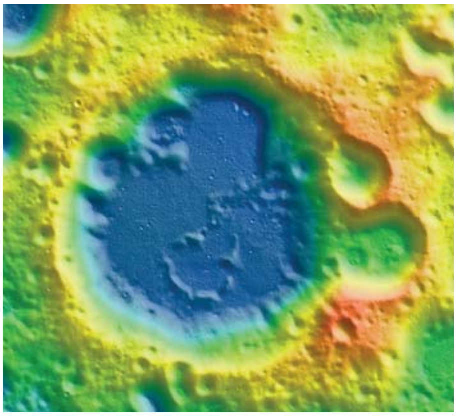
The psychology textbook left on the sidewalk that caught David Grinspoon's eye (*S&T:* June 2015, p. 18) was the first textbook I was assigned when I started college in the fall of 1973. Coincidentally, I began my subscription to *Sky & Telescope* during that same season. At the time, and for the next 42 years, I saw no connection between them. Now in one of life's strange turns, they come together again. Keep the surprises coming!

Sandy Steier
Monsey, New York

Remembering Walter Haas

Thanks for printing the article about Walter Haas's passing (*S&T:* July 2015, p. 18). It brought back many fond memories of making drawings of Mars during the 1950s and sending them to Walter. In 1958 my brother Robert and I stopped in Las Cruces overnight. We found Walter's phone number and called him. He invited us to his house, and we were privileged to observe Mars in his 12½-inch Newtonian reflector. Thanks to Walter and his Association of Lunar and Planetary Observers, many of us amateur astronomers were able to contribute to the recording of planetary details at a time when photos taken by even large professional telescopes were blurred by atmospheric turbulence.

Richard McLaughlin
Pittsburgh, Pennsylvania



NASA / LOLA TEAM

The lunar crater Apollonius, 51 km across, has a happy-looking feature on its broad, flat floor.

Is That Camera Loaded?

A caption in the August issue (p. 63) reads, in part, "The author shot himself on a night of deep-sky imaging. . . ." I hope he wasn't badly hurt.

These slips happen. My husband and I have been subscribers since about 1979. We love the magazine. Although the look, topics, authors, and editors have changed over time — and the science and technology have progressed beyond measure — the approach is the same. It's always been a great read: not terrifyingly technical but never dumbed down. You treat your readers with respect. The enthusiasm for astronomy you all demonstrate is inspiring. To me, way across the world, you feel like family.

Marilyn Hewish
Darley, Victoria, Australia

More About Riccioli's Lunar Names

Andrew Livingston's excellent article, "The Man Who Put the Names on the Moon" (*S&T:* May 2015, p. 26), missed an interesting point. Riccioli was even more broadminded than he seems; he included the names of four Jews on his list.

Messala (Masha'allah ibn Athari, AD 740–815) was a Persian astronomer who wrote what became a standard work on the cosmology of Aristotle. Abenezra (Avraham Ibn Ezra, 1089–1167) was a Spanish rabbi, immortalized in Robert Browning's poem "Rabbi Ben Ezra." French rabbi and astronomer Levi ben Gershon, also called Gersonides (1288–1344), was best known for inventing the Jacob's Staff, a tool used for centuries by sailing ships to navigate by the stars. Finally, Zagut (Abraham Zacuto, 1452–1510) was a Spanish mathematician, astronomer, and historian. He perfected the astrolabe and provided Columbus and Vasco da Gama with new astronomical navigation tables; without him, the great voyages of discovery might never have succeeded.

Lisa Budd
London, England

ATTENTION, SKETCHERS! *Send your best astronomical renderings to gallery@SkyandTelescope.com (put "sketch" in the subject line), and if we get enough good-quality submissions we'll showcase them in a future issue.*

Concerns About Green Lasers

With all the recent press about airplanes being targeted with green laser pointers, is there anything we honest astronomers should do to avoid encounters with the law when using ours for harmless star sighting or aligning? I use mine only briefly and turn it off every time I see a plane approaching. But it can be hard to tell when a plane happens upon the same path as where the laser is pointing.

Dennis Fisher
Upper St. Clair, Pennsylvania

Kelly Beatty replies: *You're wise to be cautious, especially since the beams of these handy devices are becoming more intense. Check out our online guide to using laser pointers safely:* ***http://is.gd/green_lasers***.

Seeing Pluto by Eye

From my rural location, I was able to glimpse Pluto for the first time ever on the night of July 11–12 using 132× on my 10-inch Schmidt-Cassegrain telescope. It would have been utterly impossible without the superb finder chart on *S&T*'s website (**http://is.gd/Pluto_2015**). Pluto was barely visible under the sky conditions I had, though the next night I was able to spot it a little more easily. On July 13–14, with stars in Ursa Minor visible down to magnitude 6.3, Pluto was distinctly visible with averted vision and some direct vision. I really enjoyed knowing that New Horizons was just hours from its closest approach as I watched.

Scott Harrington
Evening Shade, Arkansas

For the Record

✷ *In the caption for the galaxies NGC 5905 and 5908 (S&T: July 2015, p. 59), the identifications were inadvertently switched. They are labeled properly in the chart on page 60.*

Write to Letters to the Editor, *Sky & Telescope*,
90 Sherman St., Cambridge, MA 02140-3264,
or send e-mail to letters@SkyandTelescope.com.
Please limit your comments to 250 words.

75, 50 & 25 Years Ago

Roger W. Sinnott

December 1940

Star Power "The sun continuously pours out enormous quantities of radiation into space. . . . We know, however, from radioactive measurements that the age of the earth is at least 1,500 million years. The sun must be at least as old, and there is no reason to assume that its radiation 1,500 million years ago was much less than it is now. . . .

"The way [to understand a star's energy] was opened when [Ernest] Rutherford discovered, in 1919, the transmutation of atomic nuclei. . . . But it took until 1938 before the particular transmutations responsible were discovered and the agreement of the theory with the observational facts established. . . .

"It has been shown that the carbon cycle accounts successfully for the radiation of the most important class of stars, the so-called main sequence. . . . [Red giants and white dwarfs] have different mechanisms of energy production [which] are not yet known. . . ."

Physicist Hans A. Bethe (Cornell University) was modestly describing the discovery that would earn him a Nobel Prize in 1967.

December 1965

Comet Ikeya-Seki "Favorably placed observers on October 20–21 viewed a comet so brilliant that it could be seen with the naked eye in broad daylight, if the sun was hidden behind the side of a house or even an outstretched hand. This beautiful phenomenon is rare: the most recent daylight comets had been 1927 IX, 1910 I, 1901 I, and the great comets of 1882, 1843, and 1811. . . .

"And after perihelion passage on October 21st, the comet's tail became three-quarters of the earth-sun distance in length. It was seen curving upward from the southeastern horizon during morning twilight."

Ikeya-Seki belonged to the Kreutz family of sungrazing comets. To be visible by day, so near the Sun, it had to shine many times brighter than the full Moon.


Comet Ikeya-Seki (C/1965 S1) looms over the lights of Los Angeles in the predawn sky of October 29, 1965.

S&T ARCHIVES / WILLIAM LILLER

December 1990

Surface of Venus "NASA's Magellan spacecraft . . . is now performing so well that by this time next year geologists should have a better global map of Venus than they do for most of the Earth. . . . The heart and soul of Magellan is an imaging system known as synthetic-aperture radar. . . . The beam's 12.6-centimeter wavelength enables it to pass unimpeded through the planet's thick mantle of clouds. . . .

"Magellan's scientific potential hinges on its ability to resolve surface features as small as 120 meters across — about 10 times better than that achieved in previous radar studies by the Soviet Union's Venera orbiters and by the huge Arecibo radio antenna in Puerto Rico. While extremely useful, these earlier efforts simply didn't provide the fine-scale knowledge necessary to decipher the planet's geologic history. Comments [Brown University investigator James] Head, 'Magellan is a microscope on Venus.'"

In the years since J. Kelly Beatty's report, other spacecraft have explored Venus's atmosphere and climate, but for wholesale surface mapping the Magellan mission of 1990–94 remains the last word.

WITH ALL THESE GREAT PRICES

	Regular price	*Sale price*	***You save***
ProED 80mm Apo doublet	*$649*	*$579*	***$70***
ProED 100mm Apo doublet	*$749*	*$649*	***$100***
ProED 120mm Apo doublet	*$1549*	*$1399*	***$150***
ProView80 OTA/mount package	*$999*	*$899*	***$100***
8˝ Quattro imaging Newtonian	*$610*	*$550*	***$60***
10˝ Quattro imaging Newtonian	*$770*	*$670*	***$100***
12˝ Quattro imaging Newtonian	*$1199*	*$999*	***$200***
90mm Mak-Cassegrain	*$255*	*$225*	***$30***
102mm Mak-Cassegrain	*$305*	*$265*	***$40***
127mm Mak-Cassegrain	*$425*	*$375*	***$50***
150mm Mak-Cassegrain	*$750*	*$690*	***$60***
180mm Mak-Cassegrain	*$1275*	*$1125*	***$150***
190mm Mak-Newtonian	*$1500*	*$1300*	***$200***
6˝ Traditional Dobsonian	*$305*	*$275*	***$30***
8˝ Traditional Dobsonian	*$355*	*$315*	***$40***
10˝ Traditional Dobsonian	*$585*	*$535*	***$50***
8˝ Collapsible Dobsonian	*$449*	*$399*	***$50***
10˝ Collapsible Dobsonian	*$699*	*$629*	***$70***
12˝ Collapsible Dobsonian	*$1049*	*$899*	***$150***
14˝ Collapsible Dobsonian	*$1649*	*$1449*	***$200***
16˝ Collapsible Dobsonian	*$2199*	*$1899*	***$300***
8˝ GoTo Collapsible Dobsonian	*$1035*	*$935*	***$100***
10˝ GoTo Collapsible Dobsonian	*$1335*	*$1135*	***$200***
12˝ GoTo Collapsible Dobsonian	*$2105*	*$1805*	***$300***
14˝ GoTo Collapsible Dobsonian	*$2755*	*$2355*	***$400***
16˝ GoTo Collapsible Dobsonian	*$3655*	*$3155*	***$500***
EQ6 Mount	*$1405*	*$1155*	***$250***
Virtuoso Mount	*$250*	*$225*	***$25***

Save $250 on our beefy, 40-pound payload EQ6 mount. An ideal fit for any of your favorite Sky-Watcher OTAs.

Save up to $200 from our complete line of Maksutov OTAs that deliver high-quality, high contrast optics in compact sizes.

Save up to $200 on our selection of ultra-fast Quattro f/4 imaging Newtonians, the ideal union of aperture and speed.

Thanksgiving is coming up and we here at Sky-Watcher USA HQ have been thinking about making one of those deep fried turkeys, except we're allergic to burning down our place.

STELLAR | Twins Simplify Distance Calcs

Astronomers have devised a new ruler to measure the distance to stars in our galaxy: the spectra of stellar twins.

The most accurate galactic yardstick used today relies on a star's *parallax*, the apparent shift in the star's position as Earth loops around the Sun. The closer the star is to Earth, the more pronounced its shift. This method only works for nearby stars; even the ESA's Gaia satellite (*S&T*: Apr. 2014, p. 10) will measure the parallaxes of only 1% of the stars in the Milky Way Galaxy.

Paula Jofré (University of Cambridge, UK) recently stumbled upon a novel alternative using stellar spectra. Stars with identical spectra have other identical characteristics, including their intrinsic brightnesses. If two stars have the same absolute brightness, but one is twice as far away, it appears one-fourth as bright as the nearby one — a relationship known as the *inverse-square law*. So if astronomers know the closer star's distance, they can accurately estimate how far away the dimmer star lies.

Jofré and her colleagues analyzed 536 stable, Sun-like stars for which high-resolution spectra were available. Within this sample, the researchers found 175 pairs of spectroscopic twins. And for each set of twins, one star had a reliable parallax measurement. With that in hand, they could easily calculate the distance to the other with the inverse-square method.

As the team reports in the October 21st *Monthly Notices of the Royal Astronomical Society*, its technique showed just a 7.5% difference from parallax measurements from the Hipparcos satellite, which in turn have an uncertainty of about 3%. But the twin method's uncertainty doesn't increase for more distant stars — a nagging problem with parallax-based determinations.

■ **SHANNON HALL**

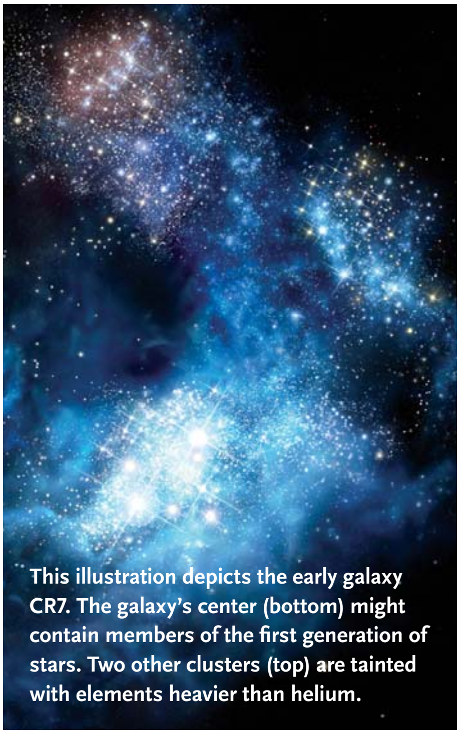
MISSIONS | Next Target for New Horizons

A small body known as 2014 MU$_{69}$ will be the next destination for NASA's New Horizons spacecraft. Astronomers found it in June 2014 with the Hubble Space Telescope, during a dedicated Kuiper Belt search. This object lies 43.3 astronomical units (6.49 billion km) from the Sun and is incredibly dim, 25.6 in magnitude.

Assuming the surface is 20% reflective, its diameter might be about 45 km (30 miles) across — roughly 10 times the size of a typical comet. The team picked 2014 MU$_{69}$ over a slightly larger candidate, 2014 PN$_{70}$, because the spacecraft can reach it more quickly and use less fuel getting there. Its near-circular, low-inclination orbit also implies that this body has not been strongly perturbed or altered since the solar system's formation. Four trajectory corrections in late October and early November should set New Horizons on course for a rendezvous on January 1, 2019 (assuming NASA extends the mission).

■ **J. KELLY BEATTY**

EARLY UNIVERSE | Light Detected from the First Stars?



This illustration depicts the early galaxy CR7. The galaxy's center (bottom) might contain members of the first generation of stars. Two other clusters (top) are tainted with elements heavier than helium.

ESO / M. KORNMESSER

Astronomers have come upon a tantalizing signal that might be from some of the universe's first stars.

The first stars appeared more than 13 billion years ago, in swirling clouds of pristine hydrogen and helium. These first-generation stars, called *Population III*, would have been responsible for churning out the heavier elements that shaped the evolution of second-generation stars and the galaxies they lived in.

Until now, this first, vital generation has been largely hypothetical. Now David Sobral (University of Lisbon, Portugal) and colleagues have discovered that the primordial galaxy CR7 has a spectrum with exactly two emission lines: the Lyman-alpha line from excited hydrogen atoms and another emission line from ionized helium.

"If this is Population-III star formation, then that is very exciting," says Jonathan Tan (University of Florida). "It would be the first example of such a process." But he cautions that marginally contaminated, second-generation stars might also produce the observed spectrum.

Whatever the stars are, they are not alone. The team reports in the August 1st *Astrophysical Journal* that two clusters of redder, second-generation stars lie roughly 10,000 light-years away from the bluish, pristine clump at the galaxy's center. The red stars irradiate their bluer siblings, altering their chemistry. The presence of other stars means that, even if the blue ones are first generation, they are not purely primordial.

The galaxy shines at us from 12.9 billion years ago. It's unclear why one part of the galaxy would already be forging the second generation of stars while another part is just getting started on the first. It could be that we are witnessing a wave of star formation sweep through the galaxy.

■ **MONICA YOUNG**

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

COSMOLOGY | Dark Energy Probably not a Chameleon

A lab experiment has all but nixed one of the theories for the mysterious force pushing the universe apart.

Astronomers don't know why the universe is expanding at an accelerating speed. For lack of a better term, they call the culprit behind this ramp-up *dark energy*. They've come up with a couple of ideas for its nature. One camp proposes it's the energy pent up in empty space itself, known as the *cosmological constant*. Another camp suggests *quintessence*, a fifth fundamental force that doesn't have to be constant — it could have arisen at some point in the early universe and might one day fade away again. Both solutions have their problems.

One version of quintessence involves particles called *chameleons*. In the world of physics, particles and forces are two sides of the same coin, with particles acting as "force carriers." Chameleon particles would carry a chameleon force, and these particles would adjust to their surroundings to hide from detection. But rather than change color, they'd change mass.

Amid high-density cosmic environs like those of Earth, the theory goes, chameleons take on high mass, and high-mass subatomic particles are difficult to detect. In consequence, the fifth force that they carry would become weak and all but impossible to measure, explaining why we haven't detected it. But in emptier space, chameleons shed mass. The fundamental force they represent would thus be felt over longer ranges and could act over cosmic scales to affect the universe's evolution.

Last year, Clare Burrage (University of Nottingham, UK) and colleagues suggested looking for chameleons using a vacuum. Inspired, Paul Hamilton (University of California, Berkeley) worked with collaborators to run the test. They used a small spherical vacuum chamber just 10 centimeters across, with a solid aluminum sphere at the center. Into this sphere, the physicists dropped 10 million cesium atoms and flashed a laser beam at them, three flashes spaced 10 milliseconds apart.

The first laser pulse quantum-mechanically "splits" the cesium atoms into two packets of information that recoil away from each other. A second flash reverses their direction and sends them back together. Then a third acts as a beamsplitter, causing the two cesium waves to overlap and interfere with each other like two sets of ripples in a pond.

If the chameleon field existed, the cesium atoms' interference pattern would show both the effect of gravity and that of the chameleon field. But the experiment found only gravity. With this null result, the team reports in the August 21st *Science*, researchers can rule out the existence of chameleon particles over a wide range of masses.

"The experiment by Paul Hamilton and colleagues is a huge step forward in chasing the chameleon field," concludes Hartmut Abele (Technical University of Vienna, Austria). "Future experiments with atoms or neutrons will either find a chameleon signal or exclude chameleon fields completely."

■ **MONICA YOUNG**

BRIEFS from the International Astronomical Union's General Assembly

More than 3,000 astronomers gathered in Honolulu this August for the IAU's 29th General Assembly. Here are some highlights:

Sunspot Cycle Fairly Constant. Until now, the scientific consensus was that solar activity has been trending slightly upward over the past 300 years. But a new study, presented by Frédéric Clette (World Data Center–SILSO) and colleagues, analyzed 400 years of sunspot records and found that the upward trend is a calibration error. Instead, solar activity has been relatively stable since the 1700s.

■ **BABAK TAFRESHI**

First Gemini Planet. The Gemini Planet Imager discovered its first exoplanet, 51 Eridani b. The gas giant is 13 astronomical units from its 20 million-year-old star. Astronomers could detect the planet directly in infrared light because, being so young, it's still glowing from the heat of its formation at 750 kelvin, or 900°F — relatively cool for a directly imaged planet.

■ **MONICA YOUNG**

First Dark-Sky Sanctuary. The International Dark-Sky Association announced the first Dark-Sky Sanctuary, located in the Elqui Valley of northern Chile. Sanctuaries will designate the rarest and most fragile dark places left on Earth. The new sanctuary, named for Chilean poet Gabriela Mistral, contains more than 90,000 acres and four major facilities, including the Cerro Tololo Inter-American Observatory and the under-construction Large Synoptic Survey Telescope.

■ **BABAK TAFRESHI**

Universe Losing Dust with Time. The new panchromatic Galaxy and Mass Assembly (GAMA) survey reveals that, although the amount of energy radiated in the universe has fallen almost 50% over 1.5 billion years, the share emitted at ultraviolet wavelengths has *increased*. That's because as cosmic time moves on, less dust pervades the universe and so isn't around to absorb UV photons. Although aging and dying stars produce most of the universe's dust (and the universe is aging), the UV photons that stars produce both at the beginning and end of their lives destroy dust. As dust is destroyed, the UV photons move more freely, attacking more dust, said GAMA head Simon Driver (University of Western Australia).

■ **MONICA YOUNG**

More Dwarf Galaxies. Josh Simon (Carnegie Institution for Science) reported that in the first two years of observations collected by the Dark Energy Survey, astronomers have found 17 new dwarf galaxies around the Milky Way. These include nine reported earlier this year (*S&T:* June 2015, p. 12).

■ **BABAK TAFRESHI**


ATIK
CAMERAS

IN BRIEF

Brown Dwarfs Form like Stars. Regular stars begin when dense cores inside massive clouds of gas collapse. Writing in the July 1st *Astrophysical Journal*, Oscar Morata (Academia Sinica, Taiwan) and colleagues present radio observations supporting the idea that brown dwarfs arise the same way. The team imaged 11 proto-brown dwarfs, objects still accreting gas and dust. Four of the young brown dwarfs show radio emission due to jets. Jets are usually seen from young protostars, when the stellar magnetic fields are still strong and the star is spinning rapidly. For those objects, the strength of the radio emission is directly tied to the overall amount of protostarlight. Morata's team found that the proto-brown dwarfs follow the same rule, showing they're more similar to stars than planets.
■ **JOHN BOCHANSKI**

Fade-out for Supernova 1987A. SN 1987A appeared in February 1987, the first time in the telescopic age that a naked-eye supernova lit up our night sky. Observers have kept an eye on SN 1987A over the years to watch it evolve. Two decades ago a glowing ring of "hotspots" around the supernova's center appeared, as the blast's shock wave slammed into material the star had thrown off before it died. Now the necklace of hotspots is beginning to fade. Claes Fransson (Stockholm University, Sweden) and colleagues predict in the June 10th *Astrophysical Journal Letters* that the spots will fade away between 2020 and 2030. Clumps of gas in the ring are likely dissipating, thanks to a combination of instabilities and conduction in the hot gas surrounding them.
■ **NATALIA GUERRERO**

NuSTAR Reveals Hidden Black Holes. Both theory and observations have pointed to the existence of a population of quasars shrouded in a thick veil of dust and gas. These black holes are probably in their teenage years and in the midst of a growth spurt, often brought on by a galaxy merger. But astronomers haven't known how large that population is. George Lansbury (University of Durham, UK) and colleagues have now used NASA's NuSTAR X-ray telescope to study nine suspected veiled quasars, detecting five of them. Compared with previous quasar records, the team estimates in the August 20th *Astrophysical Journal* that there are one-third to three times as many veiled quasars as normal ones.
■ **MONICA YOUNG**

BLACK HOLES | Teeny Supermassive Beast

Astronomers have identified the smallest supermassive black hole ever detected in a galaxy's center.

At the heart of every big galaxy sits a black hole. Some dwarf galaxies have them, too — last year astronomers reported the discovery of 151 active black holes in runt galaxies (*S&T*: Apr. 2014, p. 14). The team was able to determine masses for about two dozen of those black holes, ranging from 80,000 to 6.3 million solar masses.

As part of the ongoing investigation of the remaining 100-plus objects, Vivienne Baldassare (University of Michigan) and colleagues have determined the mass of the black hole sitting in the dwarf disk galaxy SDSS J1523+1145. The team did so by clocking how fast gas is moving near the object, based on how much the gas's whiplash speed smears out its spectral lines. The black hole has a mass between 27,000 and 62,000 Suns, making it the smallest such beast ever found in a galaxy's nucleus, the team writes in the August 10th *Astrophysical Journal Letters*.

By mass, this object might sound like one of the elusive *intermediate-mass black holes*. But the term usually indicates an object that forms differently than stellar-mass or supermassive black holes do, and the black hole in J1523+1145 definitely looks like the leviathans. It lives at its galaxy's center, as bigger ones do. Given its mass, its energy output is also the same. It even influences its galaxy in the same way, somehow governing the speeds of stars that should be out of its gravitational reach.

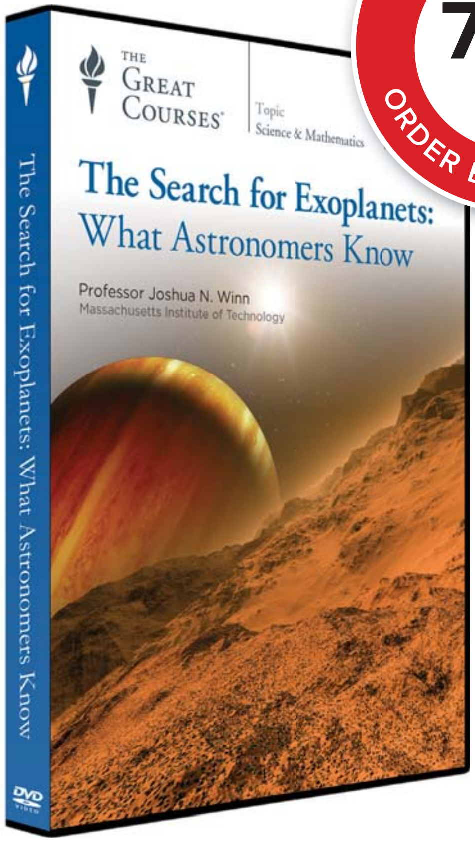
Astronomers hope that J1523+1145's black hole and others like it will help them understand what's going on in the spectrally smeared-out region, which doesn't exist around stellar-mass black holes. The lightweights might also reveal how their larger siblings form: theory predicts that if big black holes come from stellar seeds, they'll initially weigh "too little," given the star speeds in their host galaxies. But if they form directly from collapsing clouds, then they'll begin as too heavy. The newly found black hole is "just right," so we need to study more objects in order to explore the question.
■ **CAMILLE M. CARLISLE**

MARS | Ancient Lake's Salty Mark

Scientists have discovered an ancient lakebed on Mars that dates back to around the time the Red Planet dried up.

In 2010, scientists documented more than 600 chloride salt deposits on the Red Planet's surface. One is a 47-square-kilometer (18-square-mile) deposit in a low point in the planet's Meridiani region. Bryan Hynek (University of Colorado, Boulder) and colleagues have now used spacecraft observations and terrain models to determine that the deposit sits at the bottom of a depression that was once fed by channels flowing in from higher terrain and drained by what looks like a big outflow channel from the depression's lowest point. As the team argues in the August 5th *Geology*, the feature is potentially an ancient impact crater that was degraded and filled with water. The water then evaporated and left the chloride behind.

Based on the number of craters in the landscape that the outflow channel cuts through, the team estimates the lakebed is no older than 3.6 billion years. However, Mars's warmer, surface-water-sustaining era is thought to have ended roughly 100 million years prior. The lake implies that Mars could still preserve some bodies of water shortly after the planet's wet climate era supposedly ended, explains Mohamed El Maarry (Bern University, Switzerland). "This could happen right after a period of intense volcanic activity, for example, or shortly following a large impact event," he says. ✦
■ **ALEX GREEN**


THE GREAT COURSES
Topic
Science & Mathematics
The Search for Exoplanets:
What Astronomers Know
Professor Joshua N. Winn
Massachusetts Institute of Technology
The Search for Exoplanets: What Astronomers Know
DVD

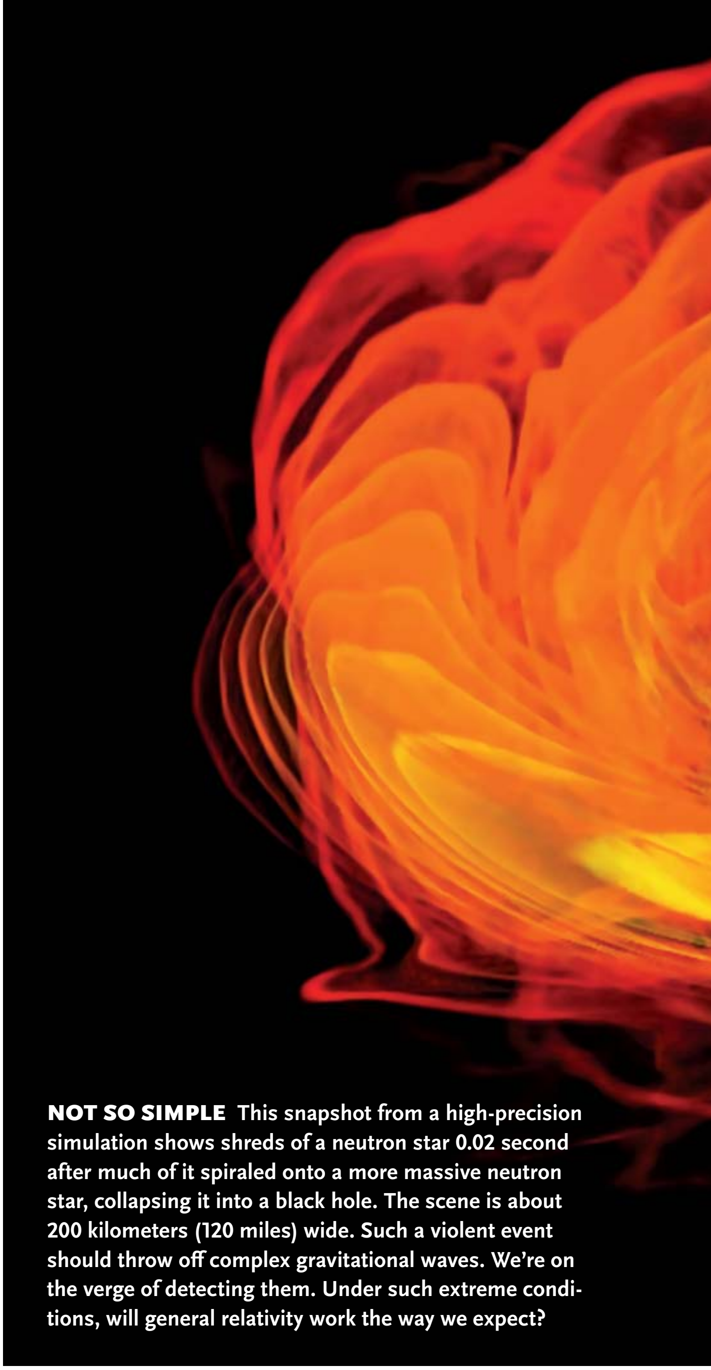
100 YEARS OF GENERAL RELATIVITY:

Einstein's Coming Golden Age

Astronomy & the Future of General Relativity

Albert Einstein published his general theory of relativity 100 years ago this month. Astronomy took half of that time to catch up. Now it's running the show.

PEDRO G. FERREIRA



NOT SO SIMPLE This snapshot from a high-precision simulation shows shreds of a neutron star 0.02 second after much of it spiraled onto a more massive neutron star, collapsing it into a black hole. The scene is about 200 kilometers (120 miles) wide. Such a violent event should throw off complex gravitational waves. We're on the verge of detecting them. Under such extreme conditions, will general relativity work the way we expect?

The summer of 1963 was eventful by any standards. In June President Kennedy proclaimed *"Ich bin ein Berliner"* to the beleaguered citizens of Berlin. In July the spy Kim Philby defected to Moscow. In August Martin Luther King, Jr., declared "I have a dream" to a crowd of a quarter million. And quietly, around the swimming pool of a suburban house in Dallas, Texas, three European emigrés drank strong martinis and planned to resurrect general relativity.

Einstein's general theory of relativity is our modern theory of gravity. It took him eight hard years to figure out, but its essential formula fits on one line. Published on December 2, 1915, it completely transformed our understanding of what gravity *is*.

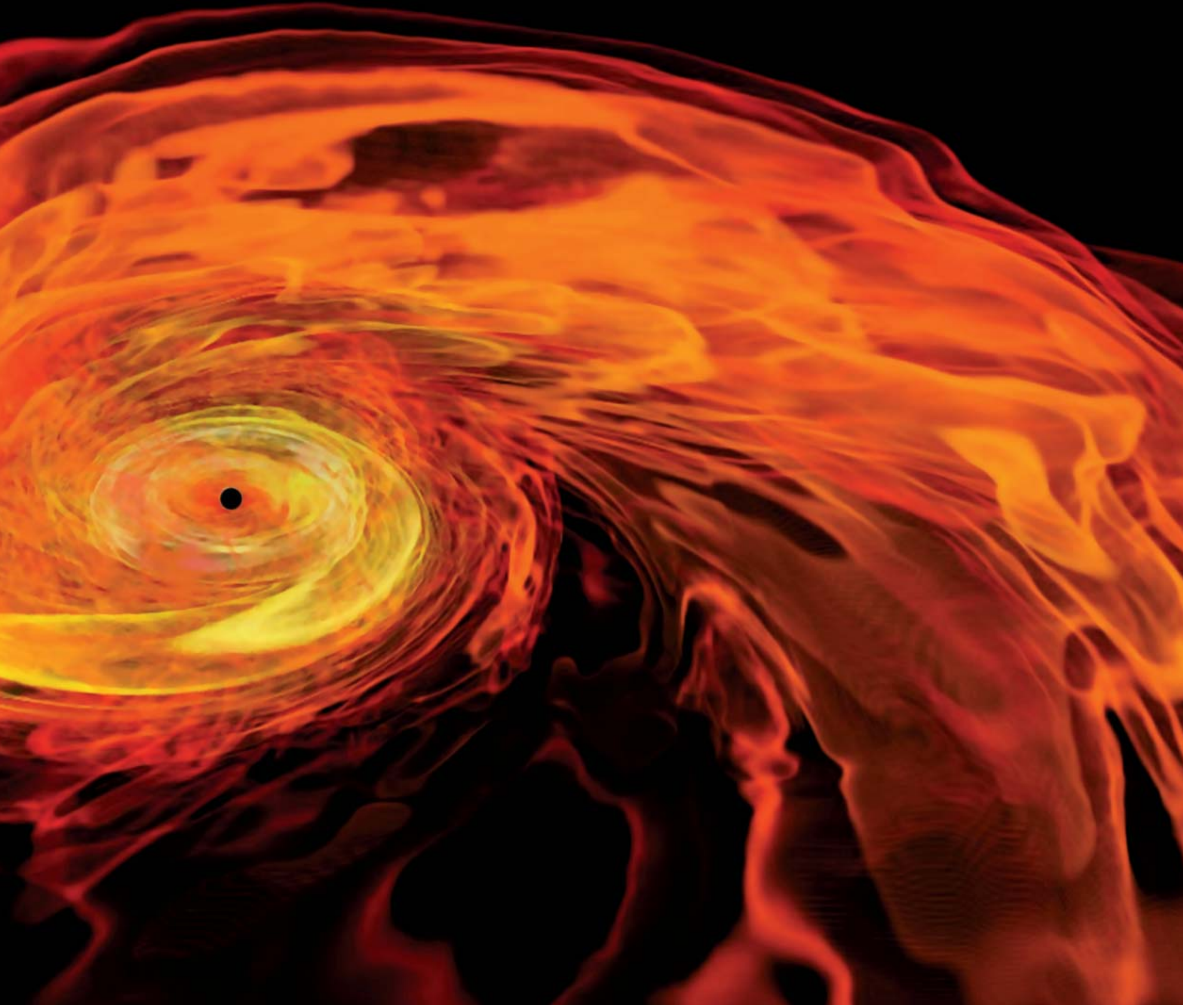
Einstein abolished the gravitational "force" proposed by Isaac Newton, which acts at a distance to pull bodies together according to their masses. Instead, space and time gain a life of their own. They form an interlocked unity, in which time is just another distance dimension except that it's multiplied by the speed of light. This unified, 4D *spacetime* becomes warped by the presence of mass. The warp alters the path that a body takes as it naturally tries (in the absence of any outside force) to continue along a straight line. This works because an object's passage through time is part of its motion through this 4D matrix (see the box on page 20.)

In other words, gravity is just geometry.

General relativity explains, with fantastic precision, the dynamics of everything from pebbles to planets to galaxies. It has passed every exquisite test that has ever been thrown at it.

Moreover, as Einstein immediately realized, it predicted slightly *different* gravitational motions than Newton's theory did. The eureka moment for Einstein came in November 1915, when he found that his spacetime equations perfectly explained the slight drift of Mercury's perihelion point, something that had baffled astronomers.

Most famously, general relativity differed from Newtonian gravity in how much it predicted starlight would



B. GIACOMAZZO / L. REZZOLLA / M. KOPPITZ (MAX PLANCK INSTITUTE FOR GRAVITATIONAL PHYSICS)

bend when it flew close by the massive Sun. The total solar eclipse of 1919, when the Sun would be in front of the Hyades cluster, offered the first great test. An eclipse expedition led by British astronomer Arthur Eddington found (just barely) that the Sun bent the apparent positions of the background stars by Einstein's predicted amount, not Newton's. The news made world headlines and catapulted Einstein to the superstar status he's held ever since.

General relativity, in its utterly weird simplicity and power, has been called the greatest intellectual achievement of all time. It reinvented reality.

But it goes much further than explaining weak effects in the solar system. It required spacetime on a cosmic scale — the universe itself — to be either expanding or contracting. This requirement greatly distressed Einstein because, like everyone else, he assumed that the universe as a whole was static. So it was quite a vindication when, in the late 1920s, astronomers discovered that distant galaxies are flying away from us, and the farther they are the faster they go. The cosmos was indeed expanding, quite uniformly.

General relativity also predicted black holes, points of infinite density and curvature, which are so full of paradoxes that they continue pushing the farthest frontiers of physics today.

It also predicted ripples in spacetime itself, called *gravitational waves* (see the next article, page 26). These carry energy away from violent gravitational events, where spacetime gets shaken like a rug.

How Gravity Is Just Geometry

General relativity says that gravity is nothing more than an object's tendency, in the absence of any force on it, to follow a straight line (technically a "geodesic") through curved 4D spacetime.

Earth bends spacetime by only a very tiny amount. So why does a ball that you toss into the air look like it follows a sharply curved arc? How can that arc be *anything like* a straight line?

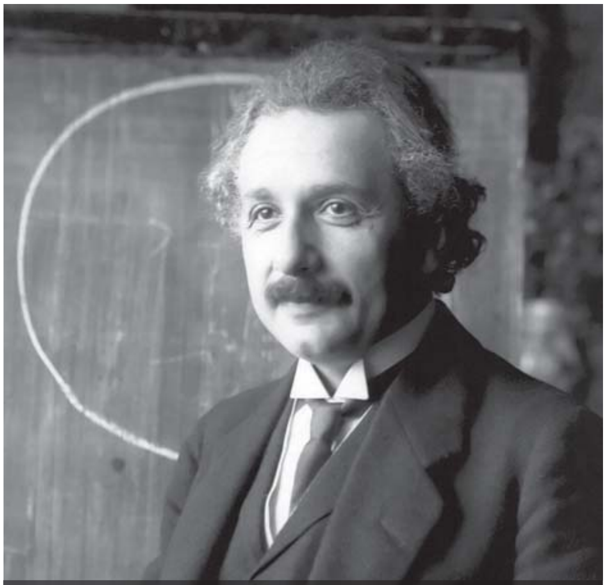
You have to think in 4D. In this perspective, the time dimension is just an extra space dimension that we're plunging through at the speed of light.

In this framework, when you toss a ball from one hand to the other, the 1 second in which the ball may be in flight is an enormous 1 light-second long: 300,000 kilometers (186,000 miles). What looks like the ball's short, sharp arc is actually stretched way out long in this unseen dimension.

You don't see how nearly straight the line is, conforming only to the very slight warping of spacetime caused by Earth, because you're moving through the time dimension right alongside the ball.

Similarly, the weight that you feel when you hold a heavy object in curved spacetime is the *acceleration* force that you have to apply to it to continually bend it away from the straight trajectory it's trying to follow as time races forward.

— Alan MacRobert



AHEAD OF HIS TIME Albert Einstein loosed general relativity onto astronomy a half century before astronomy could do much with it, aside from checking for very tiny effects. This portrait was taken in 1921, two years after the eclipse experiment of 1919 made Einstein a superstar.

FERDINAND SCHMUTZER

But most of this remained theory on paper. Astronomical techniques were not yet up to testing general relativity's wilder predictions. Some of which were hard to believe anyway.

The 1960s Revival

Fast forward half a century. Those three physicists around the pool in Texas, Alfred Schild, Engelbert Schücking, and Ivor Robinson, had fallen in love with general relativity, learning their trade in the few isolated pockets where it was still studied in earnest. For the past three decades, quantum mechanics had sucked much of the young physics talent into figuring out its weird and wonderful practical consequences, leaving general relativity in the long grass. As a result, GR (as it was known) had acquired a reputation for being esoteric and difficult: a topic for mathematicians, not physicists. And definitely not for astronomers.

But the universe was becoming insistent. With the growth of radio astronomy after World War II, new starlike objects were discovered that pumped out exorbitant amounts of energy as radio emission and light. These "quasi-stellar radio sources" displayed mysterious optical spectra — until Maarten Schmidt realized in 1963 that the spectrum of the brightest, 3C 273 in Virgo, was fairly normal, just unbelievably redshifted. It seemed to be more than a billion light-years away.

How could a starlike point appear so radio-powerful and optically bright (13th magnitude) from such a distance? It had to be truly massive. And when an object is both very massive and very concentrated, its gravity must be so intense that GR ought to play a dominating role.

These objects were the hook that the three Texas relativists needed to reel in the astronomers. They decided to organize a conference that would show astronomers how much they needed relativists in order to make sense of the cosmos. In December 1963 they put together the first Texas Symposium on Relativistic Astrophysics.

Scattered among astronomy's bigwigs at the event were a handful of pure relativists. Over three days of talks, the observations were taken apart. Fred Hoyle, always quick to come up with new ideas, had proposed that the quasi-stellar radio sources (later shortened to *quasars*) were nothing more than stars with a million times the mass of the Sun pumping out light as they imploded. Robert Oppenheimer, father of the atom bomb, had written one of the seminal papers on gravitational collapse in general relativity. He had shown that neutron stars (purely theoretical at the time) would, if they collected enough material, collapse to become what were later named black holes. He came to see what all the fuss was about, and, looking around at the excitement, told *Life* magazine that the meeting reminded him of the early days of quantum physics, "when all one had was confusion and lots of data."

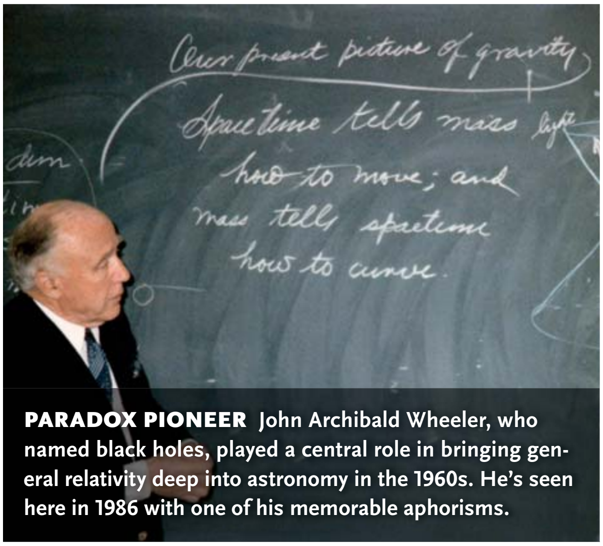
Roy Kerr, one of Alfred Schild's postdoctoral students, stood up and presented a new solution to the equations of general relativity. That summer he had found that black holes could be more complicated than physicists had thought: they could spin, dragging spacetime around with them. Kerr's solution would play a huge role in explaining the quasars as rotating black holes shredding material around them and funneling some of it into radio-emitting jets. But at the meeting his radical new result was too mathematical, too dry, and it seemed to fall on deaf ears among the astronomers. Yet, they were intrigued by what the relativists were saying. From now on the astronomers would need to pay closer attention to Einstein's theory if they were going to understand their own data.

Astronomer Thomas Gold gave the after-dinner speech. He celebrated the beginning of a new era. About the quasars, he said, "Here we have a case that allowed one to suggest that the relativists with their sophisticated work were not only magnificent cultural ornaments but might actually be useful to science!"

The Texas relativists' gamble had paid off. The "Texas Symposium" became a biannual event (the 28th happens this December 13–18 in Geneva, still under the same name). Over the next half decade, the exotic lore of general relativity — black holes, cosmology, gravitational waves — became part and parcel of astrophysics. Today they are inextricable. And new frontiers are opening.

Next Step 1: The Event Horizon Telescope

One of the speakers at that first Texas Symposium was John Archibald Wheeler. In his inimitable style he covered the blackboard with elaborate colored drawings of spacetime, the insides of neutron stars, and aphorisms such as "the issue of the final state." He was obsessed with Oppenheimer's discovery that overloaded neutron stars must collapse to a mathematical point with zero size, the mass of a star, and infinite density. Could that possibly be true? No infinite value ever exists for any physical quantity in nature . . . supposedly. Wheeler's philosophy, he later recalled, was that "by pushing a theory to its extremes, we also find out where the cracks in its structure might be hiding."

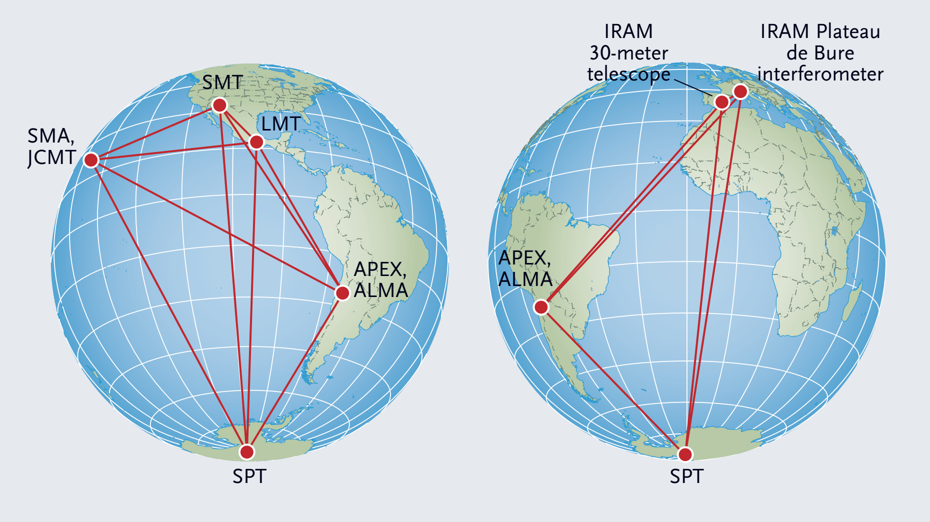


PARADOX PIONEER John Archibald Wheeler, who named black holes, played a central role in bringing general relativity deep into astronomy in the 1960s. He's seen here in 1986 with one of his memorable aphorisms.

EMILIO SEGRE / VISUAL ARCHIVES / AMERICAN INST. OF PHYSICS / SCIENCE PHOTO LIBRARY

As I look around at astronomy today, I see this viewpoint guiding some of the great astronomical endeavors of the 21st century. For a start, black holes remain one of the bugbears of physics even as astronomers find them in abundance. It's not just that they should have a central point of infinite curvature and density. Black holes that form by real-world processes should also surround themselves with an event horizon, a "surface" out of which nothing can escape, that gives fits to the theory of quantum mechanics.

In the 1960s, X-ray, radio, and optical measurements made a compelling case that the X-ray source known as Cygnus X-1, a *something* orbiting a giant, 9th-magnitude



S&T: LEAH TISCIONE, SOURCE: EHT PROJECT

WORLD'S SHARPEST TELESCOPE Millimeter-wave observatories around the globe are linking up to form the Event Horizon Telescope, a giant interferometer with baselines nearly as wide as the planet. Its team plans to incorporate at least nine dishes and arrays. The final network, with its very long baselines and very short operating wavelengths, should resolve features as tiny as 15 microarcseconds, sharp enough to reveal geometrical effects right around the black hole at the center of the Milky Way.

B star 6,000 light-years away, behaved just like matter spiraling down to the event horizon of a stellar-mass black hole. Within a few more years, the explanation of quasars as hot matter jamming into much more massive black holes became well established. My theoretical colleagues now believe that the supermassive black holes at the centers of most galaxies play a crucial role in the development of galaxies themselves. The powerful winds from such a hole's immediate surroundings can clear the gas right out of a galaxy and halt its star formation.

Yet we have never directly seen a black hole. Two things work against us. First of all, it is "black": its boundary, the event horizon, by definition emits no observable radiation. Second, black holes are very, very small. A 1-solar-mass black hole has a radius of only 2.95 kilometers. Even the 4-million-solar-mass black hole at the center of the Milky Way, which drives the radio source known as Sagittarius A* ("A-star"), has an event horizon less than a tenth of an astronomical unit in radius — 20% as large as Mercury's orbit. Trying to image it from Earth would be like trying to resolve the width of a poppy seed in Los Angeles from the distance of New York.

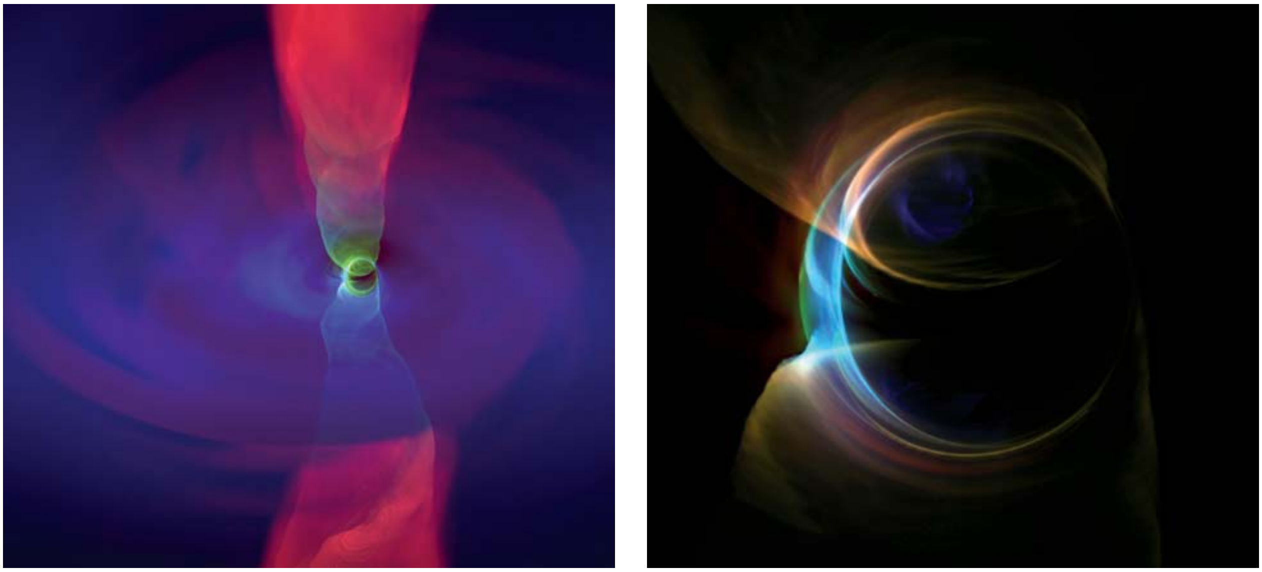
The Event Horizon Telescope should soon do it. The EHT is a consortium of telescopes in Chile, Europe, North America, Hawaii, and Antarctica observing at wavelengths of about 1 mm: in the part of the electromagnetic spectrum between the far infrared and short microwaves. The Milky Way's dust clouds are transparent to millimeter waves, and so is the dense maelstrom around Sagittarius A* itself. So we have an unimpeded view right down to the hottest material immediately around the event horizon.

The EHT's dishes, carefully linked and exquisitely phase-matched to work together as an interferometer, resolve sources almost as well as a planet-size radio dish would (*S&T*: Feb. 2012, p. 20). The long baselines, combined with the very short wavelength used, should enable the EHT to resolve Sgr A* down to a resolution of some 15 microarcseconds. That should be enough to image the black hole against the background of hot gas immediately surrounding it.

What will the EHT see? The spacetime around the event horizon should be so warped that light rays will wrap partly around it, creating an eerie, distorted apparition: a thin crown of light surrounding a silhouetted dark orb, which should be distorted and magnified by gravitational lensing to appear about five times larger than the actual event horizon.

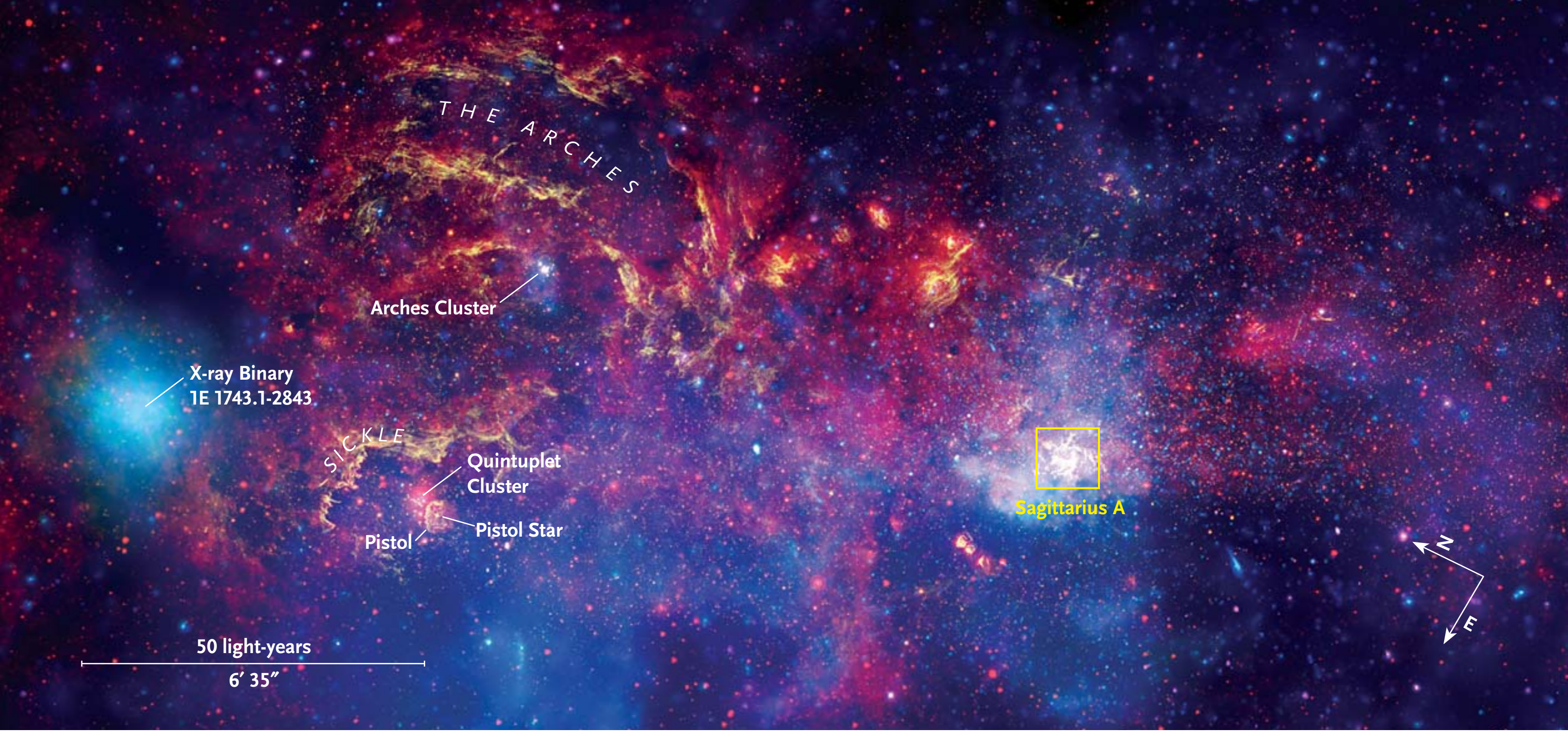
The picture the Event Horizon Telescope will take won't be sharp; the hole's magnified silhouette should appear just 10 or 15 pixels across. But for the first time, we should truly be able to see a black hole's surface pushing up through our limits of observation.

The shape of the silhouette, and how the bright crown wraps around it, will tell us whether what's there matches what GR predicts. For the first time we'll be able to explore the limits of GR directly in a place where

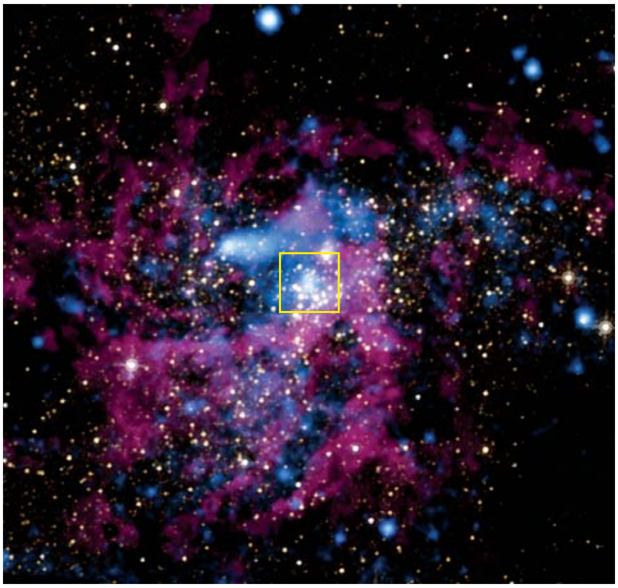


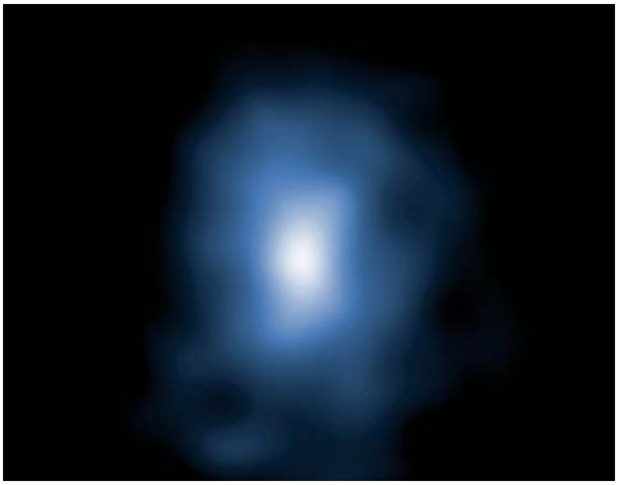
SHEPERD DOELEMAN / CHI-KWAN CHANG (2)

MONSTER TO EMERGE Close to the Milky Way's central black hole, accreting material should appear very distorted in particular ways predicted by general relativity. This frame (wide view and close-up) is from a simulation just after the hole has swallowed a "hot spot" that spiraled in through a weak accretion disk. The hole is assumed to be rapidly spinning. *Left:* Red is radio emission, green is infrared, and blue is X-ray. Some of the infalling blob was ejected in jets confined by magnetic flux tubes. The top tube is aimed more toward us; its base is seen partly superposed on the silhouette of the hole. *Right:* A closeup with brightnesses adjusted and recolored to show finer detail. The inner edge of the accretion disk is blueshifted and brightened on the side approaching us, and dimmed almost to invisibility on the side moving away. Light from behind is warped into view to ring the silhouette completely.



A ZOOM TO THE MILKY WAY'S CENTER The view above, 245 light-years wide, encompasses many landmarks of the central Milky Way including Sagittarius A. The view is 0.5° wide, about the width of a 120× eyepiece view — except you can't see at these wavelengths. This image combines X-rays (blue), near-infrared hydrogen emission (yellow), and broadband mid-infrared (red). The yellow box shows the area of the frame at right.





Right: In the Milky Way's central 7.5 light-years, swirls of hydrogen (red), X-ray emitters (blue), and giant stars (emitting infrared, yellow) orbit the galaxy's surprisingly subdued central black hole. ***Bottom right:*** An X-ray close-up of the inner 0.7 light-years around the hole. Much of the glow comes from a swarm of hot giant stars. The hole itself would be a microscopic pinprick here.

STSCI / NASA / UMASS / SSC / S. STOLOVY / D. WANG ET AL. (3)

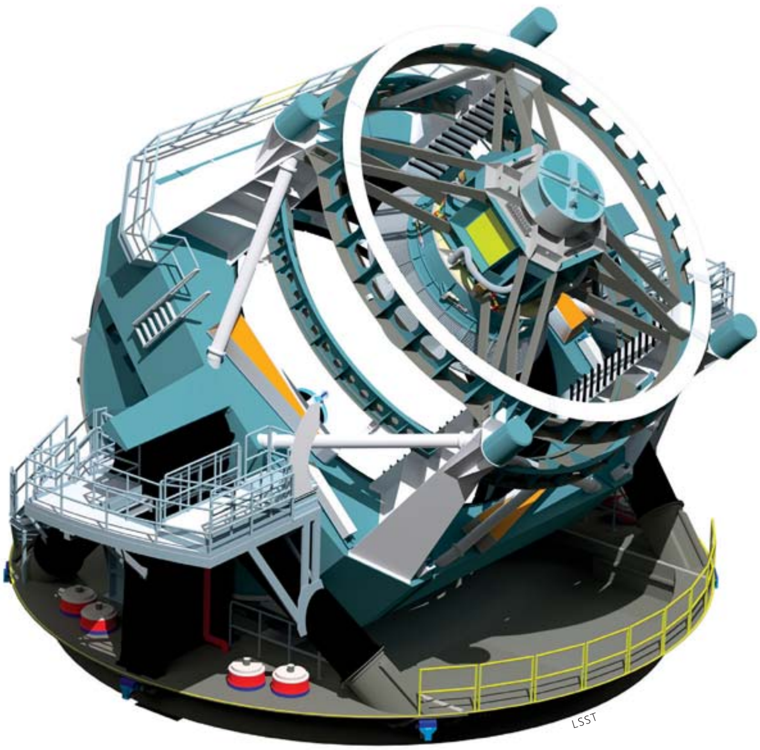
gravity is truly extreme. This is an obvious place to look for the "cracks in the structure" that Wheeler sought.

The EHT's designers also plan to observe and image the much larger black hole at the center of the supergiant elliptical galaxy M87. It's 2,000 times farther away, but with an estimated 6 billion solar masses, it should be 1,500 times wider. (A black hole's radius goes up in direct proportion to its mass.)

Next Step 2: Gravitational Wave Astronomy

On a different instrumental front, the next few years should open a completely new window on the universe: gravitational wave astronomy. Just as we've used electromagnetic waves to see celestial objects since the first humans looked up, we will begin to use gravitational waves to observe some of the most cataclysmic events.

Gravitational waves are those shaken-rug ripples in spacetime. GR predicts that any accelerating mass creates them. They become significant when the masses and accelerations are extreme — for example, if two


LSST

ALL-SEEING EYE The 8.4-meter Large Synoptic Survey Telescope (LSST) will be the most powerful survey telescope ever built. Among other things, it will map billions of galaxies back to the first era of galaxy formation, helping to determine the large-scale structure of spacetime throughout cosmic history. Will relativity hold up or need a rewrite?

neutron stars or black holes orbit each other tightly at a fair fraction of the speed of light. We know gravitational waves are real because we see their indirect consequences. For the last 40 years we have been monitoring a particular pair of neutron stars, PSR B1913+16, discovered by Russell Hulse and Joseph Taylor (for which they won the 1993 Nobel Prize in Physics). Radio astronomers continue to track the slow, inexorable decay of the neutron stars' mutual orbit as gravitational waves carry orbital energy away — at exactly the predicted rate. This is compelling evidence, but, as with black holes, we haven't yet seen gravitational waves directly.

That's also about to change. As described in the following article, a consortium of gravitational wave detectors around the world is virtually certain to see the powerful bursts of ripples flung out when pairs of neutron stars as distant as 500 million light-years from us finally spiral into each other and merge. Even more exciting is the possibility that we will pick up the final inspirals of pairs of black holes. In this case the most outlandish predictions of general relativity, black holes and gravitational waves, would show us their most extreme behavior combined. The signal from such an event can be precisely modeled from GR theory. Will it match what we see?

Next Step 3: Cosmic Structure

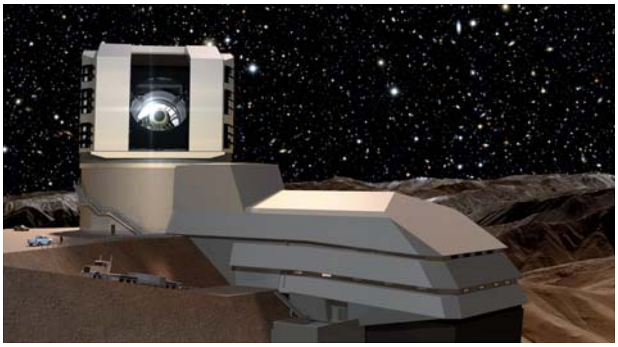
Astronomers are also embarking on an ambitious campaign to map out, over the next two decades, the 3D positions of essentially all the large observable galaxies within our cosmic horizon — and thereby reconstruct, with unprecedented precision, the largest-scale structure of spacetime itself. By accurately understanding how galaxies are laid out to form the cosmic web, and how spacetime warps itself around the galaxy superclusters, filaments, and walls, we will try to understand why, among other things, the expansion of the universe started to *accelerate* about 7 billion years ago.

Earlier than that, the expansion of the universe was slowing due to the gravitational pull of all matter on all other matter. But as space expanded and matter thinned out, some repulsive effect, discovered only in 1998, began to predominate over gravity. Is some kind of "dark energy" doing the pushing? Or does GR itself need to be reformulated or even discarded on cosmological scales?

For now, the leading opinion is that GR remains valid but a weak repulsive force is structured into the fabric of empty space itself. That's because the force seems to work like Einstein's long-abandoned "cosmological constant," which he named Lambda (Λ). From what we can tell so far, this mysterious space-pressure has remained constant throughout cosmic history. That is, despite space expanding, a cubic centimeter of space always contains the same amount of it. This is in contrast to things that exist *in* space, such as particles and fields, which thin out as space expands. But is that the true picture?

The Euclid satellite, supported by the European Space Agency, should launch at the end of this decade. Euclid will map large swaths of the universe, in particular galaxies as they existed when the universe was close to half its current age (around redshift 0.8). That's about when the cosmic expansion started speeding up. We'll get a good read on how gravity worked at that time.

Euclid will harness another of GR's great predictions: *gravitational lensing*. Gravitational lensing is the bending of light rays passing a massive object; it's the effect Eddington's expedition tested with the 1919 solar eclipse.


LSST

LOOKING AHEAD An architect's drawing (with a Hubble Deep Field backdrop) of the finished LSST facility.


LSST

COMMITTED The LSST is now under construction on Cerro Pachón in Chile. The building should be completed in January 2018, and the telescope should be finished and starting its program of observations in 2023.

By imaging a billion very distant galaxies and analyzing their slightly distorted images, we can use large-number statistics to reconstruct the characteristic warps and bends of huge regions of spacetime at various epochs.

Complementary work will happen on the ground. Moving rapidly forward is DESI, the Dark Energy Spectroscopic Instrument, which will measure redshifts and hence 3D positions for more than 30 million galaxies and quasars to redshift 3.5. But the king of all optical surveys will be the Large Synoptic Survey Telescope (LSST), now under construction in Chile. It will be the largest sky-survey camera ever, with an 8.4-meter, f/1.18 primary mirror and a 3,200-megapixel imager. It should begin work in 2023, monitoring some 37 billion stars and galaxies. Analyzing the fingerprints of dark matter and dark energy in its data will be a priority.

In parallel, preparations are under way in South Africa and Australia to build the largest radio telescope ever conceived. The Square Kilometer Array (SKA) will combine radio dishes and tens of thousands of small, fixed antennas that observers can electronically sync to reconstruct signals from across the sky. The SKA will have a total collecting area of close to a square kilometer, carefully tuned to be able to look wide and deep.

A key plan for the SKA is to map early clouds of hydrogen. These should mark where and when the first galaxies formed and how they gathered to form the cosmic web. This will, again, help show how gravity and perhaps dark energy have worked throughout cosmic history and how spacetime has evolved over a vast range of scales.

New Beginnings

Engelbert Schücking, one the Texas relativists, used to say, “An important contribution of the general theory of relativity to cosmology has been to keep out theologians by a straightforward application of tensor analysis.” For many years, it also kept out astronomers. The theoretical maths were too hard and esoteric for any right-minded astronomer to waste time on.

In 2007, I was asked to be part of an advisory board to assess proposed satellite missions for the European Space Agency’s Cosmic Visions program. With my colleagues, I waded through a stack of proposals for scientific missions that could cost up to $1 billion. Teams of astronomers had thought out the most audacious and fantastic experiments they could perform in space. To my delight, almost all of the best proposals had, in one way or another, general relativity at their core.

Sitting on that panel, it became clear to me that the vision of that Texas meeting, almost half a century before, was playing out at a completely new level. We are entering a new golden age in general relativity, fuelled by new developments in astronomy and astrophysics. As general relativity turns 100, it is the astronomers who are now driving its progress. ✦

***Pedro G. Ferreira** is professor of astrophysics at the University of Oxford and director of the Beecroft Institute for Particle Astrophysics and Cosmology. He studies the effects of general relativity on cosmological scales. He has written a biography of general relativity,* The Perfect Theory.

100 YEARS OF GENERAL RELATIVITY:

Gravitational Waves

Gravitational Waves Hit Prime Time

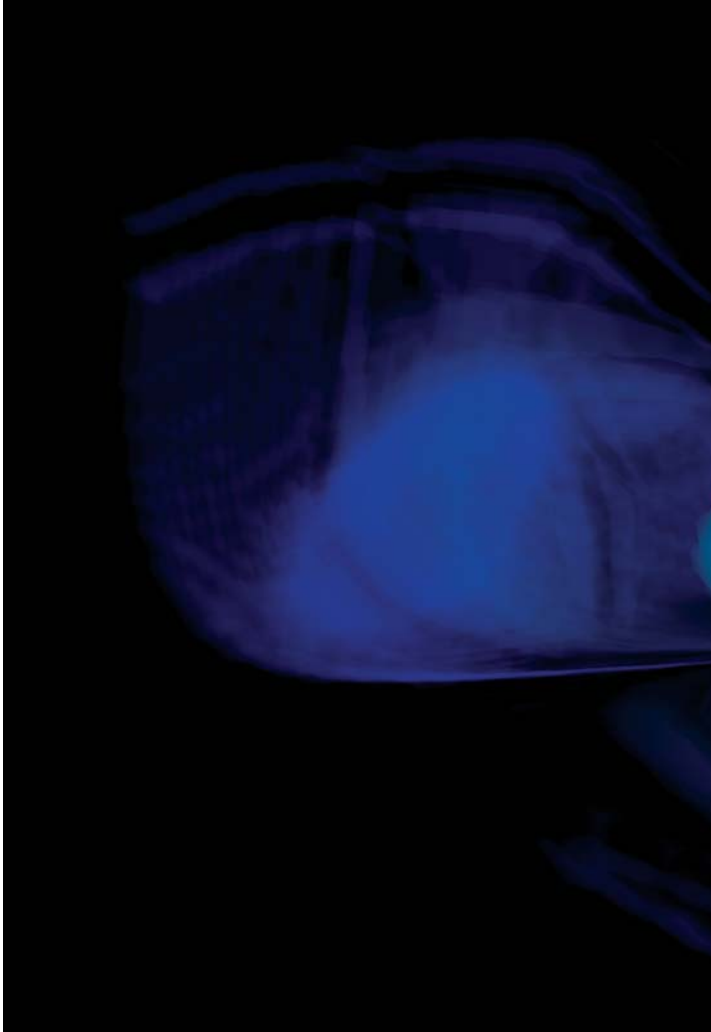
A century after Einstein predicted the existence of weak ripples in spacetime, scientists say they're on the verge of directly detecting these gravitational waves, thereby opening a revolutionary new window on the universe.

GOVERT SCHILLING

Just over 70 years ago, a plutonium reactor at the Department of Energy's Hanford Site, north of Richland, Washington, produced the nuclear fuel for the atomic bomb that exploded over the Japanese city of Nagasaki. Now, the desolate area is home to a very different kind of physics project. Here, one of the most sensitive scientific instruments ever built is poised to detect elusive spacetime ripples from the distant universe.

Researchers have recently outfitted the Laser Interferometer Gravitational-wave Observatory (LIGO) at Hanford with new powerful lasers, ultra-stable mirrors, and superfast computers for data analysis to dig out the waves' weak signal. "People will be very surprised if nothing is found," says observatory head Frederick Raab.

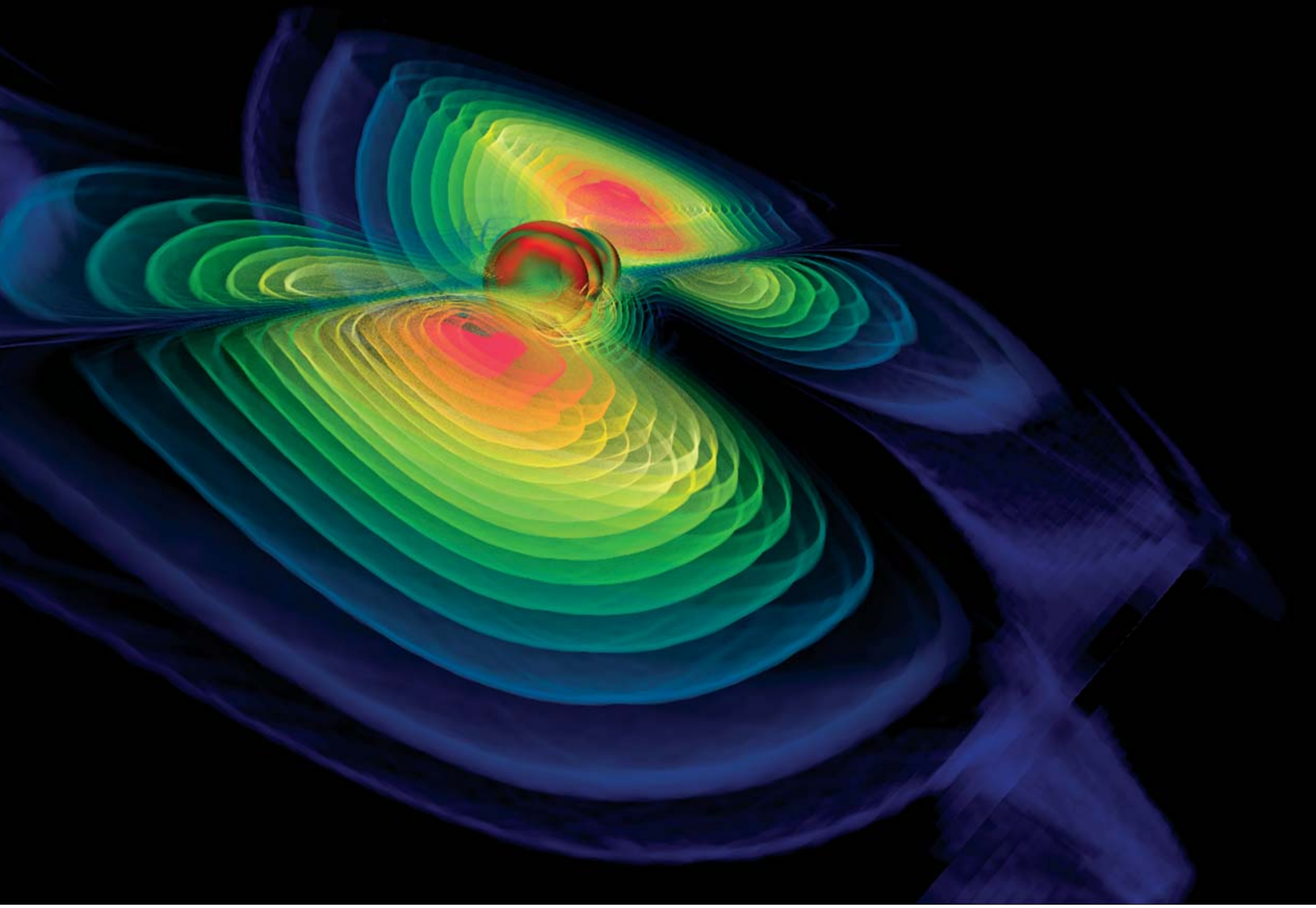
Other scientists are equally optimistic. At the 11th Edoardo Amaldi Conference on Gravitational Waves, held earlier this year in Gwangju, South Korea, there was a general consensus among attendees that we can expect the first direct detection of the elusive ripples any time now. "Listening" to these telltale cosmic waves will provide a completely new way of studying the universe, says Bernard Schutz, one of the founding directors of the Max Planck Institute for Gravitational Physics in Germany. "You can learn much more about a jungle by not just looking around, but also listening to all the sounds," he says. "Our universe is a jungle filled with mysterious creatures, and within one or two years I believe we will begin to listen to these wild animals."



WHEN BLACK HOLES MERGE This simulation shows the moment right after the merger of two black holes, when a common event horizon has just formed. The spheres in the center represent the event horizon, and the colors indicate the spacetime curvature on the horizon. The merger creates a burst of gravitational radiation, shown as cutaway surfaces, which travel out into space at the speed of light. In this simulation, one black hole was 1.5 times more massive than the other.

The LIGO Hanford Observatory is not alone in its quest. In Livingston, Louisiana, lies an identical observatory that has also been completely refurbished over the past few years. The two sites need to work together to make a reliable detection; the first joint run occurred this fall. Next year, the two LIGO detectors will join forces with the European Virgo interferometer near Pisa, Italy. A smaller instrument, called Geo600, is located near Hannover, Germany. Not to be outdone, Japan is constructing a huge underground facility to search for gravitational waves, and India has plans, too.

Meanwhile, radio astronomers all over the world are teaming up to use remote pulsars — the most stable clocks in nature — as measurement tools to look for longer, slower gravitational waves than the ones these instruments will (hopefully) sense.



MAX PLANCK INST. FOR GRAVITATIONAL PHYSICS (ALBERT EINSTEIN INST.) / ZUSE INST. BERLIN / CTR FOR COMPUTATION & TECHNOLOGY AT LOUISIANA STATE UNIV.

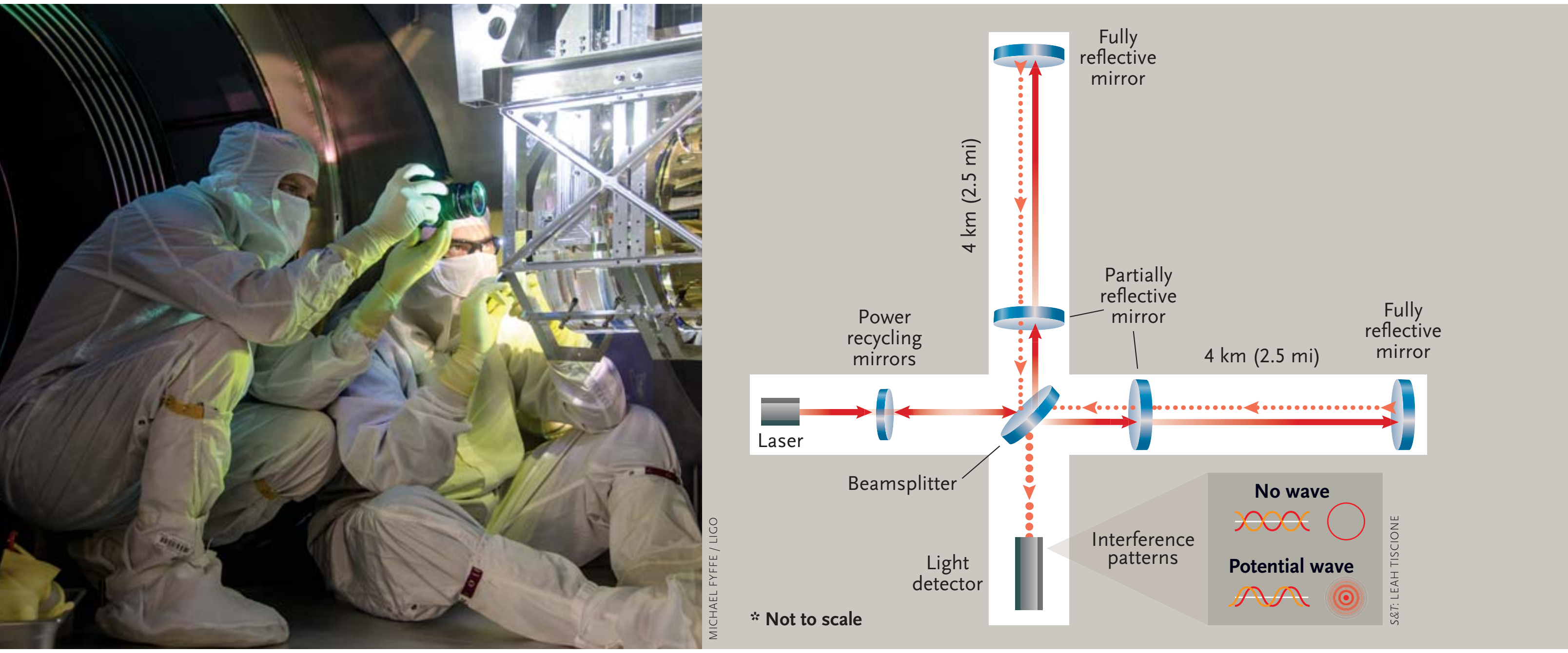
And although the first direct detection of a gravitational wave has not yet been bagged, engineers are already eyeing the future of the field. As you read this, the European LISA Pathfinder spacecraft sits atop a Vega rocket, awaiting its launch from Kourou, French Guiana. LISA Pathfinder is a technology testbed mission for eLISA, the first gravitational-wave observatory in space, planned for 2034.

Making Waves

Gravitational waves have nothing to do with sound. For starters, they travel at the speed of light — 300,000 kilometers (186,000 miles) per second. But they're not part of the electromagnetic spectrum either, like radio waves or X-rays are. Instead, gravitational waves are extremely small-amplitude undulations in the very fabric of spacetime. They are produced when masses accelerate. (Think exploding stars or orbiting black holes.) The bigger the mass and the stronger the acceleration, the more powerful the gravitational waves that the system "radiates." As they're radiated, the waves carry energy away from the system. And they're all over the universe. "They're everywhere, because space is everywhere," explains Schutz (now at Cardiff University, UK).

These spacetime swells come in a wide range of frequencies, from less than a nanohertz (corresponding to a wavelength of about 300 light-years) to a few kilohertz (a few kilometers).

Scientists can't decide when to celebrate the centenary of the prediction of gravitational waves. Albert Einstein first described them in a 1916 paper, as a consequence of his general theory of relativity. However, that origi-



MICHAEL FYFFE / LIGO

S&T: LEAH TISCIONE

QUALITY CHECK *Left:* Team members inspect one of LIGO's partially reflective "input" mirrors. *Right:* A schematic of LIGO. A beamsplitter sends light along two paths perpendicular to each other. Each beam then bounces between two mirrors, one of which allows a fraction of the light through. When the two transmitted beams meet and interfere, they'll cancel each other out — if the length of the path they've each traveled has remained constant. But if a gravitational wave passes through, it'll warp spacetime and change that distance, creating an interference pattern that the system will detect.

nal publication contained a mathematical error, which Einstein didn't repair until 1918, when he wrote a second paper. Nevertheless, he never believed that the minuscule quiverings of spacetime might actually be detectable.

Until the mid-1970s, just a handful of physicists cared about gravitational waves — one of them being Joseph Weber (University of Maryland, College Park), who constructed several massive *resonant bar* detectors in the late 1960s and early 1970s that were supposed to start "ringing" when a gravitational wave with the right frequency passed through. But that all changed in 1974 with the Nobel Prize–winning discovery of the now-famous binary pulsar PSR B1913+16. Within a few years, precision measurements of the pulsar's periodic Doppler shift revealed that the system was slowly shrinking: the two neutron stars are closing in on each other at 3.5 meters per year, heading for a merger in 300 million years or so. The corresponding energy loss — at present over 7 quadrillion gigawatts! — exactly matches the loss expected through the emission of gravitational waves. The message was loud and clear: gravitational waves exist. Now scientists only needed to be clever enough to directly detect them.

Mirror Magic

LIGO Hanford Observatory head Frederick Raab is confident that the new facility — aptly named Advanced LIGO — is up to the task. An earlier, less sensitive pathfinder version of LIGO has been operational since 2002, both in Louisiana and Washington. But, says Raab, right from the start it was evident that two generations of detectors would be needed, to gain enough experience. "This was already part of the initial 1989 proposal to the National Science Foundation," he adds. "Initial LIGO had a small chance to maybe get one detection. That's not science, that's a stunt. You need to move forward." In fact, during eight years of operation, Initial LIGO did not detect a single gravitational wave. At a much higher sensitivity, Advanced LIGO is expected to make at least a few and maybe a few dozen detections per year.

LIGO's detection technique is pretty straightforward. Two coherent laser beams are fired into two vacuum tunnels, each four kilometers long and at right angles to each other — it takes a 10-minute car drive to get from one end of the observatory's L to the other. The laser beams are bounced up and down the tunnels a couple hundred times by high-precision mirrors, increasing the effective path length to many hundreds of kilometers. Then they are recombined in such a way that the two light waves cancel each other out — so long as the distance they travel doesn't change. If a powerful gravitational wave passes through, however, space is periodically stretched and squeezed, and the distance the two laser beams travel will change minutely. If that happens, the light waves won't continuously cancel each other out.

The problem is that gravitational waves are so

MICHAEL FYFFE / LIGO

GRAVITY MISSION CONTROL *Left:* Team members put the finishing touches on one of the power recycling mirrors, which bounce the laser beams inside LIGO back into the interferometer, boosting the power and sharpening the interference pattern. *Above:* Operations specialist Michael Fyffe took this shot of the LIGO Livingston Observatory control room. The green numbers on the wall (left) give atomic time, used in GPS satellites and stations; researchers use this clock to precisely report when an event happens. The red numbers (right) are Pacific Time (for LIGO Hanford), Central Time (Livingston), and Greenwich Mean Time (for reporting to the worldwide collaboration).

unimaginably weak. LIGO is designed to be sensitive to the powerful waves produced when two neutron stars collide — the fate of PSR B1913+16. But the fabric of spacetime is incredibly stiff, so despite the enormous energies involved, the resulting ripples are extremely small. In fact, when a gravitational-wave signal from a neutron star merger 25 million light-years away passes through, the 4-kilometer separation between the end mirrors in each interferometer arm is expected to change by no more than a billionth of a nanometer a few hundred times per second. Needless to say, engineers needed to isolate the mirrors perfectly from seismic noise and other terrestrial tremors.

With its more powerful lasers and improved mirror system, Advanced LIGO should be able to detect gravitational waves from neutron star mergers out to an extraordinary distance of some 500 million light-years — a big enough volume of space to catch at least a couple of events per year from the million or so galaxies in that volume. Scientists need a simultaneous detection by both LIGO observatories to rule out local noise sources. Teaming up with Virgo and Geo600 in Europe — and, in the future, with similar facilities in Japan and India — will make it possible to broadly localize the source of the gravitational waves on the sky, enabling wide-angle optical telescopes to quickly carry out follow-up observations, like paparazzi photographers responding to sounds, voices, or other audible cues.

"That would be something like a cosmic version of Where's Waldo," Samaya Nissanke (Radboud University, the Netherlands) told the Edoardo Amaldi Conference in Gwangju. "But we're ready; an optical hunt is possible today."

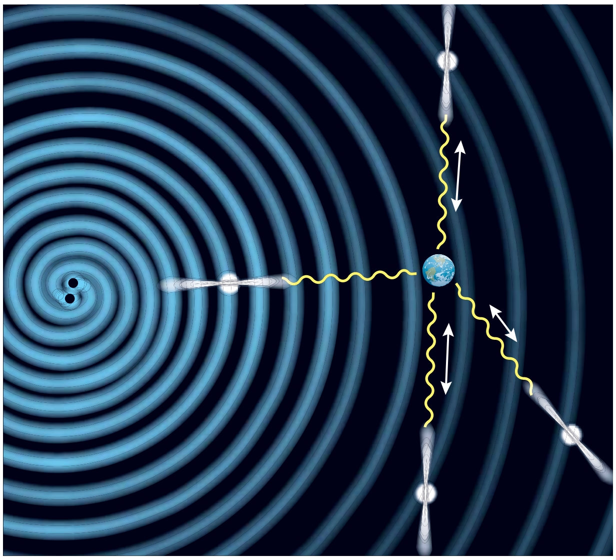
Taking the Pulse

But will interferometers like LIGO really be the first to catch a wave? Maybe not. Radio astronomers are pursuing a completely different way to detect them, using pulsars in our Milky Way Galaxy. If space is periodically stretched and squeezed, the argument goes, this should show up as minute variations in the pulse arrival times, because the pulsars' distances are periodically changing. By monitoring a number of pulsars at known distances spread across the sky, it should be possible to spot a passing wave. In a sense, it's comparable to using the bobbing motions of floats on a pond to discover waves on the water's surface. Sounds easy, and relatively cheap, too.

Primordial Waves

In March 2014, scientists working with the BICEP2 telescope claimed they'd discovered a swirly pattern in the polarization of the cosmic background radiation. They interpreted this *B-mode pattern* as an imprint from primordial gravitational waves spawned by cosmological inflation, the exponential burst of expansion when the universe was only a tiny fraction of a second old. (Astronomers can't use polarization to look for more "mundane" gravitational waves from inspiraling black holes and other systems: no black holes were around to stretch and squeeze the cosmic plasma soup and create a polarization signal. Plus, even *if* astrophysical sources could leave their mark, it'd be so weak we couldn't detect it.)

Within a few months, astronomers working with data from the European Planck mission showed that the BICEP2 results could instead be explained by dust in our own Milky Way Galaxy (*S&T:* Sept. 2014, p. 12). However, this is not to say that primordial gravitational waves from the inflationary epoch do not exist. Other submillimeter telescopes, both in Antarctica and northern Chile, might still detect their subtle fingerprints in the polarization patterns of the cosmic background radiation.


S&T: LEAH TISCIONE

HOW A PULSAR TIMING ARRAY WORKS Pulsars broadcast regular "beats" to us as their radiation jets spin in and out of view. The arrival time of those beats depends on the distance between us and the pulsar. Normally, that distance doesn't suddenly change, and so neither does the pulse's arrival time. But when gravitational waves (concentric arcs) pass between us and a pulsar, they will slightly stretch and squeeze the space perpendicular to their direction of motion — in the 2D representation here, both in the direction of the double arrows and in and out of the page. The pulsar's distance thus oscillates, making some pulses arrive earlier and others later than expected. How much the arrival time changes depends on how everything lines up: in the 2D visualization here, where all objects are in the plane of the waves' propagation, the effect will be stronger for pulsar-Earth lines that are closer to being at right angles with the wave's direction of motion (length of arrows). By combining arrival times for several pulsars in different parts of the sky, astronomers should be able to figure out where the gravitational waves came from.

Of course, it's not as straightforward as it seems. There are loads of other effects that could subtly influence pulse arrival times, explains Ryan Shannon (CSIRO, Australia), all of which astronomers have to fully understand and compensate for. Moreover, pulsar distances are generally not known precisely enough to accurately apply the technique. Still, by measuring a large ensemble of pulsars, and by carrying out a complicated statistical analysis, the pulsar timing array (PTA) technique has a lot of potential. Astrophysicists are excited by the prospects: while LIGO-like interferometers are sensitive to the high-frequency gravitational waves from merging neutron stars (a few hundred hertz), PTAs would detect the long-wavelength, very low-frequency waves from binary black holes in distant galaxies (see graph on facing page).

In fact, says Shannon, the fact that a decade-long data set from the Australian Parkes Pulsar Timing Array (PPTA, published in 2013) didn't show any evidence for those nanohertz waves has already ruled out many existing evolutionary models that predict the frequency of merging galaxies and coalescing supermassive black holes. Meanwhile, similar programs are now in progress in Europe (European Pulsar Timing Array, EPTA) and the United States (North American Nanohertz Observatory for Gravitational Waves, NANOGrav); together the three constitute the International Pulsar Timing Array (IPTA). The hope is that a firm, statistically significant detection will be made soon. Says Pablo Rosado (Swinburne University of Technology, Melbourne): "With so many models already ruled out by our current non-detection, we're starting to get worried."

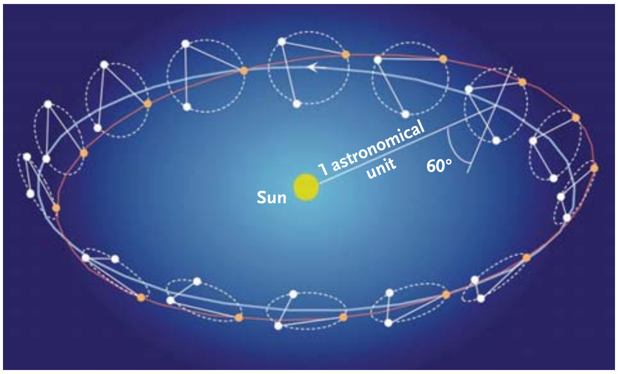
Frankly, you can't blame gravitational-wave scientists for being at least a *bit* worried. Between 2002 and 2010, Initial LIGO did not detect a single neutron star merger within 50 million light-years, although that would've been a lucky catch. But searches for long-duration "continuous wave signals" — from known X-ray binaries like Scorpius X-1 or from young, rapidly spinning neutron stars that are not perfectly spherical — also have come up empty. PTAs: nothing yet. Advanced LIGO — well, you would've seen front-page headlines if there had been a detection by now.

Still, confidence abounds. "If there are no signals out there, how would you explain the binary pulsar?" asks Raab. And in Gwangju, a self-assured Deirdre Shoemaker (Georgia Institute of Technology) told her audience that "the first gravitational-wave signal that we're going to detect has already passed Proxima Centauri." In other words: we'll hit the jackpot before 2019.

Discovery Space

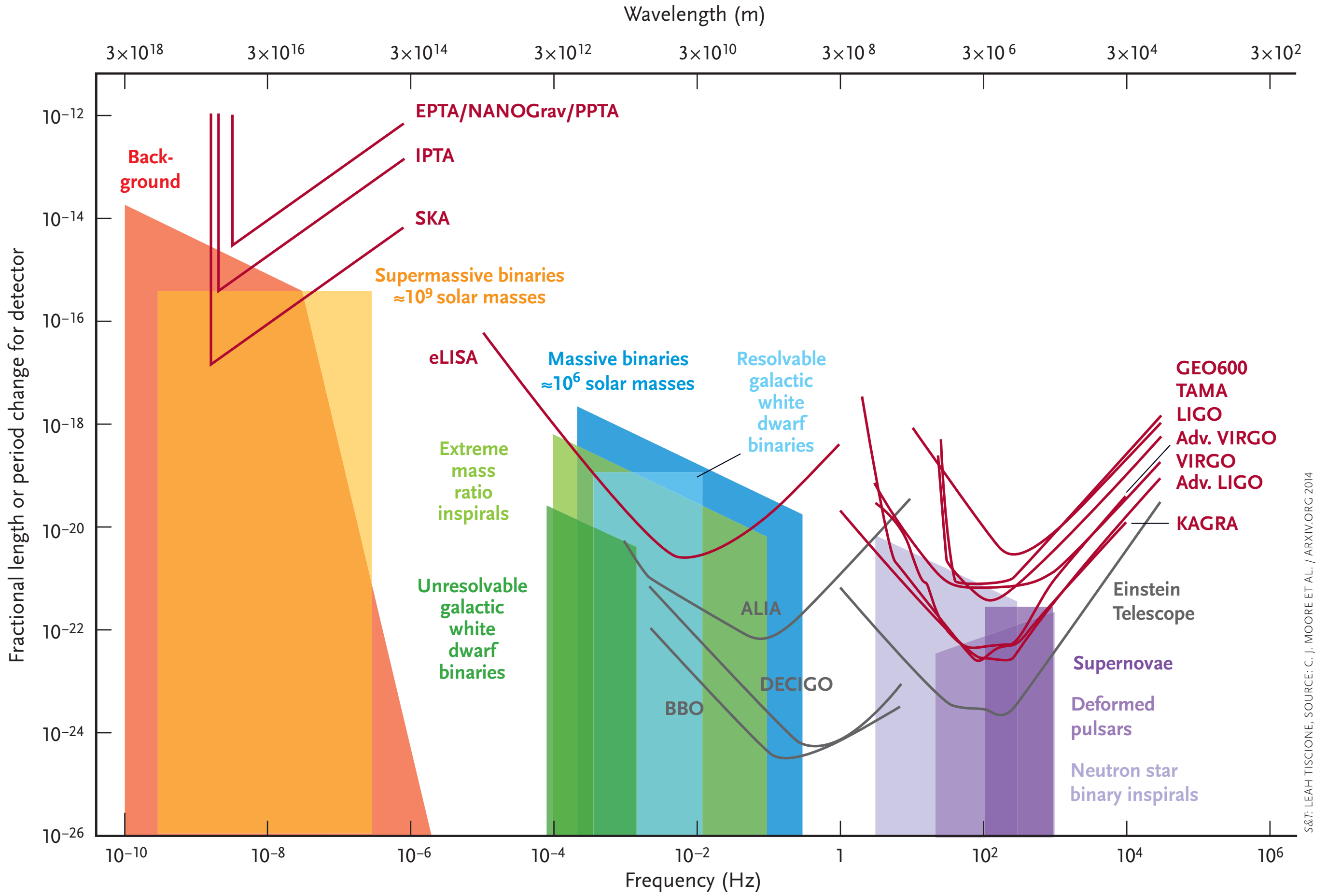
OK, so let's assume that we're indeed on the doorstep of a revolutionary discovery — the confirmation of a century-old prediction of general relativity, and the opening up of a new window on the high-energy universe. Then what?

Fast forward two decades. Somewhere on the planet — most likely in Europe — construction workers are



NASA

eLISA ORBIT ESA's eLISA mission will comprise three spacecraft flying in a triangle about a million kilometers on a side. Tilted 60° to the ecliptic, the triangle formation will cartwheel around the Sun behind Earth in our planet's orbit. Free-falling masses inside each spacecraft will hover undisturbed by forces other than gravitation.



S&T: LEAH TISCIONE, SOURCE: C. J. MOORE ET AL. / ARXIV.ORG 2014

HUNTING FOR GRAVITATIONAL WAVES Gravitational waves — and the experiments designed to find them — cover a wide range of frequencies. Last year Christopher Moore, Robert Cole, and Christopher Berry (then all at the University of Cambridge, UK) calculated approximate signal ranges and sensitivities for various gravitational wave detectors, shown here. Experiments in dark gray are proposals; those in red are in development or operational. Don't mentally extend the curves beyond where they're drawn: the limits' endpoints are intentional, because beyond these points sensitivities degrade. The team calculated each source's signal range (shaded regions) based on the characteristics of a representative (theoretical) member of that category.

digging huge tunnels to house the Einstein Telescope, a triangular underground super-LIGO with interferometer arms 10 kilometers long and capable of detecting neutron star mergers out to billions of light-years. Meanwhile, the European Space Agency (ESA) is preparing for the launch of eLISA, the first space-born gravitational-wave observatory. “eLISA will cover the millihertz frequency range, which cannot be studied from the ground because of seismic noise,” says Jonathan Gair (University of Cambridge, UK). The observatory will detect gravitational waves from relatively lightweight supermassive black holes (tens of thousands to tens of millions of solar masses) in the cores of galaxies, from thousands of compact binary stars in the Milky Way, and maybe even from cosmological sources like cosmic strings — hypothetical defects in spacetime produced in the newborn universe.

The eLISA mission will use three separate spacecraft floating in a huge triangle formation. Laser beams will fire, reflect, and recombine across distances of a million kilometers to create a giant interferometer. The LISA Pathfinder mission, due for launch before year's end, will test all necessary eLISA technologies using two test masses free-floating some 40 centimeters apart within a single hollow spacecraft.

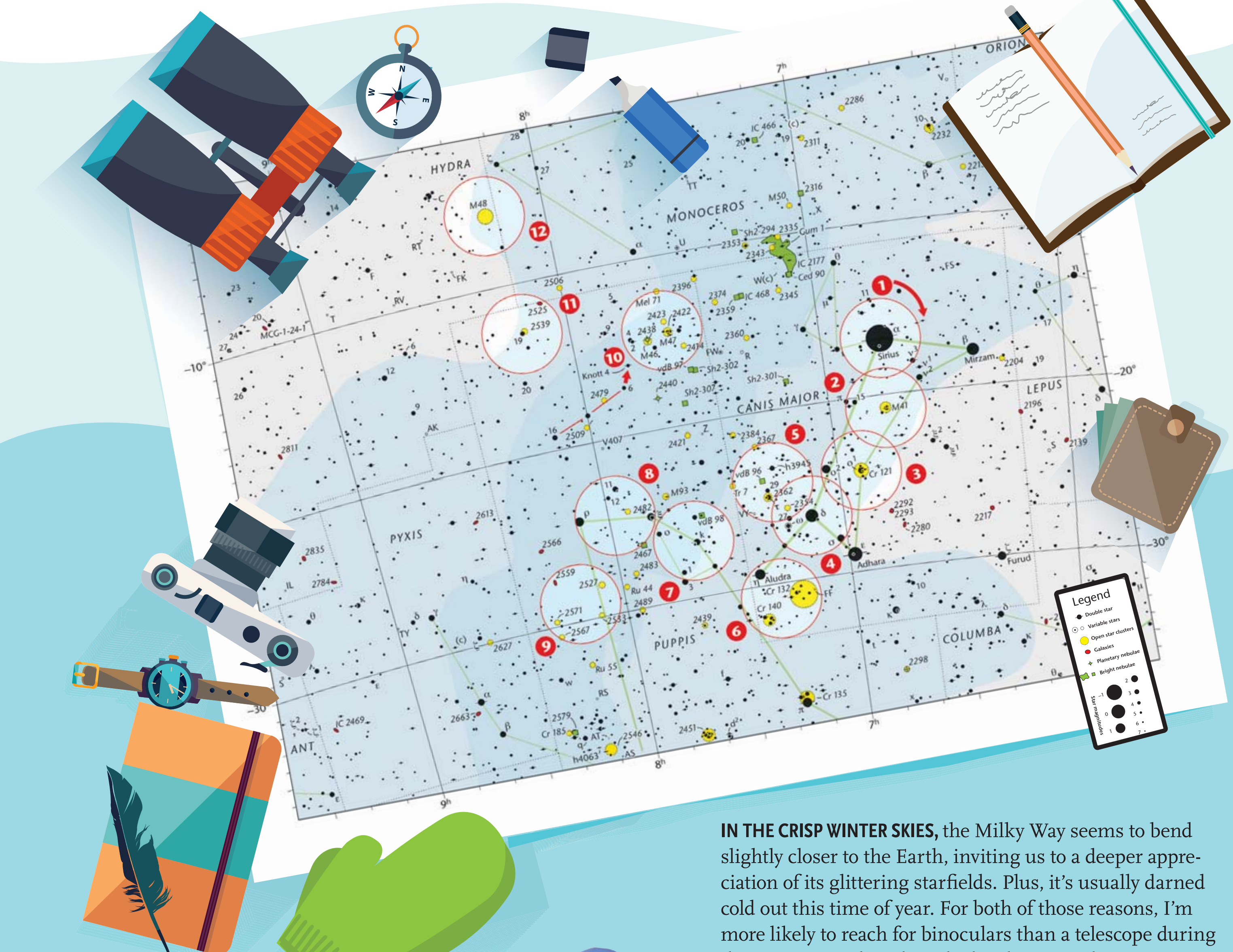
Learn more about gravitational waves — with animations, a 20-minute documentary, and more — at http://is.gd/gwtutor.

Twenty years from now, LISA Pathfinder will be history, just like Einstein's doubts about the existence of gravitational waves, the fuss around Weber's claims of measuring the waves with his bar detectors, and, hopefully, the worrisome non-detections by pulsar timing arrays. By then, gravitational-wave astronomy should have evolved into a rich and fruitful discipline, shedding light on a wide variety of astronomical objects and processes, from the Big Bang and galaxy mergers to supernova explosions, gamma-ray bursts, and compact binary stars. Who would have imagined that back in 1915? ✦

Dutch astronomy author and Sky & Telescope *Contributing Editor* ***Govert Schilling*** *plans to write a popular-level book on the hunt for gravitational waves.*

Binocular Holiday

Take a guided tour of the Milky Way's top attractions.



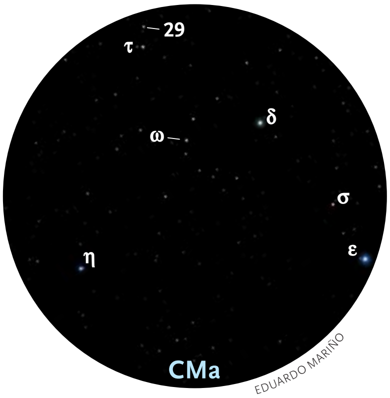
MATHEW WEDEL

IN THE CRISP WINTER SKIES, the Milky Way seems to bend slightly closer to the Earth, inviting us to a deeper appreciation of its glittering starfields. Plus, it's usually darned cold out this time of year. For both of those reasons, I'm more likely to reach for binoculars than a telescope during the winter months. I love the bright spectacles in Orion, Auriga, and Gemini, but there's a lot more to see in the winter Milky Way (see *S&T:* Feb. 2014, p. 26). This binocular tour takes you down the spine of Canis Major, the Big Dog, across Puppis, the Poop Deck, and north again to the boundary keeping Hydra, the Water Snake, away from Monoceros, the Unicorn.

ORIGINAL ART: © BIGSTOCKPHOTOS.COM / THEROMB;
IMAGE MODIFICATION: PATRICIA GILLIS-COPPOLA, CHART: GREGG DINDERMAN

SERGIO EGUIVAR

JEREMY PEREZ



EDUARDO MARIÑO

② First catalogued in the mid-17th century by Giovanni Batista Hodierna, open cluster M41 is visible to the naked eye in dark skies. With 15×45 image-stabilized binoculars, you should be able to resolve some 30 stars.

④ ⑤ ⑥ Use Delta Canis Majoris as a waymarker on the path to Omega, Tau, and 29 CMa. Eta lies approximately 5° to the southeast of your waymark.

I made these observations from my backyard in eastern Los Angeles County, using 15×70 binoculars with a 4.4° field of view. Most of the objects we'll visit on this tour are also visible in smaller instruments, especially if they're mounted on a tripod or braced against something sturdy. Equally important for rewarding binocular observing is good dark adaptation. If I pull the hood of my jacket up around my face to block out any incidental light, I'm able to go deeper and see more, even in suburban skies.

Sirius, the most spectacular jewel in the southern skies for Northern Hemisphere observers, makes a good anchor and starting point (Stop 1 on the map on page 32). From Sirius, move directly south about four degrees to find **M41**, one of the brightest open clusters in the winter skies (Stop 2). Before you move on, notice how the brighter stars in the cluster form a pair of concentric curls like breaking waves.

Another 4° slide to the east-southeast will bring you to **Collinder 121** (Cr 121), a loose association dominated by Omicron^1 (o^1) Canis Majoris (Stop 3). Evidence is mounting that the brighter O and B stars in this field are separate from the open cluster, which lies about 3,500 light-years away. Omicron^1 itself is also fairly distant, at nearly 2,000 light-years, but as an orange, *K*-type supergiant it's incredibly luminous. The complexity of the view here is a useful reminder that space has depth — we don't look *at* the night sky so much as *into* it.

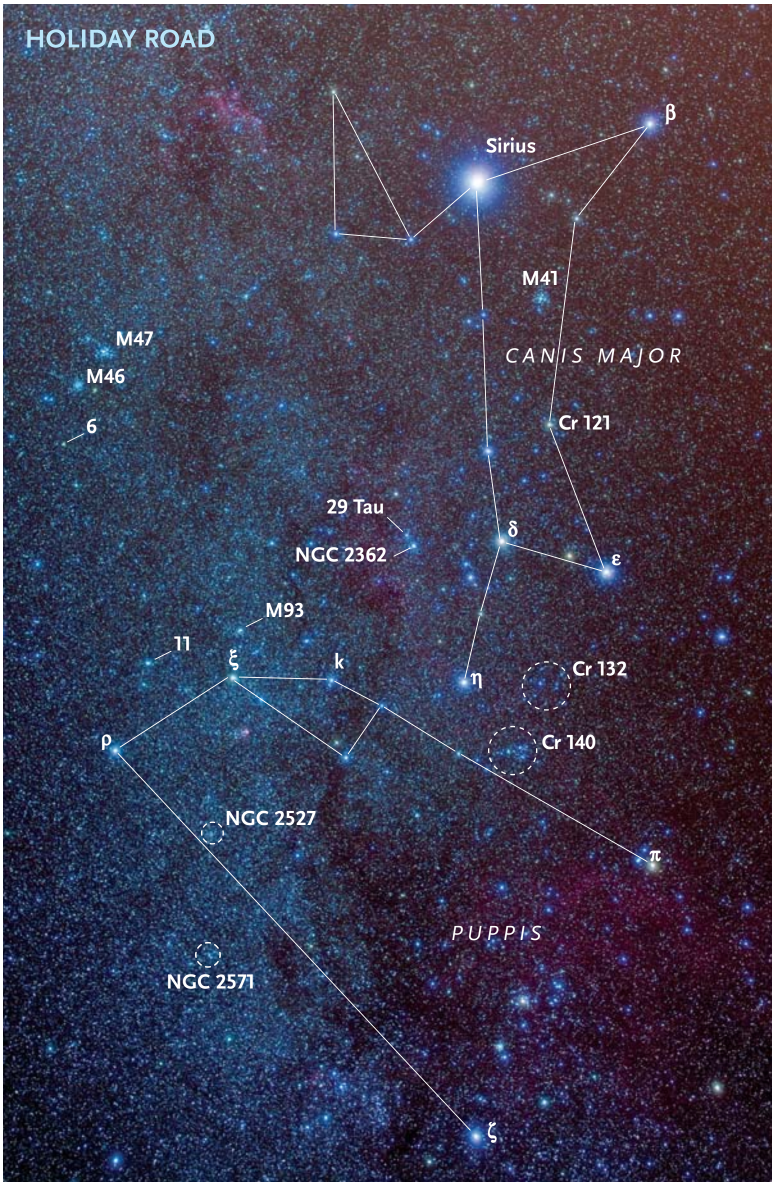
Our gentle arc to the east continues with a third 4° hop, southeast from Omicron^1 to the much brighter Delta (δ) Canis Majoris, also known as Wezen (Stop 4). This is another big, young supergiant, and we'll use it as a base camp for a little side trip. Start by taking in the arc of bright stars east of Delta, which forms a miniature "corona" asterism about 2° across. The brightest star in the arc is Omega (ω) Canis Majoris. Omega is a variable star, normally a modest magnitude 4.1 but occasionally brightening up to 3.6. The change in brightness is caused not by the star itself, apparently, but by the formation, outburst, and dissipation of a circumstellar disk.

About 2° north-northeast of Omega is a pair of bright stars oriented north-to-south: 29 Canis Majoris to the north, and Tau (τ) Canis Majoris below (Stop 5). Take a close look at Tau. If you're under good skies, you may catch a glimpse of the open cluster **NGC 2362** (Caldwell 64) as a faint wisp of light surrounding the brighter star. Or rather, brighter stars: Tau is actually a stellar system of four giant stars in a tight gravitational bear hug, plus a single smaller star, probably captured, that lies 13,000 a.u. from the rest.

Another beautiful double awaits you just over 1° north-northwest of the 29–Tau pair. This is **Herschel 3945** (h3945), the "Winter Albireo." Some observers report splitting the beautiful blue and gold components with 10×50 binoculars, but I have to go up to the 15×70s, braced very securely, to get a clean split. Give it a shot and see what works for you.

Now go back to bright Delta and shoot through the

ORIGINAL ART: © BIGSTOCKPHOTOS.COM / ALL SAUCERS: BENCHART / MAN: STUDIOSTOKS;



ALAN DYER

"corona" asterism like an arrow out of a bow. About 5° to the southeast you'll encounter **Eta (η) Canis Majoris**, also known as Aludra, a wide unequal double (Stop 6). If your southern horizon will allow excursions past –30°, venture south of Eta to pick up two more Collinder clusters: big, diffuse **Cr 132** to the southwest and the more compact **Cr 140** due south. If you park Aludra on the north edge of your field you should be able to pick up both clusters in the same view, even in the limited field of 15×70 binos.

Roughly 4° northeast of Aludra is the double star k Puppis (Stop 7). At only 9.9 arcseconds (″) apart, the two components would be a tough split for instruments with a magnification lower than 30×. Rather than trying for a probably-impossible split, relax and take in the very rich field surrounding k Puppis, which rivals some of the better Collinder clusters. Another three degrees along the same line from Aludra to k Puppis will bring you to **Xi (ξ) Puppis** (Stop 8). With its wide, bright companion, Xi is a fine binocular double. The primary looks softly yellow to me, and the companion blue-white. Now follow a chain of faint stars northwest about 1.5° to find a tight group of faint stars, **M93**. If M93 seems dim, it's because it is so far away: at 3,600 light-years it's one of the more distant open clusters in the Messier catalog.

For a charming view closer to home, sweep three degrees east of Xi to find Rho (ρ) Puppis. About 2° north of the line between Xi and Rho, you'll find 11 Puppis, which makes a wide triangle with the two other stars. Much like the field around k Pup, the vicinity of 11 Pup is packed with blue-white gems. And by a quirk of cosmic architecture, the fields around k and 11 mirror each other on opposite sides of Xi — double rich fields around a double star.

Drop down 4° south from Rho to find the open cluster **NGC 2527** (Stop 9). Another 3° to the east-southeast lies another open cluster, **NGC 2571**. The two clusters

POSS-II / STSCI / CALTECH / PALOMAR OBSERVATORY

3 The loose open cluster Collinder 121 is an easy target for binocular observers. Look for Omicron^1 Canis Majoris, an orange supergiant (spectral type *K*2.5Iab) that fronts the open cluster. Advanced astroimaging will reveal the Wolf-Rayet ring nebula Sh2-308 nearby.

ORIGINAL ART: © BIGSTOCKPHOTOS.COM / STUDIOSTOKS; IMAGE MODIFICATION: PATRICIA GILLIS-COPPOLA


M93

SERGIO EGUIVAR


M93

JEREMY PEREZ

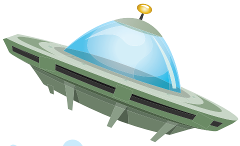

NGC 2571

B. HUBL / C. KALTSEIS / W. LEITNER / H. WALTER

lie close enough to hold in the same binocular field and they make an instructive contrast. In my 15×70s, NGC 2571 is a faint patch of light that just starts to resolve with patient study. I find the individual stars in NGC 2527 easier to resolve, even though the cluster itself seems a bit dimmer overall. This isn't surprising in view of the clusters' distances. NGC 2571 is truly remote as open clusters go, at about 4,000 light-years away; NGC 2527 is only half as far off.

⑧ At 3,600 light-years, M93 is one of the more distant open clusters in the Messier catalog. Look for the bright giants HD 62679 and TYC 6540-4176-1 to the southeast of the cluster's center.

⑨ Although typically considered a telescopic object, NGC 2571 can be picked up with 15×70 binoculars; look for the roughly linear distribution of the cluster's brighter stars.



Travel Itinerary

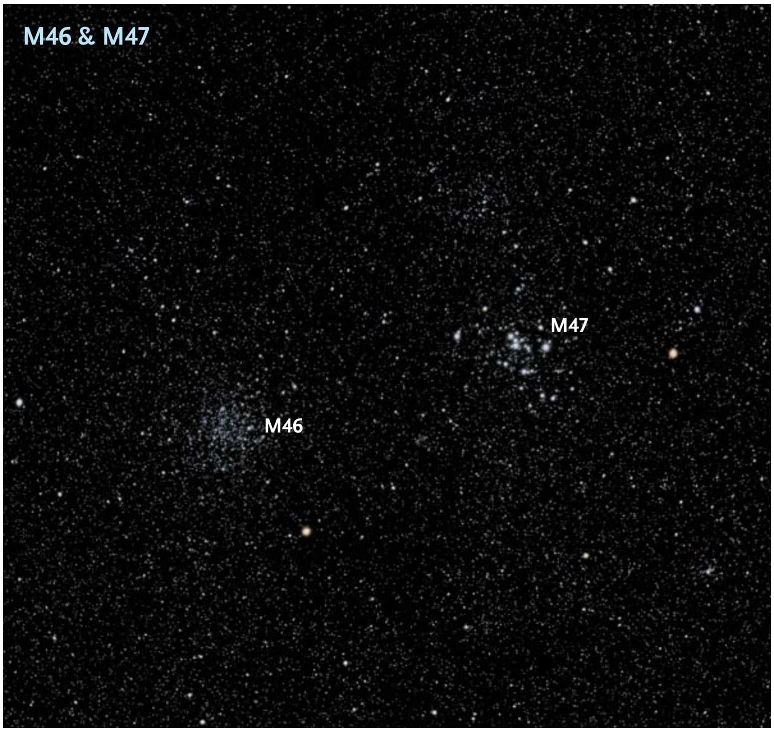
Object	Type	Spec	Mag(v)	Size/Sep	RA	Dec.
Messier 41	Open cluster	—	4.5	38′	$06^h\ 46.0^m$	–20° 45′
Collinder 121	Open cluster	—	2.6	50′	$06^h\ 54.2^m$	–24° 43′
NGC 2362	Open cluster	—	4.1	8′	$07^h\ 18.7^m$	–24° 57′
Herschel 3945	Double star	*K3I, dF0*	5.0, 5.8	26.8″	$07^h\ 16.6^m$	–23° 19′
Eta Canis Majoris	Double star	*B5I*	2.4, 6.8	179″	$07^h\ 24.1^m$	–29° 18′
Collinder 132	Open cluster	—	3.6	95′	$07^h\ 14.4^m$	–31° 10′
Collinder 140	Open cluster	—	3.5	42′	$07^h\ 23.9^m$	–32° 12′
Xi Puppis	Double star	*G6Ib*	3.4, 13.0	4.8″	$07^h\ 49.3^m$	–24° 51′
Messier 93	Open cluster	—	6.2	22′	$07^h\ 44.5^m$	–23° 51′
NGC 2527	Open cluster	—	6.5	22′	$08^h\ 05.0^m$	–28° 09′
NGC 2571	Open cluster	—	7.0	13′	$08^h\ 18.9^m$	–29° 45′
Knott 4	Double star	*M2II, M2III*	6.5, 6.6	129.4″	$07^h\ 47.8^m$	–16° 01′
Messier 46	Open cluster	—	6.1	27′	$07^h\ 41.8^m$	–14° 49′
Messier 47	Open cluster	—	4.4	30′	$07^h\ 36.6^m$	–14° 29′
NGC 2423	Open cluster	—	6.7	19′	$07^h\ 37.1^m$	–13° 52′
NGC 2539	Open cluster	—	6.5	22′	$08^h\ 10.6^m$	–12° 49′
Messier 48	Open cluster	—	5.8	54′	$08^h\ 13.8^m$	–05° 45′

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

If you live far enough south to see to –40° or –50°, the stretch of the Milky Way that runs through southern Puppis and Vela is fantastically rich, and it will reward patient exploration. But there are wonders to the north as well, and that is where we're headed next.

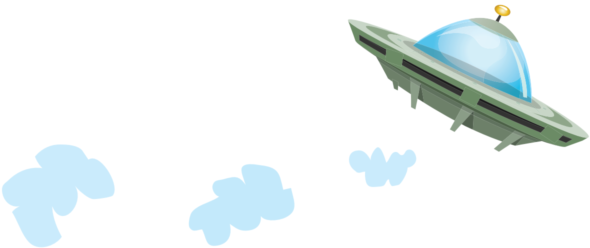
The wide triangle formed by Xi, Rho, and 11 Puppis is an arrowhead pointing north and a bit west. Follow the arrow about five degrees and you'll find a line of three equally bright stars trending to the northwest — 16 Puppis, HD 65810, and 6 Puppis. Just over 1° north of 6 Pup is the fine binocular double **Knott 4**. With a separation of 129″ it should be an easy split. Two degrees northwest of Knott 4 you'll find the famous pair of Messier open clusters, **M46** and **M47** (Stop 10).

If appreciating celestial objects through a telescope is enhanced by knowing what they are, enjoying them through binoculars is about seeing them in context — and nowhere is that more true than with M46 and M47. First, compare the clusters themselves. M47 is a bright shotgun blast of splashy stars, compared to the dense swarm of dimmer lights that makes up M46. Now, widen your view. Notice how the pair is bounded to the east and west by wide, canted pairs of stars. These are 2 and 4 Puppis on the east, and KQ Puppis and HD 60325 on the west. Another bright star, HD 61722, sits between the clusters to the south, much closer to M46 than to its sibling. Taken together, the five bright stars on the east, west, and south of the clusters form a wide "bowl" that seems to hold the clusters and associations stacked within.



TOM WILDONER

10 Visible to the naked eye under dark skies, M47 sparks to life even through modest binoculars. Under high power, the cluster's central stars jump from sparks to blazes. Neighboring M46 appears dimmer, a cluster of pinpricks of light piercing a patch of haze.



Wait — stacked? Yes! About ½° north of M46 is a bright association that may outshine the neighboring Messier cluster. About the same distance north of M47 is a genuine cluster, **NGC 2423**. People have spotted NGC 2423 in 70-mm binoculars, but you'll need dark skies and good transparency to pick up this faint wisp of light. Taken altogether, there's a lot more going on in the northwest corner of Puppis than just the two Messier objects.

For our last two stops you'll need your astronomical seven-league boots. We're going to take a couple of long strides east and north to pick up two more binocular clusters. First, line up M46 with the bright stars to the east — 2 and 4 Pup, and 9 Pup another 1.5° out. They don't fall perfectly in line, but if you sweep east-northeast from M46 about 7° along that rough line, you'll come to 19 Puppis and the open cluster **NGC 2539** (Stop 11). The star is only 185 light-years out, compared to 4,000 light-years for the cluster. I find NGC 2539 a challenging target. It's almost overwhelmed by the glare from 19 Puppis — if a 4th-magnitude star can be said to have "glare"! But spend some time here and see how many stars you can fish out of NGC 2539 by steadying your instrument and using averted vision.

We've come to the end of Puppis, but there's one more stop, across the border in Hydra. Another 7° sweep, this time to the north of 19 Puppis, will bring you to **M48** (Stop 12). This sprawling expanse of distant suns looks like a wide chevron to me. Two to three degrees north on either side are the bright stars C Hydrae and Zeta (ζ) Monocerotis. Fix these as landmarks and see if you can spot M48 with your naked eyes. I've never managed it myself, but other observers have. And when failure means that you spend a couple of minutes looking at a pretty part of the sky, there's not much to lose by trying.

There's a lot more to see in this part of the sky — the whole winter Milky Way from Puppis to Gemini and beyond is packed with wonders. Many of them are associations and asterisms that don't appear in the famous observing catalogs or "best of" lists, but they're well worth seeking out. Realizing how much there is to see beyond the Messiers was a big step in my binocular observing. I hope you get swept up in the same exploratory spirit. ✦

Matt Wedel is a mild-mannered paleontologist by day and an adventurous stargazer by night. He blogs at **10minuteastronomy.wordpress.com**.

In This Section

Additional Observing Article:

ESO / DIGITIZED SKY SURVEY 2 / MARTINE DE MARTIN

This wide-field image of Puppis includes several open star clusters, the brightest amongst them being Messier 47 (center); approximately a half degree east of M47 is the denser but more distant open cluster Messier 46 (left); see page 32.

Sky at a Glance

DECEMBER 2015

2 **MORNING:** Look for Regulus, the brightest star in Leo, about 4° left or above the Moon.

5 **MORNING:** Venus rises about 3½ hours before the Sun, anchoring a chain that stretches past Spica to connect Mars, the crescent Moon, Beta (β) Virginis, Jupiter, and finally Regulus.

7 **DAY:** The waning crescent Moon occults Venus in the daytime for North and Central America; see page 46.

13–14 **ALL NIGHT:** The Geminid meteor shower peaks on December 13th at 1 p.m. EST; viewing should be strong that night and the next; see page 44.

17 **EVENING:** Algol shines at minimum brightness for roughly two hours centered at 10:48 p.m. EST (7:48 p.m. PST); see page 47.

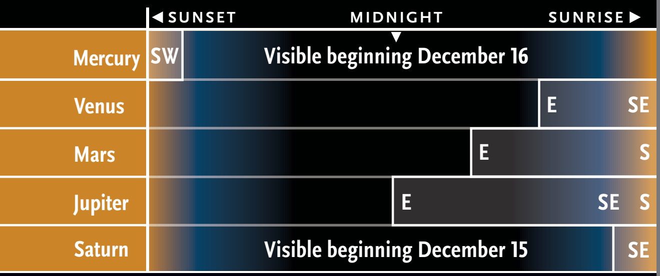
21 **THE LONGEST NIGHT OF THE YEAR** in the Northern Hemisphere. Winter begins at the solstice at 11:48 p.m. EST (8:48 p.m. PST).

23 **MORNING:** Mars rises after midnight about 3° upper left of Spica. Watch each morning as Spica appears to move away from the Red Planet. **EVENING:** As twilight deepends, look for Aldebaran about 3° right or upper right of the waxing gibbous Moon.

28 **NIGHT:** Regulus is 7° or 8° lower left of the waning gibbous Moon.

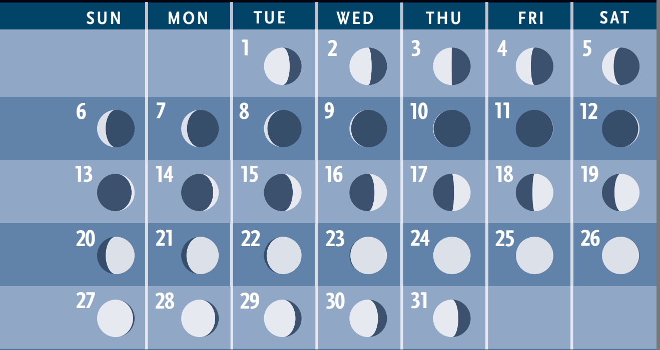
30 **NIGHT:** The Moon rises before midnight with Jupiter trailing behind to the lower left. The duo accompanies the hind foot of Leo across the sky through the early morning hours.

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



Moon Phases

◐ Last Qtr December 3 2:40 a.m. EST
○ New December 11 5:29 a.m. EST
◑ First Qtr December 18 10:14 a.m. EST
● Full December 25 6:11 a.m. EST

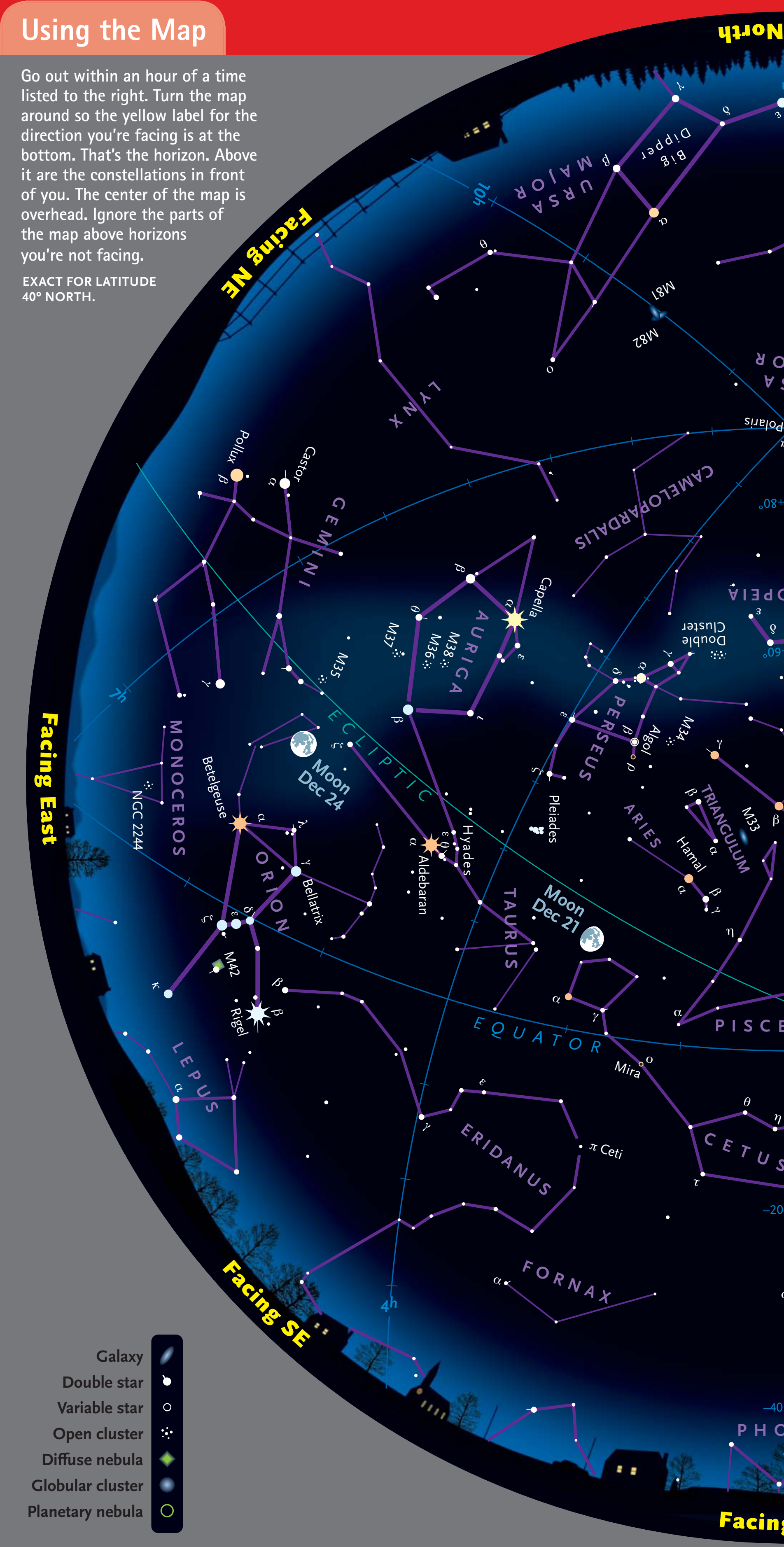


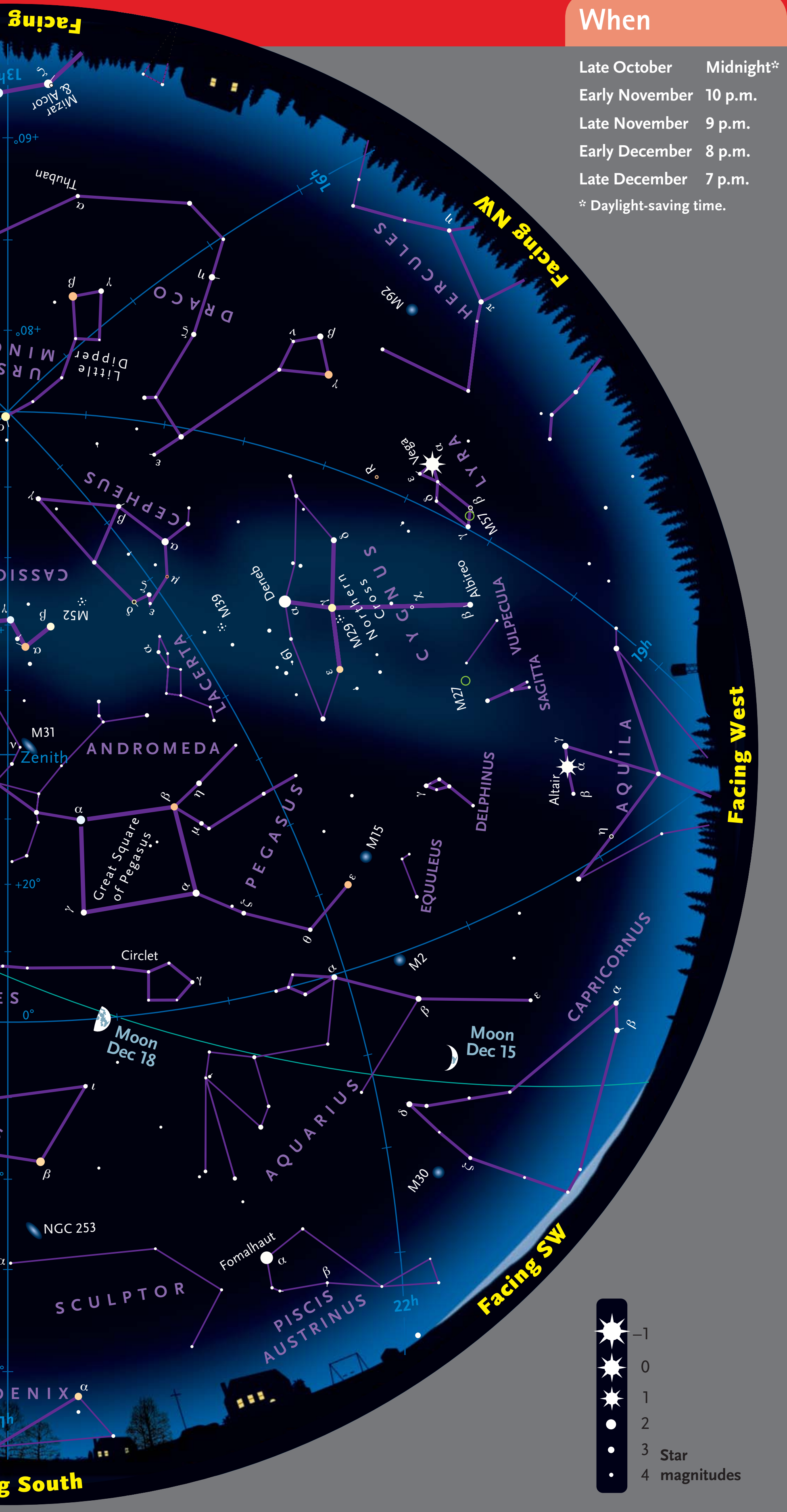
SUN	MON	TUE	WED	THU	FRI	SAT
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

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

* Daylight-saving time.

Gary Seronik

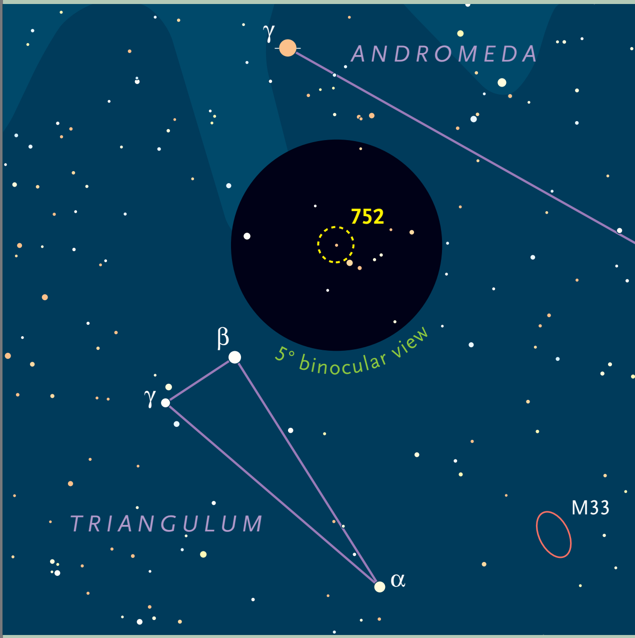
Binocular Highlight

Betwixt & Between

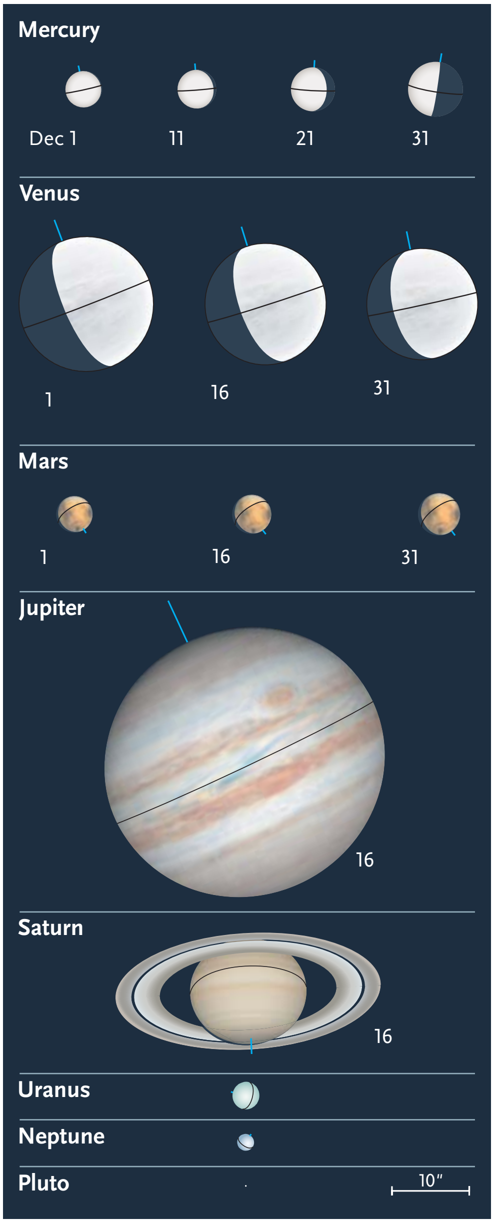
We sometimes overlook deep-sky treasures because they're not close to prominent landmarks. Take open cluster NGC 752, for example. It's situated in a kind of no man's land between the dual curving arcs of Andromeda and the geometrically tidy constellation Triangulum. Although it's well within the confines of the former constellation, the easiest way to reach the cluster is to extend a line through Gamma (γ) and Beta (β) Trianguli, about double the distance between the stars, and then sweep just a little to the northeast of that point.

NGC 752 spans a little less than 1° and is cataloged at magnitude 5.7. In my 10×30 image-stabilized binoculars, it resembles a celestial spider with ragged rows of stars fanning out from the middle toward the east, and a northern edge bounded by a string of faint stars. I count roughly a dozen individual stars spread more or less evenly across its diameter, though a few extra wink in and out of view at the threshold of visibility. Bumping up the magnification and aperture by switching to my 15×45 image-stabilized binos makes the faint stars easier to see and gives the brighter ones a little extra luster, but doesn't markedly change the view.

NGC 752 looks a little unusual because it is a little unusual. Much of its ragged, sparse appearance is a result of its extreme age. Cluster stars tend to drift farther and farther apart as they get older, until they're so scattered there's really nothing left to call a "cluster." Typical open clusters are usually on the order of tens of millions of years old, but NGC 752 has been around for perhaps two billion years. That fact alone makes venturing into no man's land worthwhile. ✦



Planetary Almanac



Sun and Planets, December 2015

	December	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$16^h\ 25.9^m$	−21° 41′	—	−26.8	32′ 26″	—	0.986
	31	$18^h\ 38.1^m$	−23° 09′	—	−26.8	32′ 32″	—	0.983
Mercury	1	$16^h\ 57.1^m$	−24° 14′	8° Ev	−0.8	4.7″	98%	1.421
	11	$18^h\ 05.1^m$	−25° 37′	13° Ev	−0.6	5.0″	93%	1.334
	21	$19^h\ 11.3^m$	−24° 36′	18° Ev	−0.6	5.7″	81%	1.179
	31	$20^h\ 02.4^m$	−21° 28′	20° Ev	−0.5	7.1″	53%	0.947
Venus	1	$13^h\ 35.5^m$	−7° 38′	43° Mo	−4.2	17.4″	67%	0.957
	11	$14^h\ 20.3^m$	−11° 34′	42° Mo	−4.2	16.2″	70%	1.027
	21	$15^h\ 07.0^m$	−15° 12′	40° Mo	−4.1	15.2″	74%	1.095
	31	$15^h\ 55.7^m$	−18° 18′	38° Mo	−4.1	14.4″	77%	1.160
Mars	1	$12^h\ 41.1^m$	−2° 50′	58° Mo	+1.5	4.8″	93%	1.969
	16	$13^h\ 13.5^m$	−6° 10′	64° Mo	+1.4	5.1″	92%	1.836
	31	$13^h\ 45.4^m$	−9° 17′	71° Mo	+1.3	5.5″	91%	1.694
Jupiter	1	$11^h\ 27.9^m$	+4° 40′	77° Mo	−2.0	35.6″	99%	5.538
	31	$11^h\ 35.9^m$	+3° 57′	106° Mo	−2.2	38.9″	99%	5.064
Saturn	1	$16^h\ 23.3^m$	−19° 55′	2° Mo	+0.4	15.1″	100%	10.992
	31	$16^h\ 37.9^m$	−20° 27′	28° Mo	+0.5	15.3″	100%	10.868
Uranus	16	$1^h\ 01.4^m$	+5° 51′	113° Ev	+5.8	3.6″	100%	19.573
Neptune	16	$22^h\ 36.1^m$	−9° 41′	74° Ev	+7.9	2.3″	100%	30.224
Pluto	16	$19^h\ 01.3^m$	−21° 04′	21° Ev	+14.2	0.1″	100%	33.921

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

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

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

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

Fred Schaaf

The Zero Hour

The Greek hero Perseus leads us to his secret stellar stash.

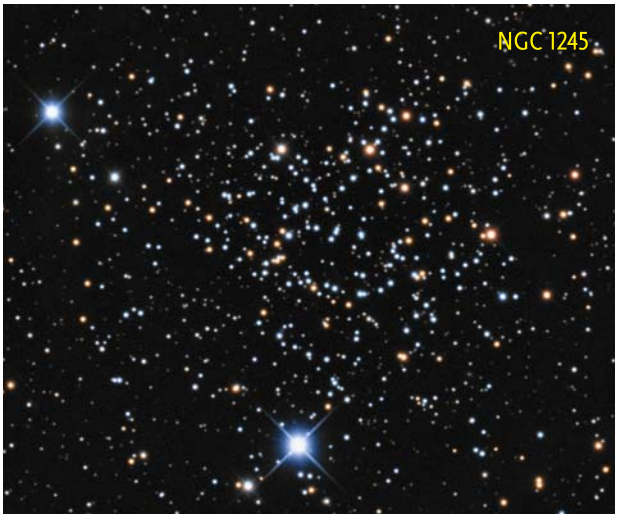
Our all-sky map this month shows the sky when the 0^h line of right ascension is on the meridian. This could be considered the "starting sky" of the heavens because the beginning of right ascension's west-to-east measure of the heavens is the 0^h line. Yet this sky scene is presented to us in the prime hours of evening not at the start of our calendar year, but instead near the end — in November and December.

Zero hour and the lesser-known marvels of Perseus. Start or end, this is a marvelous time for observers at mid-northern latitudes. It's a time when the soft, elongated glow of M31, the Great Andromeda Galaxy, is almost overhead. It's also the time when the brightest of all constellations, Orion the Hunter, has lifted entirely above the east horizon in all its glory. But much higher in the northeast now is another figure of stars, representing a hero of Greek mythology who was certainly nobler than the vain Orion. I refer, of course, to Perseus.

The most spectacular stars and deep-sky objects of Perseus are among the most famous and frequently observed in all the heavens. But sometimes there can be a drawback having such renowned attractions in a constellation. The famed marvels can take attention away from lesser but still deserving objects.

Perseus is famous for the brightest eclipsing binary, Beta (β) Persei, for what some observers consider the most impressive open star cluster sight (the Double Cluster), and for Alpha (α) Persei, with its very large, bright cluster of stars. Even rather dim M76, the Little Dumbbell Nebula, and NGC 1499, the elusive California Nebula, get considerable attention. But Perseus also offers two fine overlooked double stars, three pretty but little-known open clusters, and an amazingly young stellar association.

Two fine Perseus double stars. Beta Persei (Algol) is a double star, but the components are much too close together to split in telescopes. That's certainly not the case with Eta (η) Persei. Eta Persei marks the north end of Perseus, the peak of the hero's helmet, not far from the Double Cluster. It consists of a magnitude-3.8 orange supergiant and an 8.5-magnitude blue companion a healthy 28″ away. Experiment with different (small) telescopic apertures at very low power to see which gives you the best color of the companion and view of the attractive surrounding field.



BOB FRANKE

Another interesting double star in Perseus is Epsilon (ε) Persei. Its components are magnitudes 2.9 and 7.6 with only a 9″ separation, making the dimmer star hard to distinguish from the bright one through small telescopes. The colors are somewhat controversial — see what you think about them.

Alternative clusters of Perseus. Imagine an open cluster that is 24′ across and magnitude 6.4 — but missed by almost everyone. This is NGC 1528, near the curl of faint naked-eye stars in northeastern Perseus that represents the trailing leg of the flying hero. The cluster has some sparse areas in it but its few brighter stars can be resolved even with small telescopes.

Another Perseus cluster requires a larger telescope to properly appreciate: NGC 1245. It's a fine patch of more than 150 stars of about 12th magnitude (with a few bright foreground stars). On the other hand, while you're checking out Eta Persei, scan about 2° west of it to locate a non-NGC open cluster that's easy to see and resolve with small aperture — Trumpler 2, which includes a number of 7th-magnitude stars.

The million-year association. Zeta (ζ) Persei is the most southerly bright star of Perseus — and also the brightest star in the Zeta Persei OB Association. Other hot stars of spectral type O and B in the association, which is estimated to have a remarkably young age of only about 1 million years, include Omicron (ο), Xi (χ), 40, X, and AG Persei. ✦

The Before Breakfast Club

You'll need to be up and out early to catch December's planetary happenings.

If you're an avid planet observer, this month you'll still need to be a member of the "Morning Planets Club." No bright planet is visible at dusk in early December, though Mercury comes into view low in the southwest as the month progresses.

Jupiter enters at the other end of evening after mid-December, rising in the hour before midnight. But Jupiter isn't at its highest until morning twilight. That's also when we get our best looks at Mars, which rises around 2 a.m., and Venus, which rises between 3 and 4 a.m. Saturn rises last, emerging low in the dawn around mid-December.

DUSK

Mercury sets too soon after the Sun to glimpse until mid-month, when binoculars may reveal it just above the southwest horizon about 15 minutes after sunset. The planet maintains a magnitude of –0.6 or –0.7 virtually all month, coming into view a little higher at each successive nightfall. It sets about an hour and a half after the Sun by the time it reaches a greatest elongation of 20° east from the Sun on December 28th.

Neptune, in Aquarius, is still high in the southwest as evening twilight fades but sets before midnight. **Uranus**, in Pisces, transits the meridian at the end of astronomical twilight as 2015 ends. Finder charts for these well-placed planets are in the September issue, page 48, and at **skypub.com/urnep**.

LATE EVENING TO DAWN

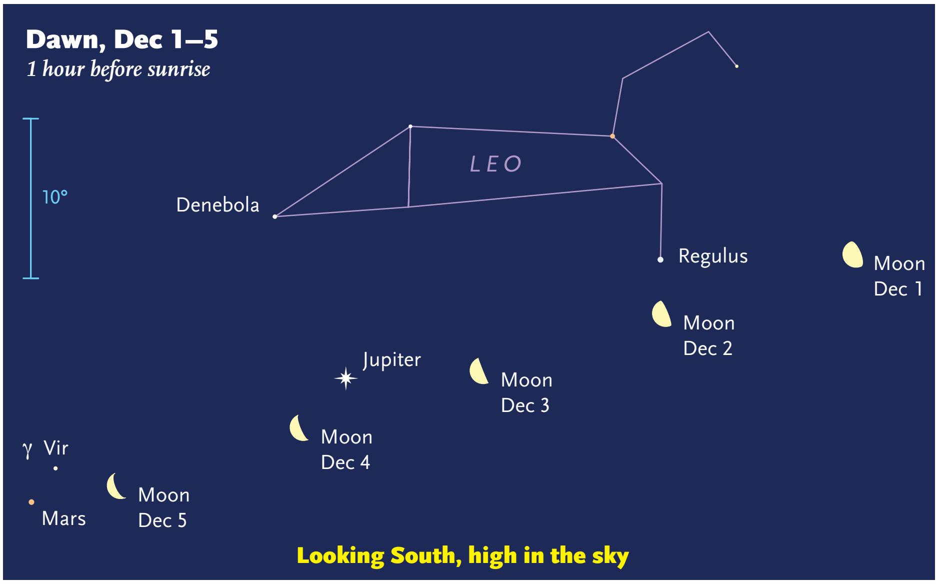
Jupiter starts December rising around 12:30 a.m., but comes up around 10:30 p.m. by the close of the month. The kingly planet is slowing its direct motion (eastward against the background stars) in easternmost Leo.

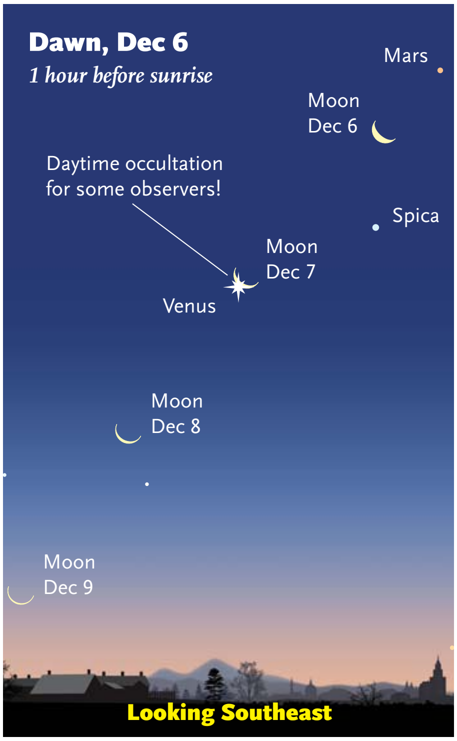
During the month Jupiter brightens from –2.0 to –2.2 and in telescopes grows from about 36″ to 39″ wide. The giant world reaches western quadrature (90° west of the Sun) on December 14th, so all month it casts its shadow farthest to the side, improving our view of many Galilean satellite events. The best time for sharp telescopic views of Jupiter is when it's highest, crossing the sky's central meridian. That happens about 10 minutes before sunrise at the beginning of the month, but some 2½ hours before sunrise by the end. Jupiter will reach opposition next March 8th.

DAWN

Mars rises in the east around 2 a.m. in early December, and only about a half hour earlier at the end of the month. It brightens from magnitude +1.5 to +1.3 this month, making it nearly as bright as Spica when it passes about 4° north (upper left) of the star on the mornings of December 23rd and 24th.

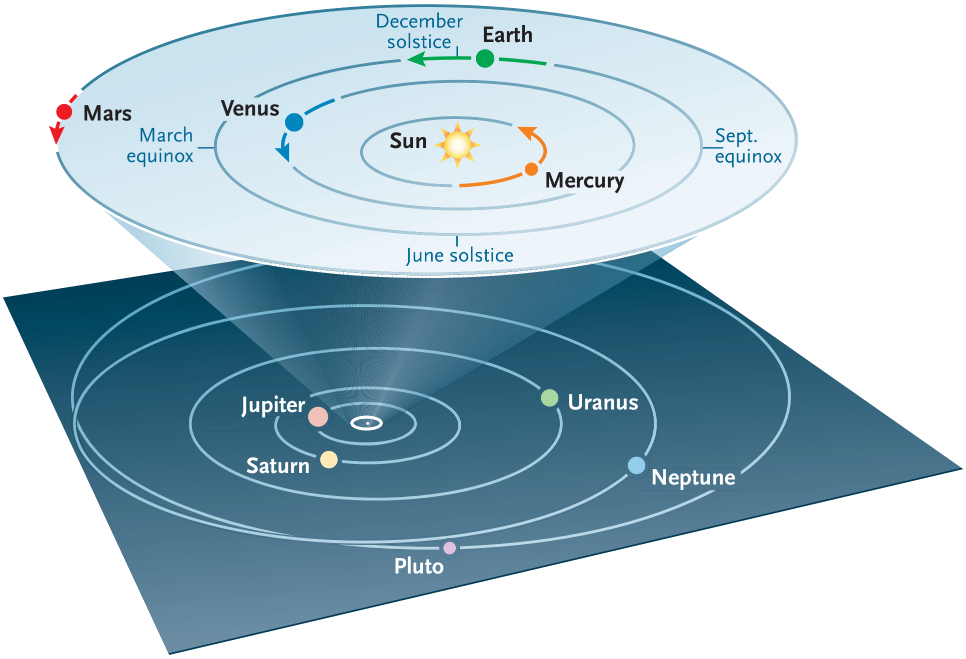
The Red Planet starts December near 3rd-magnitude Gamma (γ) Virginis (the double star Porrima) and brushes just past 4th-magnitude Theta (θ) Virginis on





ORBITS OF THE PLANETS

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



December 12th and 13th. By late December Mars reaches the meridian a little before sunrise. A telescope still shows it as a featureless orange dot only 5″ wide. At opposition next May, however, Mars will appear the brightest and biggest it has since 2005.

Venus loses about an hour of its lead on the Sun this month, but even at month's end still rises almost 3 hours before sunup. Venus also loses altitude in December, dropping from less than 30° to less than 20° high an hour before sunrise for observers at mid-northern latitudes. Venus dims a bit to magnitude –4.0; a telescope shows its globe shrink from about 17.5″ to 14.5″ in diameter while its gibbous phase increases from about ⅔ to ¾ sunlit.

Venus is within 5° of Spica from November 28th through December 1st, passes double star Alpha (α) Librae on the 17th and 18th, and pulls very close to the telescopic double star Beta (β) Scorpii at month's end.

Also at month's end, another bright planet looms lower left of Venus: Saturn.

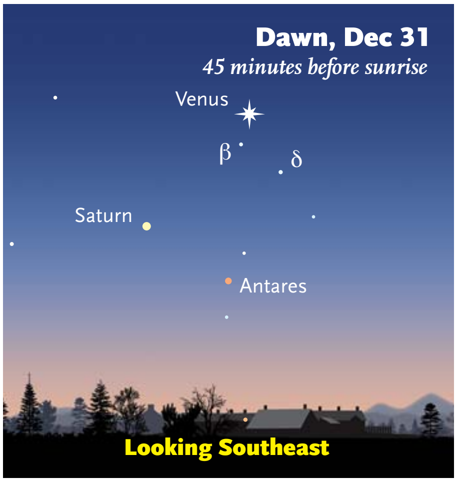
Saturn was at conjunction with the Sun on November 30th and becomes plainly visible around mid-December, when it rises in the southeast more than an hour before sunup. By the final day of the year, the ringed planet precedes the Sun by more than two hours. Magnitude +0.5 Saturn is just over 6° north (upper left) of slightly dimmer Antares on December 21st.

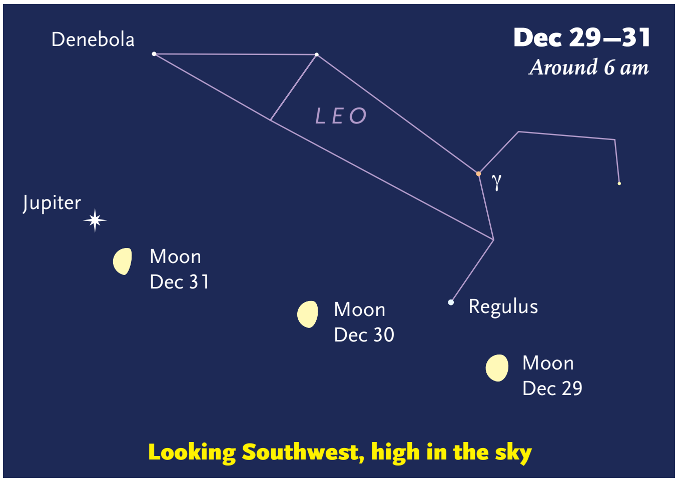
But far more exciting is the closing gap between Saturn and Venus in the final days of the year. The two will have an extremely close conjunction on the morning of January 9, 2016.

SUN AND MOON

The **Sun** arrives at the December solstice at 11:48 p.m. EST on December 21st. This marks the start of winter in the Northern Hemisphere and of summer in the Southern Hemisphere.

The waning **Moon** shines near Regulus on the morning of December 2nd and near Jupiter on December 3rd and 4th. On December 6th, it's about equidistant from Mars and Spica. The waning lunar crescent is quite near Venus on the American dawn of December 7th, and during the daytime occults Venus for virtually all of North America (see page 46). Late on New Year's Eve, December 31st, the waning gibbous Moon rises with Jupiter not far below, their second encounter this month. ✦


Dawn, Dec 31
45 minutes before sunrise


Dec 29–31
Around 6 am

These scenes are drawn for observers near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. For clarity, the Moon is shown three times its actual apparent size.

A Moonless Geminid Shower

The nights of December 13th and 14th offer dark skies for frequent meteors.

During last year's peak Geminid night, Ken Brandon shot about 700 30-second exposures from Big Sur, California, with an untracked camera. He writes, "I found 61 frames with meteors in them. I stacked the frames and created masks for each meteor," then added them to a single exposure of the sky from the end of the series. The meteors appear to come from many directions because the shower's radiant rose from low to high during the series, while the camera did not. Brandon used a 50-mm lens on a DSLR set to ISO 6400.

The Geminid meteor shower ranks with the August Perseids for showiness, and it's easier on your sleep schedule too. The Geminid radiant point (near Castor in Gemini) climbs as high by 11 p.m. standard time as the Perseid radiant does by 2 a.m. daylight-saving time on the peak Perseid nights. The higher the radiant, the more of a shower's meteors you see.

The International Meteor Organization (IMO) predicts that the Geminids should reach an impressive *zenithal hourly rate* (ZHR) of 120 this year. This is the number you would see per hour in a very dark sky if the radiant were at the zenith. The peak should be centered on roughly 18^h Universal Time (1 p.m. EST, 10 a.m. PST) August 14th. For North America, that splits the difference between the late nights of December 13–14 and 14–15. So the performance on both those nights is likely to be similar.

And, notes the IMO, "near-peak Geminid rates persist for almost a day, so much of the world has a chance to enjoy something of the shower's best." In addition, "mass-sorting within the stream means fainter telescopic meteors should be most abundant almost a day ahead of the visual maximum." After maximum, the meteors are often brighter than average.

FOLLOW THE SHOWER ONLINE

As observers report their counts to the International Meteor Organization, you can watch this year's Geminid activity curve develop at **imo.net**.

The Moon will be a waxing crescent a few days old, no trouble at all.

Early in the evening the radiant will still be low in the east; it rises around the end of twilight. So early-evening Geminids will be few. But if you do catch one then, it will be an unusually long, dramatic earthgrazer flying far across the sky as it skims the upper atmosphere.

Plan Your Watch

The only drawback to the Geminids is the cold! So consider this an exercise in observing-session planning. Add layers under your coat and pants, and bring along a blanket or a sleeping bag.

Scout a spot with an open view overhead and somewhat east, with no lights that you can't block out. Lie back and gaze into sky's the darkest part, preferably inclining a bit toward the radiant. Be patient. You might see a meteor a minute on average after 10 p.m. under a dark sky; fewer under suburban light pollution.

You can do a scientific meteor count for reporting to the IMO if you have a moderately dark sky and at least one hour. You'll need to follow standardized methods, so the IMO can use your *observed* rate to derive the ZHR at the time. Part of this means counting the stars you can see in a standard area to find your limiting magnitude. This way, hundreds of counts from around the world can be matched to track what the shower is doing continuously, hopefully for many days running as night circles the globe. For the instructions, see **imo.net/visual/major**.

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

Alan MacRobert

Comet Catalina Glows at Dawn

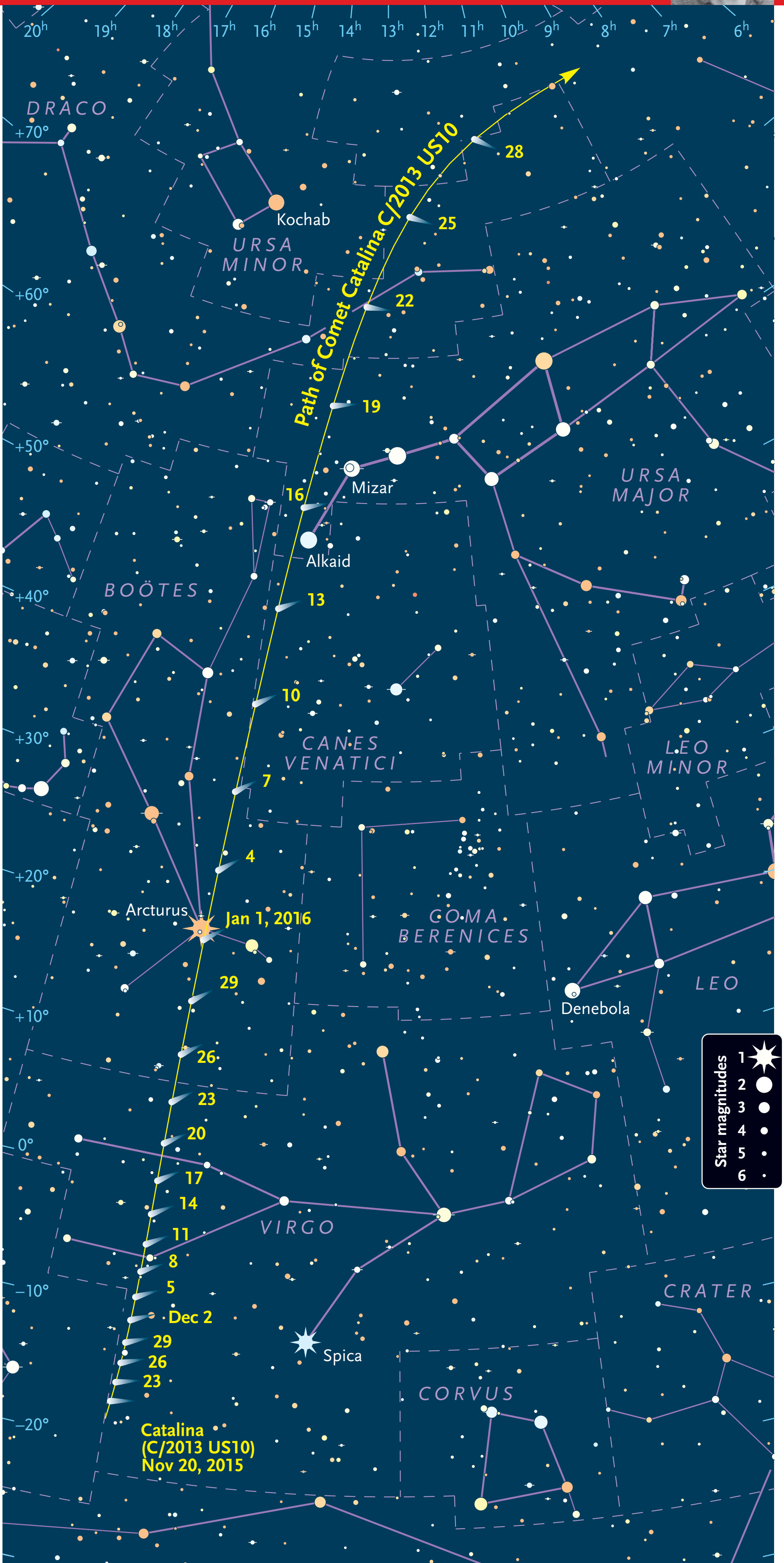
December and January should find a nice binocular comet climbing straight up the eastern sky just before the beginning of dawn. Comet C/2013 US10 (Catalina) should glow at an steady 5th magnitude from late November all the way through mid-January, as it moves farther from the Sun but closer to Earth.

Discovered two years ago by the Catalina Sky Survey, Comet Catalina passes through perihelion on November 15th, 0.82 astronomical unit from the Sun. That's far enough that predictions of its post-perihelion brightness should be pretty reliable, but on the other hand, it's a fresh comet falling into the solar system from the Oort Cloud for the first time, and such comets, with their pristine surfaces, are known for surprises.

By late November, mid-northern observers should be picking up the comet low above the eastern horizon just before the first glimmer of dawn (which means about 90 minutes before sunrise). In the following weeks it will ascend much higher before dawn, as it travels northward against the constellations — toward upper left — while the constellations themselves shift upper right with the turning of the season.

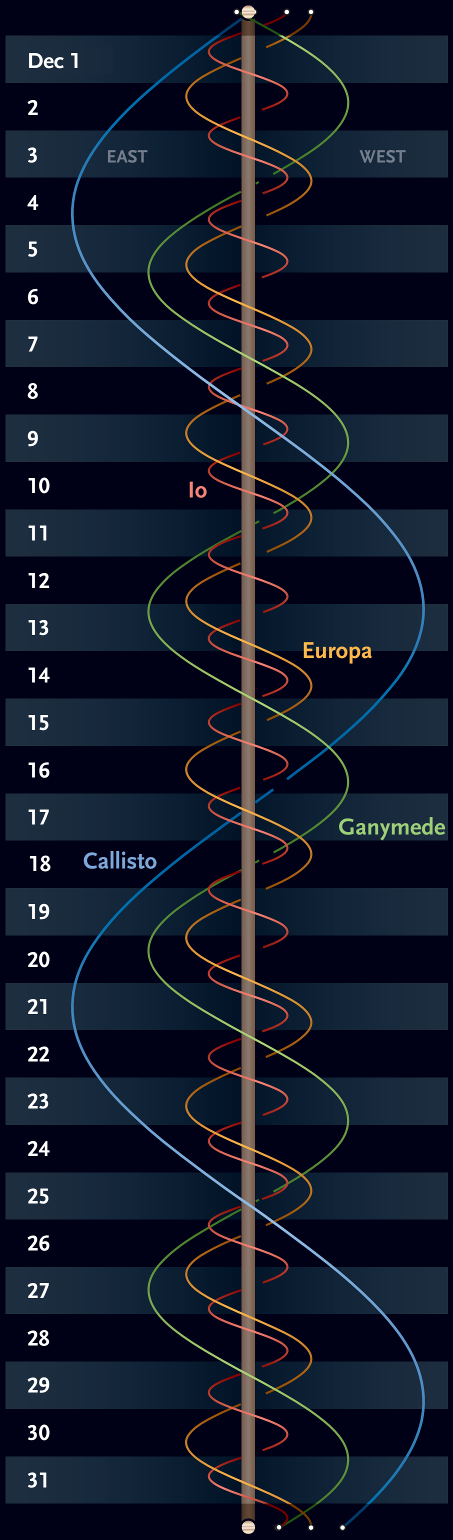
On New Year's morning Comet Catalina will be about ½° from Arcturus for the time zones of North America. Arcturus will be shining about 100 times brighter. The comet will pass closest to Earth, 0.72 a.u., on January 12th while sailing north past Mizar. After that it should fade rapidly.

Slight perturbations by the planets during its pass through the solar system are sending it on a trajectory to interstellar space, never to return.



Comet Catalina flies north across morning constellations in the eastern sky from now through January. Ticks mark its position at 0:00 Universal Time every three days. Stars are plotted here to 5th magnitude, about as faint as the comet will be; its symbol is exaggerated.

Jupiter's Moons



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

Moon Occults Venus in

The waning Moon had crept right up to Venus when Ravindra Aradhya took this picture from Bangalore on February 26, 2014. "It was an amazing sight," he writes. "This photo was taken just before the Moon fully occulted the dark side of Venus." He used an 8-inch f/10 Schmidt-Cassegrain scope.

On December 7th, if the sky is clear, practically everyone with a telescope or binoculars in North and Central America will have a chance to see the thin waning crescent Moon cover and uncover Venus in the daytime.

Watching this event may or may not be easy; the deeper the blue of your sky the better. The slim Moon will be just 13% illuminated and about 43° west of the Sun. If there's any haze, Venus may be the first thing you spot in your binoculars or finderscope. It's tiny, but it has a much greater surface brightness to penetrate a bright sky. Carefully sweep the area of sky about four fist-widths to the Sun's right if you're in the East, a little above right in the Midwest, and higher to the upper right farther west. You're looking for a tiny white dot close to a

Morning Action at Jupiter

December finds Jupiter rising in the middle of the night and, finally, standing at its highest in the south around the first light of dawn. That's the best time to train a telescope on its banded globe, which enlarges this month from 36 to 39 arcseconds wide across its equator. That's smallish for Jupiter but bigger than any other planet (see page 44).

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

All the interactions in October between Jupiter and its satellites and their shadows are tabulated at right.

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

November 1, 8:30, 18:25; **2**, 4:21, 14:17; **3**, 0:13, 10:08, 20:04; **4**, 6:00, 15:56; **5**, 1:51, 11:47, 21:43; **6**, 7:39, 17:34; **7**, 3:30, 13:26, 23:22; **8**, 9:17, 19:13; **9**, 5:09, 15:05; **10**, 1:00, 10:56, 20:52; **11**, 6:48, 16:43; **12**, 2:39, 12:35, 22:30; **13**, 8:26, 18:22; **14**, 4:18, 14:13; **15**, 0:09, 10:05, 20:01; **16**, 5:56, 15:52; **17**, 1:48, 11:43, 21:39; **18**, 7:35, 17:31; **19**, 3:26, 13:22, 23:18; **20**, 9:14, 19:09; **21**, 5:05, 15:01; **22**, 0:56, 10:52, 20:48; **23**, 6:44, 16:39; **24**, 2:35, 12:31, 22:26; **25**, 8:22, 18:18; **26**, 4:14, 14:09; **27**, 0:05, 10:01, 19:56; **28**, 5:52, 15:48; **29**, 1:43, 11:39, 21:35; **30**, 7:31, 17:26.

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

These times assume that the spot is at System II longitude 230°. Features on Jupiter appear closer to the central meridian than to the limb for 50 minutes before and after transiting. A light blue or green filter will slightly improve the contrast of Jupiter's reddish and brownish markings.

a Sunny Blue Sky

dim gray ghost of a lunar crescent.

Alaskans will see the event in a better sky before sunrise, but the Moon and Venus will be quite low in the southeast.

Since the Moon is waning, Venus will disappear behind its bright limb and reappear from behind the dark limb, which will be quite invisible in daylight. The gibbous ball of Venus (69% sunlit and 17 arcseconds from top to bottom) will appear to emerge from behind an invisible wall.

Both the disappearance and reappearance will be protracted events, taking at least 23 seconds and probably somewhat longer depending on where you are.

The bright side of Venus, of course, will face in the same sunward direction as the bright side of the Moon.

Some predicted times: **Montreal**, *disappearance* 12:38, *reappearance* 1:35 p.m. EST. **Western Massachusetts,** *d.* 12:41, *r.* 1:45 p.m. EST. **Toronto,** *d.* 12:32, *r.* 1:36 p.m. EST. **Washington, DC,** *d.* 12:39, *r.* 1:51 p.m. EST. **Atlanta,** *d.* 12:32, *r.* 1:57 p.m. EST. **Miami,** *d.* 12:51, *r.* 2:16 p.m. EST. **Chicago,** *d.* 11:18 a.m., *r.* 12:32 p.m. CST. **Kansas City,** *d.* 11:04 a.m., *r.* 12:31 p.m. CST. **Austin,** *d.* 11:05 a.m., *r.* 12:47 p.m. CST. **Winnipeg,** *d.* 10:53, *r.* 11:57 a.m. CST. **Denver,** *d.* 9:35, *r.* 11:13 a.m. MST. **Edmonton,** *d.* 9:17, *r.* 10:29 a.m. MST. **Vancouver,** *d.* 7:53, *r.* 9:23 a.m. PST. **Berkeley,** *d.* 7:53, *r.* 9:39 a.m. PST, **Los Angeles,** *d.* 8:04, *r.* 9:53 a.m. PST, **Anchorage,** *d.* 6:34, *r.* 7:47 a.m. AKST.

Interpolate between cities near you to estimate the times for your location. Start setting up early; occultations don't wait! ✦

Minima of Algol

Nov.	UT	Dec.	UT
2	4:43	3	17:41
5	1:32	6	14:30
7	22:21	9	11:20
10	19:10	12	8:09
13	15:59	15	4:58
16	12:48	18	1:48
19	9:37	20	22:37
22	6:26	23	19:26
25	3:15	26	15:15
28	0:03	29	12:04
30	22:52		

These new predictions are about two hours ahead of those formerly used, based on new informaton about Algol's changing period from the AAVSO. They're from the heliocentric elements Min. = JD 2440953.5087 + 2.8673075*E*, where *E* is any integer.

Phenomena of Jupiter's Moons, December 2015

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

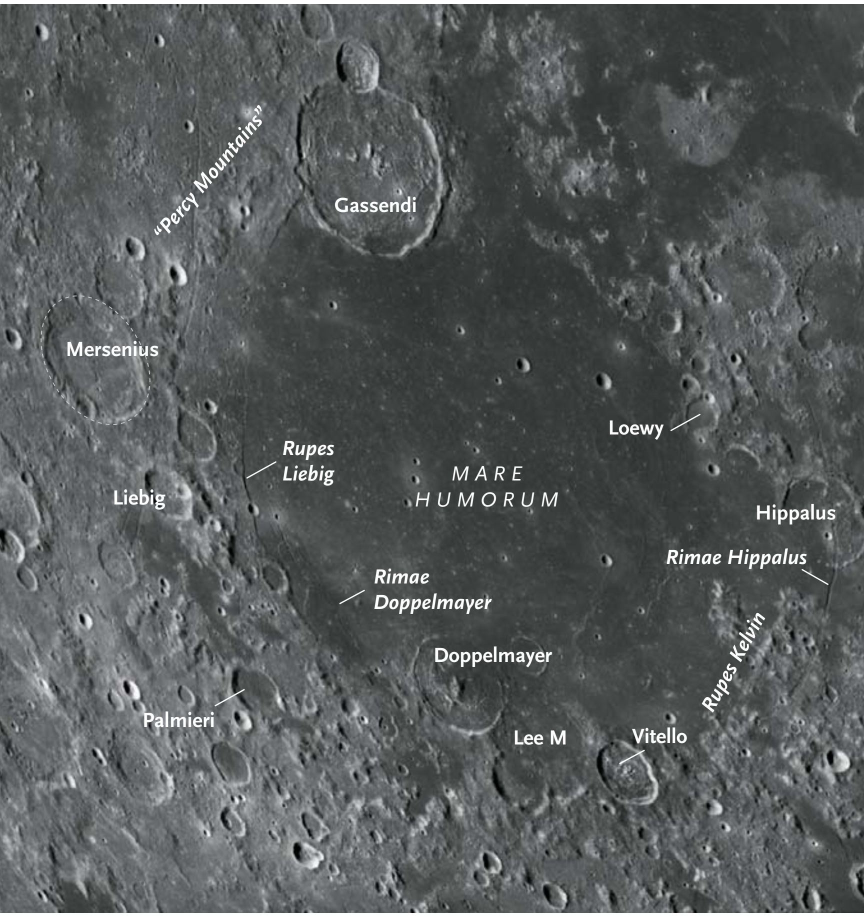
Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 5 hours ahead of Eastern Standard Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede,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

Humorum in the Eyepiece

Here's a medium-size lunar basin that's packed with interesting geologic features observable through your telescope.

The dark maria are the most conspicuous features of the Moon, but more important are the giant basins that contain them. Each basin controls the geology of the area around it. One easy-to-see example is the Humorum basin, whose central depression is partially filled by the lava plains of **Mare Humorum**. This mid-size impact basin preserves many structural features that one can appreciate only by careful observation. So let's do so!

Younger, less-modified lunar basins (Orientale comes to mind) are defined by multiple concentric mountain ranges. We assume that the Humorum basin had them as well when it formed, but only a few fragments of the original rims survive. Can you see any? The basin's best-seen rim segment appears as a short lumpy ridge (once known as the **Percy Mountains**) that starts on the west side of the big crater **Gassendi**, which intrudes into Mare Humorum's northern boundary.



NASA / LUNAR RECONNAISSANCE ORBITER

Mare Humorum's lava flows fill a medium-size lunar basin that's 425 km across. Little remains today of the multiple rings that once marked its rim.

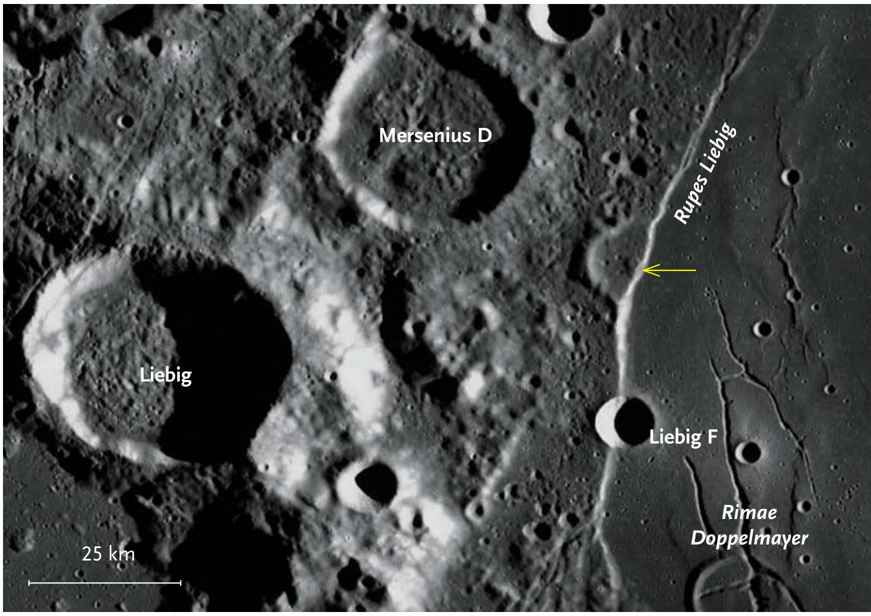
If you draw an imaginary circle through this range, and then continue along other isolated mountains east of the craters **Mersenius** and **Liebig**, you will find that the extrapolated circle passes along the straight **Rupes Kelvin** scarp on the southwestern side of the mare. To the northeast from there, the basin rim becomes harder to trace, having more gaps than continuity. This circular rim, so discontinuous that its definition depends on faith as much as evidence, has a diameter of about 425 km.

A second basin ring, even easier to overlook, is marked by a low mountain ridge parallel to the Percy Mountains but about 150 km to their northwest. Individual local hills hint at this barely visible ring curving around the western side of Mersenius, but then farther south and east it mostly disappears. The moat between the Percy Mountains rim and this larger ring is at lower elevation than most of the terrain beyond, a fact made noticeable by the occurrence of mare patches between Liebig and **Palmieri**, and between Ramsden and Campanus. This is a small-scale version of the low spots of Sinus Aestuum, Mare Vaporum, and Mare Frigoris that occur beyond the Apennine rim of the Imbrium basin.

Looking around the shore of Mare Humorum, you'll see that the basin floor has subsided toward the basin center. The evidence? Note the large craters with rims breached on their mare-facing sides. Examples are **Doppelmayer** and its larger neighbor, **Lee M**, along the southern extent of the mare, and **Hippalus** and **Loewy** along the eastern shore. To the north, Gassendi's walls also dip inward. Perhaps the basin floor had a sloped, saucer shape after its formation, or perhaps the inward tilt occurred as the basin filled with lava. Whatever the reason, these craters tilted inward and the ejecta around them became buried under flows that erupted later.

Cracking Under Pressure

The massive mare slab also sank under its own weight and caused fracturing around its eastern edge, producing three parallel arc-shaped rilles — the **Rimae Hippalus**.



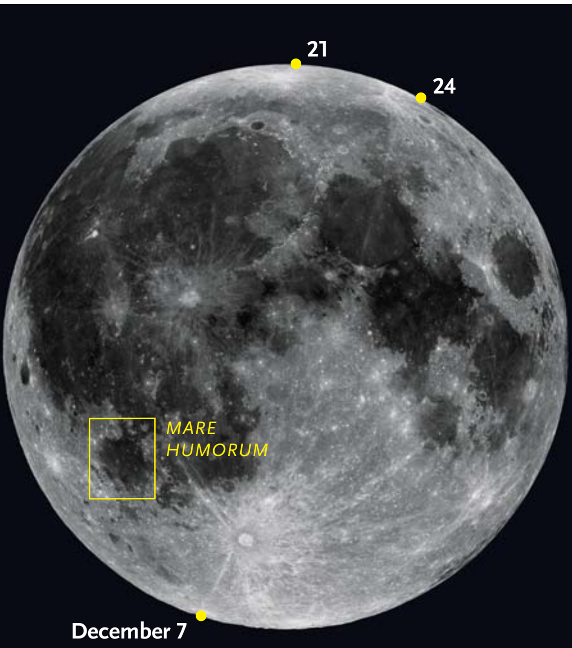
NASA / LUNAR RECONNAISSANCE ORBITER

This close-up of western Mare Humorum shows how the long fracture Rupes Liebig has sliced through an unnamed crater (arrow). Its right (eastern) half dropped down and was later covered with lava flows.

Other basins have such extension cracks, but few are as large and dramatic as these. Also look for a family of three or four mare ridges along the eastern interior of the mare that are best seen with sunrise illumination (when the Moon's phase is waxing gibbous). These formed as the basin's center subsided, which forced the solidified mare flows to fit into a smaller volume. The kilometer-thick slab accommodated this squeezing by fracturing multiple times. Some parts of the mare slid up over adjacent parts, creating the mare ridges.

Use high magnification to observe that the western edge of the mare, just inside the Percy Mountains, is sharply bounded by a fault that separates the smooth lava from older rugged terrain to the west. Farther south, along the mare's western margin and inward from the 39-km-wide crater Liebig, the fault boundary becomes detectable again — at least near local sunrise or sunset, when the scarp's higher western face is starkly illuminated or shadowed, respectively. **Rupes Liebig** truly is a fault, as dramatically illustrated by an older, 10-km-wide crater just east of Liebig that's been sliced in half. Its eastern side dropped down and became smothered by mare lavas, making its eastern rim completely invisible. Just to its south, look for a younger, 8-km crater gouged out right on the fault scarp. Topographic data from the Lunar Reconnaissance Orbiter (LRO) show that the eastern rim of this crater is 500 m lower than the western rim. That's not at all obvious telescopically.

When you observe Humorum near full Moon, note that the area around **Rimae Doppelmayer** in the southwestern corner is much darker than most of Mare Humorum. Spectral studies confirm that this dark material consists of pyroclastic glass beads that must have been tossed out of a volcanic vent. But no vents are visible, even in high-resolution LRO images, so the explosive activity that laid down the dark deposits probably came from eruptions along the rille's 300-km length. In fact, the rille runs down the middle of a wide ridge, 7 to 8 km across, that rises up to 100 m above the surrounding mare. This is probably the pile of pyroclastic material that accumulated around the long eruption fissure. Sadly, we're about 3½ billion years too late to witness the fireworks! ✦



NASA / LRO

The Moon • December 2015

Phases

◑ **LAST QUARTER**
December 3, 7:40 UT

● **NEW MOON**
December 11, 10:29 UT

◐ **FIRST QUARTER**
December 18, 15:14 UT

○ **FULL MOON**
December 25, 11:11 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	**December 5, 15^h UT**
251,531 miles	diam. 29′ 46″
Perigee	**December 23, 20^h UT**
228,924 miles	diam. 32′ 18″

Librations

Bailly (crater)	**December 7**
Byrd (crater)	**December 21**
Mare Humboldtianum	**December 24**

Night's Serenity

The jewels of Cassiopeia sparkle on a peaceful winter night.

The evening lays its golden bars
Across the empire of the blue,
And one by one the taper stars
Gleam silently to view.

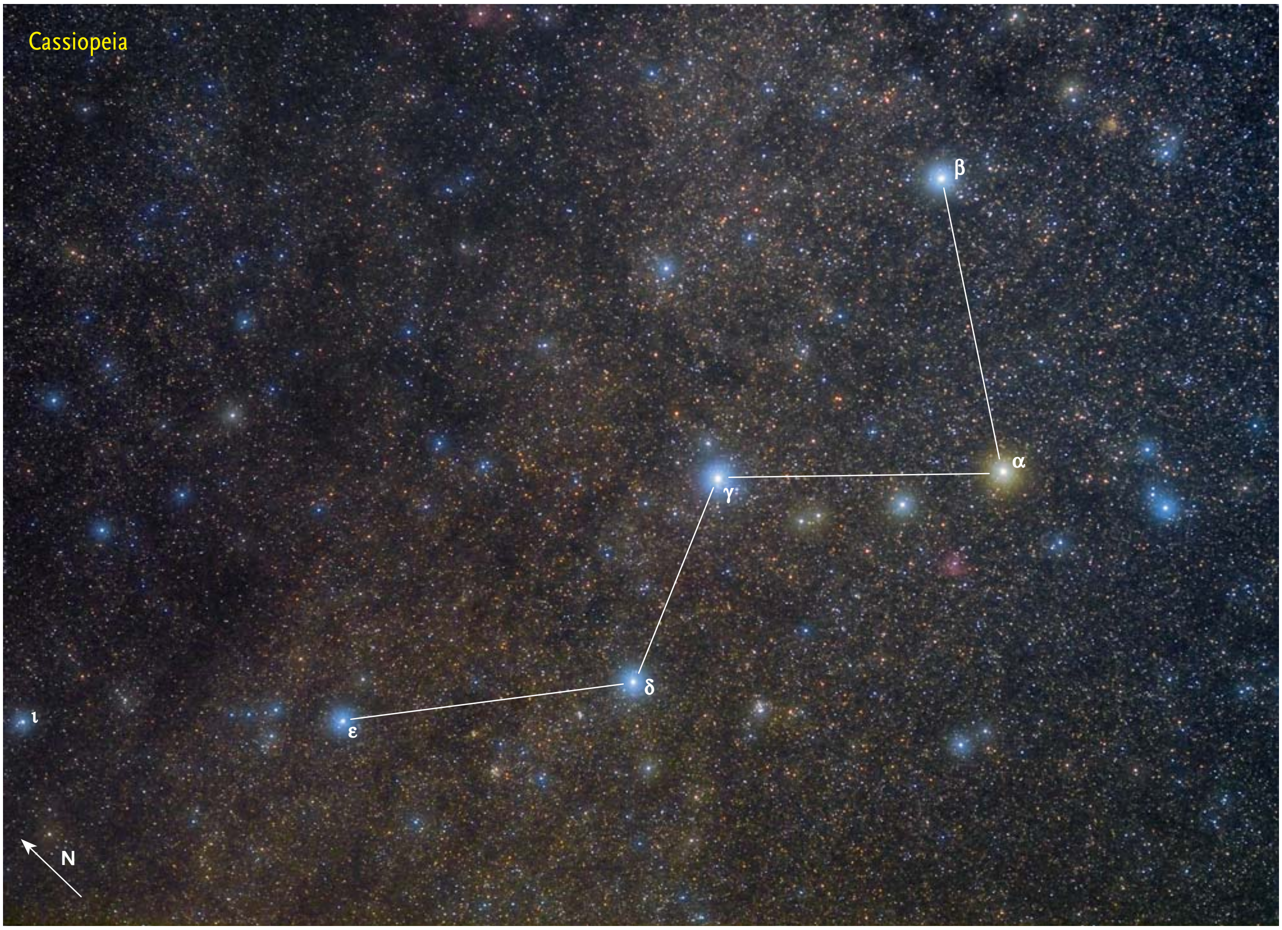
Till all their tenderness and light,
The burning beauty of the whole
Cathedral of the spherèd night,
Is mirrored in the soul.

Now fade the glowing vesper bars
That gird the pillars of the west,
And all the lustres of the stars
Burn in their rooms of rest.

— Albert Durrant Watson, *Evening Peace*, 1923

As the last blush of light fades from the evening sky, devoted skygazers around the world give welcome to the starry night and the precious tranquility it offers. Let's open our questing souls to the lustrous stars that burn in one of the sky's most memorable constellations, Cassiopeia, the Queen.

We'll begin with **Iota (ι) Cassiopeiae**, a particularly attractive star that dwells in the Queen's eastern realms at a distance of about 140 light-years. Shining at magnitude 4.6, it's visible to the unaided eye in a moderately dark sky. Iota is quite easy to locate, since stars Delta (δ) and Epsilon (ε) in Cassiopeia's landmark W or M shape point straight to it. What draws our attention, however, is the view through a telescope, which reveals a beautiful triplet. Observed through my 130-mm refractor at 63×,



BORIS ŠTROMAR

the bright primary (A) appears white, and there's a much dimmer, orange companion (C) to its east-southeast. Boosting the magnification to 117×, a brighter, yellow-white companion (B) pops out close southwest of the primary. These colors correspond fairly well with their spectral types of *A*5 (A), *F*5 (B), and *K*3 (C).

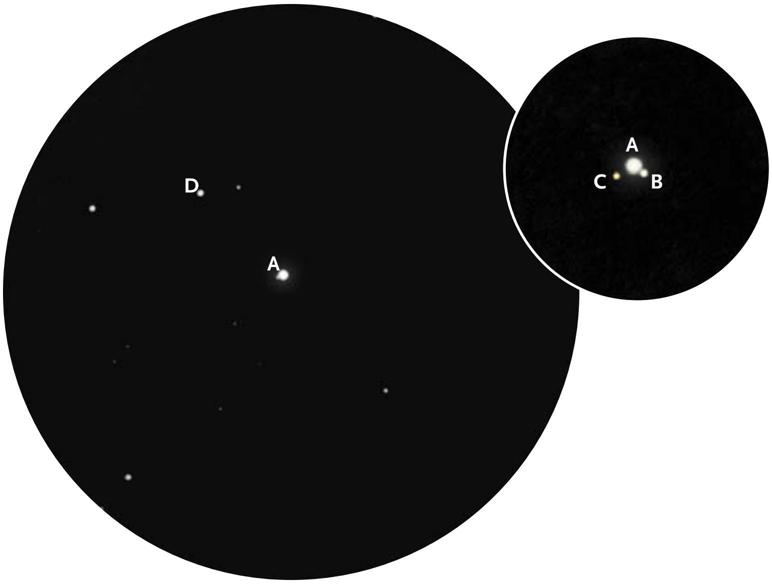
Contrast illusions often play havoc with an observer's perception of color, especially with tightly grouped stars such as these. In his 1844 *Bedford Catalogue*, Admiral William Henry Smyth described the A, B, and C components as pale yellow, lilac, and fine blue, respectively. Swedish astronomer Nils Christoffer Dunér saw the C component as pink. Try detecting the hues of these stars for yourself using two tricks to help you see colors better. Slightly defocus the stars to give them a little dimension, and increase the apparent separation of the stars with high powers to lessen color-contrast effects.

In the June 2006 *Astronomical Journal*, Julian Christou and Jack Drummond published a remarkable infrared image of Iota Cassiopeiae taken with the Lick Observatory adaptive optics system. (Adaptive optics improve a telescope's resolution by making rapid adjustments to a deformable mirror to compensate for image blurring caused by atmospheric turbulence.) Iota's image shows close, faint companions to both the A and C components, the latter previously unknown. Further measurements are needed to determine whether C and its apparent companion form a true pair.

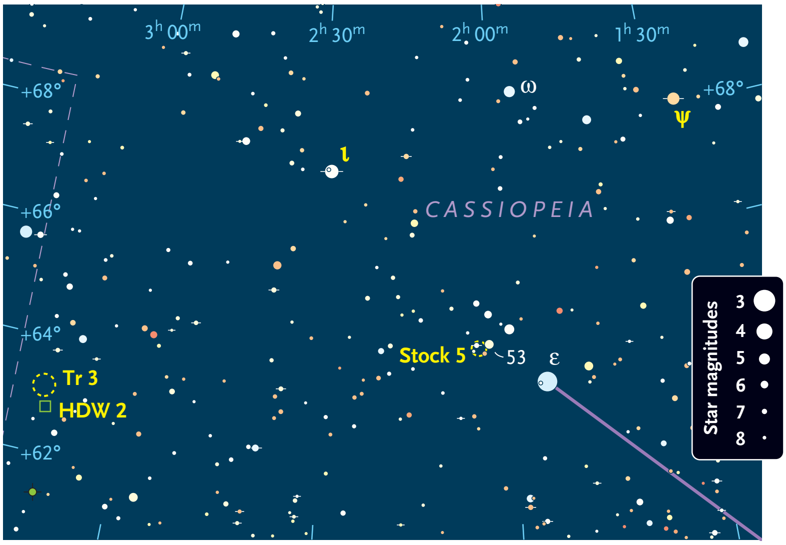
Another delightful group of stars is found in the guise of **Stock 5**, an open cluster located 1.3° northeast of Epsilon (ε) Cassiopeiae. Through my 130-mm scope at 48×, its four brightest suns form a misshapen kite flying east-southeast. The kite's bottom is marked by 5.6-magnitude 53 Cassiopeiae, which appears yellow-white. The northern star of the kite's crossbar seems creamy white to me, and the southern one looks orange. About 20 faint stars fill out this 24′ group. Stock 5 looks more cluster-like at 63×, boasting a total of 45 stars. Most are concentrated in the vicinity of the kite, and the rest are loosely scattered north of it.

Stock 5 lies about 3,600 light-years away from us, and its stars have an average age of 50 million years. There are roughly 180 probable cluster members within a 24′ diameter, but 53 Cassiopeiae and the bright, orange star HD 12399 aren't among them.

My Deep-Sky Wonders column for January 2011 included the open cluster **Trumpler 3** in far eastern Cassiopeiae. It's visible in my 9×50 finder as a patch of fog harboring 5 stars, while the 130-mm refractor at 37× displays 30 fairly bright to faint stars loosely flung across nearly 18′. An orange gem adorns the southeastern quadrant. At the time, I twice attempted to observe nearby



As shown by his sketches, Michael Vlasov easily resolved the triple star Iota Cassiopeiae with an 8-inch f/5 Newtonian reflector at 125×.



In Royal Favor

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Iota (ι) Cas	Triple star	4.6, 6.9, 9.1	2.9″, 7.1″	02h 29.1m	+67° 24′
Stock 5	Open cluster	~6	24′	02h 04.4m	+64° 23′
Trumpler 3	Open cluster	7.0	15′	03h 12.0m	+63° 11′
HDW 2	Planetary nebula	—	5.7′	03h 11.0m	+62° 48′
Psi (ψ) Cas	Triple star	4.7, 9.2, 10.0	20″ (AC), 2.3″ (CD)	01h 25.9m	+68° 08′

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.

Don Goldman compiled this image of HDW 2 from 22.5 hours of 3-nm O III and Hα narrowband data with an additional 75 minutes of RGB for star color. He mapped the Hα data to red/magenta and the O III data to blue/green.

Using her 15-inch reflector at 102×, the author tracked down HDW 2 south-southwest of Trumpler 3. Her sketch shows an arc of stars marking a large "cavity" surrounded by faint nebulosity. North is to the left.

Hartl-Dengel-Weinberger 2 (HDW 2) with my 10-inch reflector. While I thought I might have detected part of this planetary nebula with a great deal of effort, I wasn't convinced enough to mention it.

More recently, I tackled HDW 2 with my 15-inch reflector. Its position is easy to pinpoint because it rests 24′ south-southwest of Trumpler 3's center, and a hill of 6 stars (magnitudes 11 to 14) is contained within it. Using a narrowband nebula filter and a magnification of 102×, I can see an extremely faint and peculiar-looking nebula, but averted vision is needed for a good view. (Averted vision is the practice of looking a bit off to one side of a faint object so that its light will fall on a more sensitive area of your eye's retina.) It's vaguely annular, with the arc of stars lining the northern part of a large, off-center "cavity." The "annulus" appears widest and brightest from the east through the north to the west-northwest. It seems to be slightly elongated east-west, spanning roughly 6′ × 5½′. The brighter section is also visible with an O III filter, but the dimmer part is difficult to see. I sketched HDW 2 on a subsequent night, when it was higher in the sky.

The Austrian astronomers for whom HDW 2 is named announced their discovery in the *Mitteilungen der Astronomischen Gesellschaft Hamburg* (Communications of the Astronomical Society of Hamburg) in 1983. They were the first to suggest that this object is a planetary nebula, although it was previously listed as object 200 in the 1959 *Catalogue of HII Regions*, a second catalog by Stewart Sharpless, which extended and superseded his first. As a consequence, HDW 2 is also called Sharpless 2-200 (Sh 2-200).

Deep images of HDW 2 show an external halo that spans approximately ½° and is most prominent along an arc that cradles the nebula northeast through south. This halo isn't part of HDW 2, but rather interstellar gas that's been ionized by radiation escaping the planetary nebula. Some images reveal striping across HDW 2 that may be due to instabilities created by either the local magnetic field or the planetary's motion through interstellar gas and dust.

We launched our deep-sky tour with lovely Iota Cassiopeiae, so let's conclude it with another pretty triple star, **Psi (ψ) Cassiopeiae**. Through my 105-mm refractor at 28×, its bright, golden primary watches over a considerably fainter companion 20″ to the southeast. At 87× the companion splits into a close pair. The brighter star shines at magnitude 9.2 and its 10.0-magnitude attendant lies a scant 2.3″ west-southwest. I couldn't judge the colors of this pair with the little refractor, but through my 10-inch reflector, they looked blue-white and white to me. What do you think?

In order of decreasing magnitude, the stars described above are given as components A, C, and D in the online Washington Double Star Catalog, maintained by the United States Naval Observatory. The omitted B component is a 14.0-magnitude star only 2.4″ northeast of A. The small separation combined with the large magnitude difference makes it impossible for me to distinguish the AD pair. Although components C and D form a physical pair, they aren't allied with star A. No determination has been made for the AB pair, but with such a magnitude difference, the components are most likely just a chance alignment of stars at different distances along our line of sight.

Whatever their association, these taper-stars handsomely gleam in our sky, shedding their light for us to enjoy on the sable vault of night. ✦

Join us
and expect the
extraordinary.

2016

SOUTHERN SKY

- Costa Rica

TOTAL ECLIPSE

- Bali New Year
- Indonesia & Borneo Cruise

2017

TOTAL ECLIPSE – USA

- America's Music Cities
- Coastal Pacific NW & San Francisco
- National Parks of the West
- Yellowstone Family Adventure

TRAVEL**QUEST**
international

TravelQuestTours.com
1 800 830-1998

FOCUS ON

WALPACK VALLEY ENVIRONMENTAL EDUCATION CENTER

Eatontown Public Schools, Walpack, NJ

The **ASH-DOME** pictured is 12′6″ in diameter. The observatory is designed with a separate display and instructional area below.

ASH MANUFACTURING COMPANY
P.O. Box 312, Plainfield, IL, USA 60544
815-436-9403 • FAX 815-436-1032
www.ashdome.com
Email: customerservice@ashdome.com

Ash-Dome is recognized internationally by major astronomical groups, amateurs, universities, colleges, and secondary and primary schools for its performance, durability, and dependability. Manual or electrically operated units in sizes from 8 to 30 feet in diameter available. Brochures and specifications upon request.

PlaneWave™
INSTRUMENTS

CDK Series

Full Line of Corrected Dall-Kirkham Optical Systems

- Coma Free Design
- No Off-Axis Astigmatism
- Carbon Fiber Truss Design
- Flat Field Across A 52-70mm Image Circle
- Most Models Delta-T Ready With Built-In Dew Heaters

For custom research applications, PlaneWave is proud to feature our PW-RC Series.

- 20 Inch, 24 Inch and 0.7m Ritchey-Chrétien OTAs and Complete Systems

Learn More at www.planewave.com

M51 by Warren Keller

Tony Flanders

Three Bargains for Beginners

We put three entry-level scopes through their paces.

ALL PHOTOGRAPHS TAKEN BY *S&T:* SEAN WALKER

Choosing the right telescope for beginners can be difficult, particularly on a limited budget. Tony Flanders compares three telescopes that give excellent value for their prices.

HOW MUCH DOES a decent beginner scope cost? There are plenty of good choices for $400, and the options are almost limitless if you're willing to spend more. At the opposite extreme, it's possible to buy a good telescope for as little as $100 (*S&T:* March 2011, p. 52). But $100 scopes have very small apertures and limited capabilities.

Things change when you move up a notch in price. If you shop carefully, a $200 telescope can provide very good views of planets and deep-sky objects. Two of these have been reviewed in prior issues: the Orion StarBlast 4.5 Astro Reflector (*S&T,* June 2003, p. 46), and the Astronomers Without Borders OneSky Reflector (*S&T,* Feb. 2014, p. 60). But how do they compare to each other? And are there other worthy candidates in the same price range?

While searching for good telescopes in the $200 price range, we evaluated many other scopes, and one of them stood out. The Meade Infinity 90 Refractor offers a fair amount of aperture with a rich package of accessories. Its 90-mm f/6.7 achromatic objective lens has just 62% the light-gathering area of the StarBlast's mirror, but that's partially offset by the refractor's unobstructed aperture.

StarBlast Versus OneSky

The StarBlast and OneSky are strikingly similar. Both are small Newtonian reflectors, though the OneSky's 130-mm f/5 mirror gathers 30% more light and has a 44% longer focal length than the StarBlast's 114-mm f/4 mirror. Their mounts are identical, requiring a table or similar support to hold them.

The most obvious difference between the StarBlast

Meade Infinity 90mm Altazimuth Refractor

U.S. price: $219.95

Available at meade.com and various dealers worldwide

Meade's Infinity 90mm Altazimuth Refractor has enough aperture to produce satisfying views of the Sun, Moon, and planets, as well as bright deep-sky objects and double stars.

Orion StarBlast 4.5 Astro Reflector Telescope

U.S. price: $209.99

Available at telescope.com

For more than a decade, Orion's StarBlast has been one of the best "bang-for-the-buck" telescopes, featuring a 4½-inch parabolic mirror in a compact alt-az configuration.

Astronomers Without Borders OneSky Reflector

U.S. price: $199.95

Available in the U.S. (online orders only) at astronomerswithoutborders.org

The Astronomers Without Borders OneSky Reflector packs a moderately large 5.1-inch aperture mirror into a collapsible tube design.

All three telescopes include enough eyepieces to provide satisfying wide-field and close-up views of targets, and the Infinity 90mm includes a 2× Barlow lens (not shown). The StarBlast and OneSky both come with a useful collimating tools.

WHAT WE LIKE:

Good high power with stock eyepiece

No collimation or cool down required

Good slow-motion controls

WHAT WE DON'T LIKE:

Awkward when pointed near zenith

Poor-quality Barlow lens

WHAT WE LIKE:

Very easy to use

Adjustable eyepiece angle

WHAT WE DON'T LIKE:

Requires table or other stand

Not great at high power

WHAT WE LIKE:

Very easy to use

Good high power with supplementary Barlow

WHAT WE DON'T LIKE:

Requires table or other stand

Awkward eyepiece angle

Slightly crude helical focuser

Although the OneSky has both a larger aperture and longer focal length than the StarBlast, it collapses into a somewhat smaller package for convenient storage and travel.

and OneSky is that users can collapse the OneSky's tube for convenient transportation. This also allows it to incorporate a much longer focal length into a slightly smaller package.

The OneSky's open tube works well under dark skies. But the view is plagued by reflections that dramatically decrease the contrast of deep-sky objects when the scope is used near bright lights. Users can fix this by constructing a simple shroud out of lightweight foam material (see **http://is.gd/GMPMMW**).

The StarBlast has a standard rack-and-pinion focuser. While this would be adequate in many scopes, it's slightly crude with the StarBlast's f/4 focal ratio, in which a tiny change in eyepiece position causes a big change in focus. The OneSky's simple helical focuser is easier to fine-tune with the lightweight eyepieces supplied with the scope.

Both optical tubes slide back and forth to achieve balance. The OneSky uses a Vixen-style dovetail bar that holds the tube at a fixed orientation, placing the focuser about 20° left of vertical. This requires you to stand behind the scope when aiming high in the sky. The StarBlast uses tube rings that allow you to rotate the tube and adjust the eyepiece angle to a comfortable angle.

The OneSky we reviewed in 2014 had a very good mirror, as does the OneSky that I borrowed for this review, suggesting that this is typical for the model. StarBlasts, by contrast, have shown considerable variation in optical quality. My own StarBlast has a good mirror, though not as good as the one in the OneSky. The best StarBlast mirrors are excellent and the worst are merely acceptable — fine for deep-sky observing but less than ideal for viewing the Moon and planets.

The OneSky works best on a standard-height table or similar support. The telescope focuser's fixed position forces users to stand behind the instrument when viewing near the zenith.

The Orion StarBlast is extremely comfortable to use when seated, though a small table or other support is necessary to perch the scope at a comfortable height.

All three of the telescopes include eyepieces that are variants of the three-element Kellner design. Their optical quality is very similar, as I verified by using each of the eyepieces in all of the scopes. The design works significantly better in the OneSky than in the StarBlast. The eyepieces are quite sharp in the center in both scopes, but stars are severely distorted near the edge of the field in the StarBlast due to its very fast f/4 focal ratio. The fraction of the field that's truly sharp is much larger in the f/5 OneSky.

To achieve high magnifications, the StarBlast needs short-focal-length eyepieces, which tend to have less eye relief. I found my eyeball uncomfortably close to the glass when using the stock 6-mm eyepiece. On the flip side, the StarBlast's short focal length gives it an expansive field of view when used with premium eyepieces: a 24-mm wide-field design produces a magnificent 3.4° field, big enough to take in the entire Veil Nebula.

All three scopes have variable-intensity red-dot finders. These work much better than the low-quality finderscopes that used to be included with budget-priced telescopes, but they do have their quirks. The electrical contacts tend to be a little balky, sometimes requiring jiggling the battery case before the finders light up.

Good as they are, the StarBlast and OneSky have a number of limitations. Most obviously, they require a table or similar support. Some users have good results using milk crates, buckets, or other found objects. An ideal solution is to build your own support, like the one shown above or the more robust model described under "DIY Improvements" at **eyesonthesky.com**.

One big consideration for beginners is that all reflecting telescopes require collimation. To their credit, both the StarBlast and OneSky ship with center-spotted mirrors and simple but effective collimation tools — features often omitted with scopes that cost several times as much. Using these, collimation is fairly quick and easy once you've learned to do it, but it's still a major psychological hurdle for most beginners.

Reflectors also take a fair amount of time to cool down to the ambient temperature before they deliver truly sharp images. And they're problematic for viewing terrestrial subjects because they show everything upside down.

Refractors sidestep all of these problems. They require no collimation, cool down in a matter of minutes, and they're typically used with star diagonals that show objects right-side up. A small refractor is more appropriate than a reflector for many beginners despite the fact that you get significantly less aperture for any given amount of money. Let's take a quick look at our refractor before discussing how all three scopes perform under the night sky.

The Infinity 90

The Meade Infinity 90 offers a respectable aperture at an attractive focal ratio. F/6.7 is short enough to give the telescope a wide field of view and a reasonably compact tube. But it's also long enough to avoid the extreme false color that sometimes exists with inexpensive achromatic objectives. An unusual feature of the Infinity 90 is that it includes a 90° image-erecting prism that shows objects in correct orientation rather than mirror-reversed as with most refractors used with a conventional star diagonal — very handy for terrestrial viewing. Unlike some inexpensive image-erecting prisms, this one has very good optical quality.

The Infinity 90's biggest shortcoming is its mount. It's quite stable and vibration-free unless you're using it in a strong wind — far superior to the wobbly mounts supplied with most low-cost 60-mm refractors. But it's awkward to use. The scope isn't counterbalanced, so the altitude bearing needs a lot of friction to prevent the scope

The Equatorial StarBlast

The 4.5-inch StarBlast is available with a lightweight equatorial mount, which I also used during this review. I'm not usually a fan of ultralight equatorial mounts, but this one works quite well with the StarBlast due to the optical tube's extreme shortness and light weight.

Equatorial mounts can be daunting to beginners because of their complexity. But they can also be used in alt-azimuth mode by setting the altitude scale to 90°, and in that configuration they're just as simple as tabletop mounts, with the added benefit of slow-motion controls.

from toppling backward when pointed high in the sky. It's impossible to make fine adjustments with such stiff bearings, though the long handle supplied with the mount helps a lot. In practice, I almost always needed the slow-motion controls to center my target. This two-step process makes it frustrating to browse galaxy fields or the Milky Way with the ease and grace of the other two scopes.

The slow-motion controls are very handy for keeping the planets centered as they drift across the field at high power. But they have a limited range of motion, so they eventually "bottom out." Then you have to reset them, recenter the planet, and start over again.

The refractor's tripod is also fairly short. That keeps it both stable and light; the entire assembled scope is easy to carry in one hand. But even with its legs fully extended, I had to sit on a low footstool to view through the eyepiece when the scope was aimed high in the sky. It's exceedingly awkward to view through the red-dot finder in this position, so I avoided targets within 30° of the zenith.

The Infinity 90 costs a little more than the OneSky and StarBlast, but that's offset by the inclusion of an extra eyepiece offering 95× magnification, making it the only one of the three scopes that can provide detailed views of the planets without a supplementary eyepiece or 2× Barlow lens.

The Infinity 90 does in fact include a 2× Barlow. Unfortunately, it exhibits strong false color everywhere except the center of the field. But even without the Barlow, the Infinity 90 has the most versatile eyepiece collection of all the scopes.

All three scopes have eyepieces with thoughtfully selected focal lengths, as shown on the facing page. Low power is 26× for the StarBlast and OneSky and 23× for the Infinity 90. These are ideal magnifications for viewing large star clusters such as the Pleiades (M45) and Beehive (M44) and also very good for star-hopping. Medium-high is 75× for the StarBlast, 65× for the OneSky, and 67× for the Infinity 90 — excellent for close-up views of deep-sky objects, but a little low for viewing the Moon and planets.

The OneSky's collapsible tube is susceptible to stray light that can compromise its otherwise excellent views. The author made this simple shroud out of a piece of lightweight foam that can be found at most arts and crafts stores.

Under the Stars

When I tested the StarBlast, OneSky, and Infinity 90, I mostly restricted myself to using the stock eyepieces, sometimes with the addition of my own 2× Barlow. I used one or more of the scopes on most clear nights in May 2015, viewing the Moon, Venus, Jupiter, Saturn, and

Left: **The Infinity 90 includes a quality image-erecting prism that makes the scope useful for both terrestrial and astronomical observing.** ***Middle:*** **Even when fully-extended, the Infinity 90 tripod is short. While this provides a stable view at high magnification, a low stool or observing chair is required for comfortable viewing in most positions.** ***Right:*** **Aiming the refractor at targets anywhere near the zenith is awkward, due to the position of the red-dot pointer. A better placement for the finder would be near the objective lens.**

Roughly aiming the Meade Infinity 90 refractor is aided by using the long handle at the back of the tripod. Targets can then be centered with the slow-motion controls.

TELESCOPE SPECIFICATIONS

	Infinity 90	StarBlast	OneSky
Aperture	90 mm	114 mm	130 mm
Focal length	600 mm	450 mm	650 mm
Focal ratio	f/6.7	f/4.0	f/5.0
Weight	11.9 lb. (5.4 kg)	13.0 lb. (5.9 kg)	14.8 lb. (6.7 kg)
Low mag.	23×	26×	26×
Medium mag.	67×	75×	65×
High mag.	95×	—	—

Optical specifications are based on advertised data.
Weights are as measured.

a wide range of deep-sky objects. I compared the scopes side by side on specific targets and also used each scope by itself for an entire evening to get a sense of its overall feel.

The planets are particularly attractive targets for beginners — and challenging targets for small telescopes. Even at medium-high magnifications (67× to 75×), all three scopes easily displayed the phase of Venus, the two main belts of Jupiter, and gorgeous views of Saturn's rings. My best views of the planets came at 95× with the 6.3-mm eyepiece on the Infinity 90, 112× with my own 4-mm eyepiece on the StarBlast, and 130× using the OneSky with its 10-mm eyepiece plus a 2× Barlow. At these magnifications, I could see the Jupiter's Great Red Spot, shadow transits of its moons, and the Cassini Division in Saturn's rings when atmospheric steadiness allowed. These features were quite obvious in the OneSky, a little harder to pick out in the Infinity 90, and problematic with the StarBlast.

I also tried the StarBlast at 150× with the stock 6-mm eyepiece and a 2× Barlow, but I found the scope very hard to focus at this magnification, and I saw little improvement over the view at 112×. One problem with the StarBlast is that the "sweet spot" where the view is truly sharp is relatively small, requiring you to nudge the scope quite frequently.

At the opposite extreme, the Infinity 90's view is sharp all the way to the field stop; the 3-element eyepieces work very well at f/6.7. Together with the slow-motion controls, this makes it very easy to track the planets. Like all fast achromats, the Infinity 90 shows violet halos around the Moon and planets, but the planetary views are otherwise quite attractive and detailed.

Under the semi-dark skies of my country home, all three scopes performed admirably on deep-sky objects, given their apertures. They showed all of the Messier objects with ease, and provided detailed views of many. The OneSky wins the prize on globular clusters, but all three scopes resolve a half dozen to a dozen stars in M4, M22, M5, and M13. The Infinity 90 is best for large open clusters such as M44, the Beehive, due to the scope's sharp field with the stock low-power eyepiece. But the OneSky is also superb, and the StarBlast isn't far behind. On galaxies and nebulae, the scopes perform in aperture order with the best views in the largest aperture.

Conclusions

The OneSky probably ranks highest among these scopes because it provides the best overall views both of planets and deep-sky objects. But it does require a supplementary 2× Barlow to show the planets in detail, and its focuser works poorly with heavy eyepieces. Moreover, each of the other scopes has advantages that might be compelling in specific circumstances.

The StarBlast has superb ergonomics due to its rotatable tube; it's ideal for viewing from a seated position. Deep-sky enthusiasts will also appreciate its extraordinarily wide maximum field of view when used with an additional 24- or 25-mm eyepiece. It's the weakest of the three on planets, but still comfortably ahead of most telescopes in its price class.

The Infinity 90 is best for people who want quick looks at the Moon and planets because it requires no collimation, cools down in a matter of minutes, and offers views not far behind the OneSky's. And it's completely self-contained, needing no table or stand to support it. But its alt-azimuth mount isn't well suited to browsing the deep sky.

While each of these telescopes has some flaws and limitations, they're all easy to use and a joy to look through. Best of all, they offer outstanding value for their amazingly low prices. ✦

Sky & Telescope *Contributing Editor* ***Tony Flanders*** *loves to use compact, convenient telescopes.*

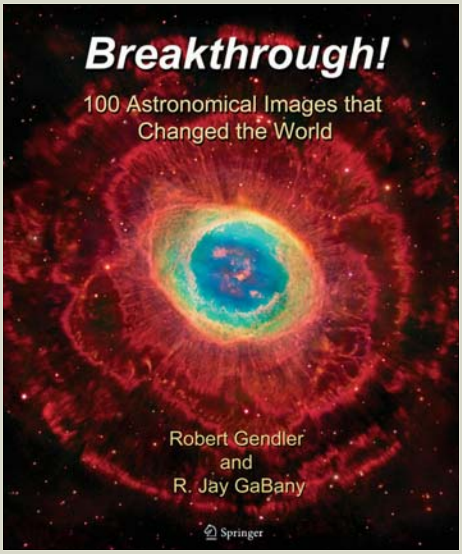
New Product Showcase

▼ **ULTRA-SENSITIVE CAMERA** Andor announces the iKon-XL, a large-format CCD camera. This specialized camera is built around e2v front- or back-illuminated sensors in a 4,096 × 4,096 array of 15-micron-square pixels, ideally suited for large instruments. Its innovative cooling is capable of sustained temperatures down to -100°C without liquid nitrogen or other cryogenic cooling. The iKon-XL weighs 26.5 pounds (12 kg) and is available with USB3 or direct fiber optic interface. Contact the manufacturer for pricing and other options.

Andor Technology Ltd.
7 Millennium Way,
Springvale Business Park,
Belfast, UK BT12 7AL
+44-(28) 9023 7126;
andor.com

▼ **EXPLORE CASES** Explore Scientific announces new carrying cases for their telescopes. These soft-sided telescope cases ($189.99) are designed to carefully cradle your telescope while organizing your eyepieces and other observing accessories. Made primarily for the Explore Scientific ED127, ED127CF, DAR127, and DAR152 refractors, its exterior consists of a soft-sided polyester shell with reinforced back and sides, and includes handles as well as a rugged shoulder strap. The interior features user-adjustable velcro compartments.

Explore Scientific
621 Madison St., Springdale, AR 72762
866-252-3811; explorescientific.com



HISTORICAL ASTRONOMY Premier astro-imagers Robert Gendler and R. Jay GaBany team up in their latest work *Breakthrough!: 100 Astronomical Images that Changed the World* (hardcover edition: $34.99). As the title suggests, the book highlights 100 astrophotographs, from the first successful image of the Moon captured in the mid-19th century through the discoveries by orbiting observatories and interplanetary probes. Essays on the groundbreaking science behind each discovery accompany each image. The authors have carefully selected their list of images to bring to the reader the most relevant photographic images of the science of astronomy. Springer, 171 pages, ISBN 978-3-319-20972-2.

Springer
233 Spring St., New York, NY 10013
212-460-1507; springer.com

Stay *Warm* While Stargazing

With *S&T's* *NEW* Fleece Jacket

- Soft microfleece (black only)
- Men's L/XL, Women's S/M/L/XL
- Zippered front and pockets
- Embroidered *Sky & Telescope* logo

Limited quantities available — order now!

ShopatSky.com
888-253-0230

SHOP at SKY

JMI Announces the Second Generation of Binoculars

What's new?

- Upper cage rotates to change eye spacing
- This adjustment no longer requires refocusing
- Folding tripod, light-weight 50 lb optical tube assembly
- Explore Scientific 16mm 68 degree eyepieces

Introductory Special - $500 Off and free US shipping

Offer expires Jan. 1, 2016

Comfortable viewing – look up by looking down.

Binos eliminate the eye fatigue of one-eye viewing.

Imagine visual enjoyment that surpasses a 16″ scope in this small package.
This statement is based on testimonials and our experience. Tony Hallas says "I have had more aesthetic pleasure in 3 nights with the 10″ Binos than I had in a year with a 25″ scope." Jim found the same with a 12″ and a 30″.

JMI Telescopes.com **303-233-5353**

TelescopeS.NET

by Woodland Hills Camera & Telescopes

MEADE

LX850
Built-in guiding
for imaging

CELESTRON

CGE Pro 1400 HD
Your ultimate
portable 14″ scope

EXPLORE SCIENTIFIC

80mmf/6 ED Essential • Excellent Value!

iOptron

SkyTracker w/Polar Scope
Easy setup,
Excellent
performance

Special

lunt engineering

100mm ED-APO has
incredible optics for
incredible views!

Sky-Watcher USA
Be amazed.

8-inch **Go To**
Collapsible
Dobsonian
$1,035

888-427-8766 Intnl: 818-347-2270 • 5348 Topanga Canyon Boulevard, Woodland Hills, CA 91364

Gary Seronik
Telescope Workshop

Spring Counterweight

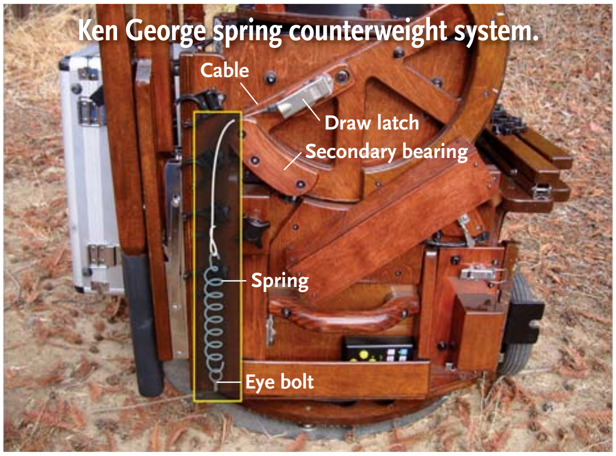
Here's a weight-saving solution to a common problem.

LAST MONTH I HIGHLIGHTED a splendid 10-inch f/7 reflector made by Novato, California ATM Ken George. This fine instrument has so many noteworthy features that one article simply wasn't enough to describe them all.

Ken's scope is optimized for planetary performance and public viewing, but achieving the necessary transportability and quick setup wasn't easy. To ensure a compact configuration that would fit into his car, he needed a low-profile rocker box. But how to accomplish that goal? The scope has two significant strikes against it. First is its 70-inch focal length. The longer the tube, the farther the balance point must lie from the back end. The second strike is the scope is front-end heavy. "A binoviewer is the one accessory I'll never part with," Ken says. That accessory, plus two eyepieces, adds four pounds to the front end. Include a dew heater and a big finderscope, and the secondary cage now tips the scales at seven pounds.

Key to making Ken George's 10-inch f/7 Dobsonian transportable is a compact configuration that relies on a low-profile rocker box and a virtual counterweight system that utilizes a strong spring.

KEN GEORGE (2)



Ken George spring counterweight system.

The net result is that a whopping 35 pounds of counterweight would be required to balance the tube. "That kind of extra weight on a portable scope just isn't practical," Ken states. "But after reading about telescope makers who utilized springs in place of counterweights, I decided to give the idea a shot."

Spring counterweight systems aren't new — we've featured several articles in this magazine describing them. They run the gamut from the dead simple scheme I used on my 8-inch travelscope (*S&T:* May 2013, p. 68) to the meticulously precise implementation described by Tom Krajci (*S&T:* Nov. 1999, p. 130). In terms of sophistication, Ken's setup lies somewhere between those two examples.

The instrument's spring counterweight setup is mostly concealed (which is one of its nice features) and consists of only a few parts, most of which can be found at a well-stocked hardware store or purchased online from McMaster-Carr (**mcmaster.com**). The scope has one complete spring system on each side. As the illustration above shows, one end of the spring is attached to an eye bolt mounted on the bottom of the rocker box. At the other end of the spring is a length of nylon-coated, braided wire that passes over a small secondary bearing with a guide groove cut into it. The other end of the wire is affixed to a quick-release draw latch. "This fitting allows me to quickly and easily detach the rocker box from the mirror box, and dial in just the right amount of spring tension by adjusting the hook-arm length," Ken notes.

The most important component is, of course, the spring. Choosing the correct one means juggling several variables. To begin, you have to figure out how much force your scope will require to achieve balance. Once you know that, you can use basic torque calculations to narrow down your selection. As Ken says, "you find a spring that has the right counterweight force, diameter, stretch length (both free and maximum), and wire diameter (for overall strength) for your particular scope." He tried several springs purchased from Century Spring Corp. (**centuryspring.com**) and selected the one that gave his scope's motions the best feel, demonstrating that even after all the calculations have been made, some experimentation is still valuable.

"With only a few pounds of hardware, I successfully eliminated more than 35 pounds of counterweight," Ken reports. That's a big difference in any size telescope. If this all sounds like the proverbial free lunch, to some extent it is. There are limits to how far you can push the concept. While a properly implemented spring counterweight system will make your scope move as if it's perfectly balanced, you have to keep in mind that it's not *really* balanced. In other words, it's a "virtual" counterweight — if you make the front of the scope heavy enough, or the mount's ground board too small, the scope will tip over, spring counterweight or not! That said, the benefits Ken describes are substantial and worthwhile.

Of course, as is the case with the whole telescope, refinements are possible for the counterweight system. Ken says, "In the future, I might simplify the system by positioning each cable along the top edge of the side bearings, eliminating the need for the secondary bearings entirely."

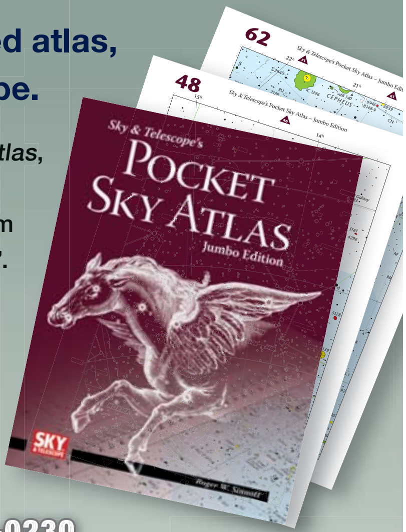
Readers interested in learning more about his scope and its spring counterweight setup can e-mail Ken at **myinem@yahoo.com**. ✦

---

*Contributing editor **Gary Seronik** is an experienced telescope maker. Contact him via his website, **garyseronik.com**.*


What's new that's used?
INDIVIDUAL (PRIVATE PARTY)
Losmandy G 11 w/ Gemini 1 L4 on CI700 Tripod
Santa Barbara, CA
1/21/2014
$2,100.00
USED
SKY MarketPlace

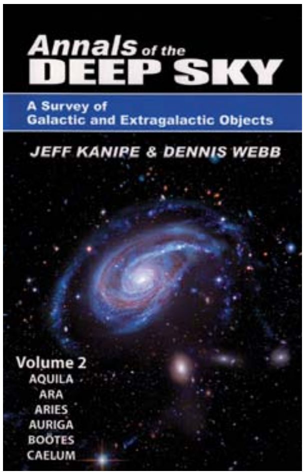

SKY & TELESCOPE
Top 10 Questions About Your Telescope
SKYWATCH 2016
FAMILY FUN UNDER THE STARS
Backyard Astronomy
Get to Know Your Night Sky


Sky & Telescope's
Pocket Sky Atlas
Jumbo Edition
62
48

Book Review
Alan MacRobert

The Next Great Deep-Sky Handbook

Annals of the Deep Sky: A Survey of Galactic and Extragalactic Objects



Jeff Kanipe and Dennis Webb
Willmann Bell, 2015+

Vol. 1: 358 pages, ISBN 978-1-942675-00-6
$24.95, paperback.

Vol. 2: 342 pages, ISBN 978-1-942675-01-3
$24.95, paperback.

I'VE BEEN WAITING since the 1980s. Now it's happening. We're getting an expanded, updated successor to the legendary *Burnham's Celestial Handbook*.

Someday, I was sure, the next heir would be born to a long and distinguished literary line founded 171 years ago: big, chatty, history- and science-rich guidebooks for telescope enthusiasts, arranged alphabetically by constellation. Admiral William Henry Smyth founded it in 1844 with *The Bedford Catalogue* (Volume 2 of his *A Cycle of Celestial Objects*); it's still in print. Carrying the line forward were Reverend T. W. Webb's *Celestial Objects for Common Telescopes* (first published in 1858), William Tyler Olcott's slimmer *A Field Book of the Stars* (1907, with many editions following), C. E. Barns's *1001 Celestial Wonders* (1929), and then *Burnham's,* biggest of all, published from 1966 to 1978 — full of observational details, science, poetry, and astronomical history in three volumes totaling 2,138 pages.

Annals of the Deep Sky is even more ambitious. Authors Jeff Kanipe and Dennis Webb have made a long-term commitment to it for the astronomical book publisher Willmann Bell, Inc. The first two volumes are out, covering the first 10 of the 88 constellations, Andromeda through Caelum. Volume 3 with five more, Camelopardalis through Canis Minor, should be out in January.

Volume 1, like *Burnham's,* begins with a roughly 100-page introduction to the astronomy that an amateur really needs to know: the celestial sphere and the sky's motions, the magnitude system, angular measures, and so on, along with lots about the various types of objects to be seen in amateur scopes. Here in one place is pretty much everything *Sky & Telescope* assumes its regular readers know and then some.

Then the constellations begin. Andromeda runs to 92 pages, compared to 57 sparser pages in *Burnham's*. Only 17 telescopic targets (or groups of targets) in Andromeda are treated, but with extraordinary depth and interest. *Annals* isn't meant to be a complete deep-sky list. For that, get Kepple and Sanner's *The Night Sky Observer's Guide* (listing 7,935 objects, many with paragraph visual descriptions and a photo or sketch) or the *Uranometria 2000.0 Deep Sky Field Guide* (with dense data tables and one-line descriptions for 30,000 objects). Instead, *Annals* dives deep into a constellation's primary targets and explores around — telling not just what they look like, but their history, lore, and especially their scientific underpinnings and the astrophysics they illuminate.

There's poetry too, and biography. Every constellation chapter ends with an innovative section called "The Third Dimension," following outward a fan of space that spans the width of the constellation and extends past nearby stars to structures in the local and distant Milky

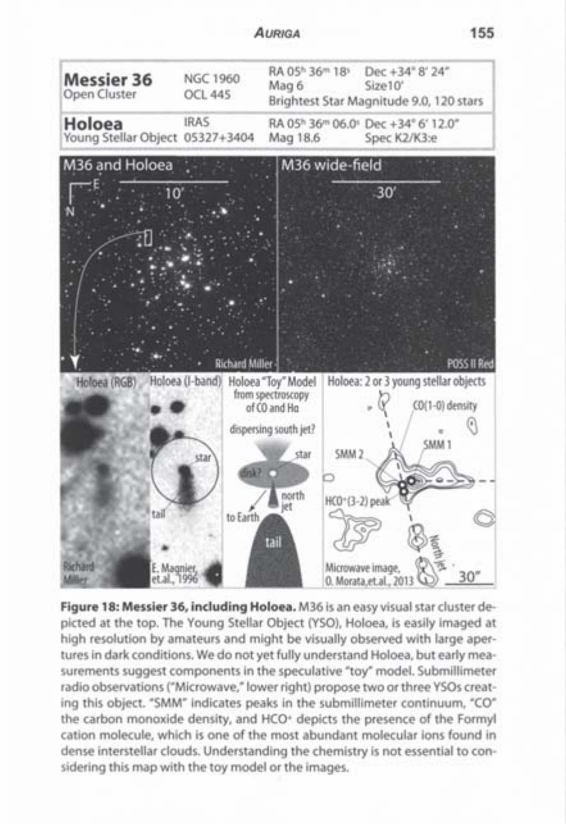
Way, then to galaxy groups, clusters, and voids.

Simon Newcomb's provocative 1878 essay on the "Andromeda Nebula" (M31) gets a page to itself, with a period engraving of the 26-inch U.S. Naval Observatory refractor that Newcomb used. Later in the M31 entry we learn the recent story of the galaxy's complex multiple nucleus, partially resolved by the Hubble Space Telescope (a photo is included) and analyzed by cutting-edge techniques. The nucleus alone gets 5 of the 33 pages on M31 and its satellite galaxies.

Images, diagrams and tables abound. Every constellation has a finder chart for its featured objects. Tales of important astronomers appear in relevant spots. Volume 2 ends with a 70-page glossary not just defining terms, but putting each into wider context, an education in itself.

Dip around here and there, and the authors' secret agenda becomes evident. They inveigle you in with, say, an orbit diagram of the close visual binary Zeta Aquarii (currently a nice test for a 3-inch scope), and from there they draw you into Zeta Aquarii's last 60 years of revelations, controversies, and ever-improving analyses — educating you in astrophysics and instrumental methods along the way. It's an education on the sly.

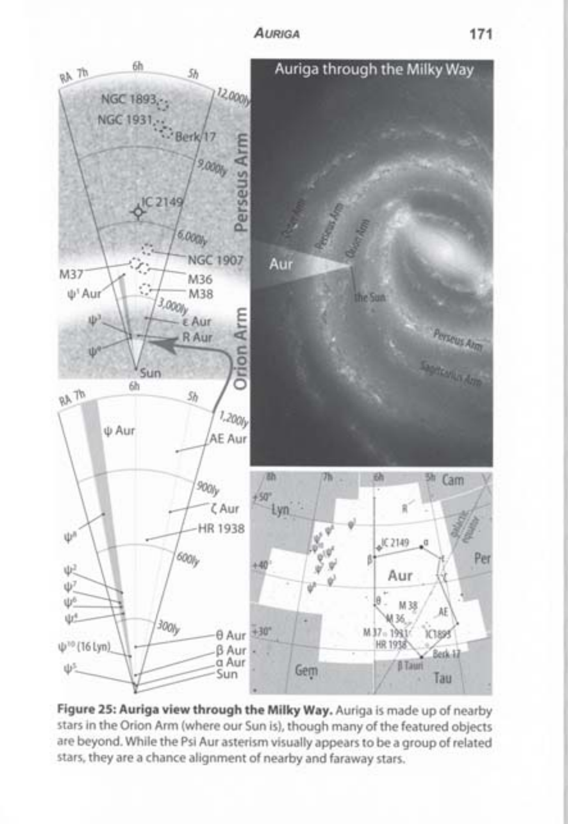
Not that these books are a substitute for a college astronomy course; they're object- and personality-based, not theory- and principle-based. But they'll be my bedtime reading for years to come.



AURIGA 155

Messier 36 Open Cluster	NGC 1960 OCL 445	RA 05ʰ 36ᵐ 18ˢ Mag 6 Brightest Star Magnitude 9.0, 120 stars	Dec +34° 8′ 24″ Size10′
Holoea Young Stellar Object	IRAS 05327+3404	RA 05ʰ 36ᵐ 06.0ˢ Mag 18.6	Dec +34° 6′ 12.0″ Spec K2/K3:e

Figure 18: Messier 36, including Holoea. M36 is an easy visual star cluster depicted at the top. The Young Stellar Object (YSO), Holoea, is easily imaged at high resolution by amateurs and might be visually observed with large apertures in dark conditions. We do not yet fully understand Holoea, but early measurements suggest components in the speculative "toy" model. Submillimeter radio observations ("Microwave," lower right) propose two or three YSOs creating this object. "SMM" indicates peaks in the submillimeter continuum, "CO" the carbon monoxide density, and HCO^+ depicts the presence of the Formyl cation molecule, which is one of the most abundant molecular ions found in dense interstellar clouds. Understanding the chemistry is not essential to considering this map with the toy model or the images.



AURIGA 171

Figure 25: Auriga view through the Milky Way. Auriga is made up of nearby stars in the Orion Arm (where our Sun is), though many of the featured objects are beyond. While the Psi Aur asterism visually appears to be a group of related stars, they are a chance alignment of nearby and faraway stars.

Criticisms? A treatment of this depth ought to have more about how the objects appear visually in scopes of different apertures, I would think. And sometimes the text could have used another editor's run-through for smoothness and elegance.

Perry Remaklus, the man behind Willmann Bell, says that Kanipe is currently working on Volume 5. "We spent seven years planning this thing out before we even launched the first two volumes," Remaklus says. At this rate *Annals of the Deep Sky* will span more than a dozen 350-page volumes by the time it reaches Vulpecula at the alphabet's end.

By then the science in the first ones will surely be getting dated. But Remaklus sees this series as a permanent living thing, with future editors reworking the volumes from beginning to end every decade or two.

If so, the *next* heir to Admiral Smyth may not be required for the rest of the 21st century. ✦

S&T *Senior Editor* ***Alan MacRobert*** *once offered Robert Burnham, Jr., a chance to update his* Celestial Handbook *for reissuance by Sky Publishing Corporation — but Burnham, by then a hermit in the Arizona desert, refused. Suffering from worsening mental health, Burnham spent his last years mostly on a park bench in San Diego selling paintings of cats. He died in 1993 destitute and unnoticed. A biography:* ***is.gd/burnhambio****.*

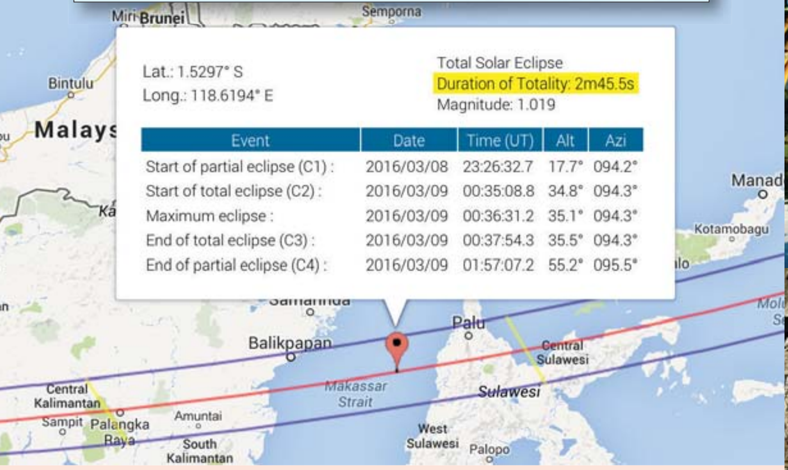
ECLIPSE • MARCH 2016

INDONESIA, MARCH 1–17, 2016

http://InsightCruises.com/Sky-7

Sail roundtrip Singapore on Holland America's Volendam with former editors Bob Naeye and Greg Bryant, astronomer David Tholen, Ph.D., and geologist Michael Wysession, Ph.D. on the eclipse trip of a lifetime.

Join the fun and experience legendary Indonesia's cultures. You can explore Komodo, Bali, Lombok, UNESCO sites, and traditional cuisines all in the company of fellow eclipse buffs. When it's time to capture eclipse memories, tap *Sky & Telescope's* expertise. Reserve now for best cabin selection as this sailing is guaranteed to sell out.



Lat.: 1.5297° S
Long.: 118.6194° E

Total Solar Eclipse
Duration of Totality: 2m45.5s
Magnitude: 1.019

Event	Date	Time (UT)	Alt	Azi
Start of partial eclipse (C1) :	2016/03/08	23:26:32.7	17.7°	094.2°
Start of total eclipse (C2) :	2016/03/09	00:35:08.8	34.8°	094.3°
Maximum eclipse :	2016/03/09	00:36:31.2	35.1°	094.3°
End of total eclipse (C3) :	2016/03/09	00:37:54.3	35.5°	094.3°
End of partial eclipse (C4) :	2016/03/09	01:57:07.2	55.2°	095.5°

Add eight (8) hours to UT time for local time. I.e., the start of the total eclipse (C2) will be 8:35am.

Cruise prices vary from $1,999 for an interior stateroom to $8,299 for a Neptune Suite, per person, based on double occupancy. (Plus taxes, fees, and gratuities.) For those attending our SEMINARS, there is a $1,075 fee. Itinerary has been confirmed but the speaker Program is subject to change. Prices also subject to change. For full terms and conditions please visit: http://InsightCruises.com/Sky-7

For more info call 650-787-5665 or Info@InsightCruises.com CST# 2065380-40

Greg Bryant was the Editor of *Australian Sky & Telescope* from 2006–2014 and is a Contributing Editor to *Sky & Telescope*. He has also been involved with the publication of an Australian annual astronomy yearbook since the early '90s and science writing for the Australian Research Council's Centre of Excellence *All-sky Astrophysics*. A keen amateur astronomer for more than 30 years, Greg most recently teamed up with Insight Cruises for their successful 2012 Total Solar Eclipse tour in Australia. In 2000, the International Astronomical Union named asteroid 9984 Gregbryant in his honor.

SEMINARS The speaker Program includes eclipse-viewing glasses, 15 seminars, a planetary debate, Q&As, and several receptions.

Robert Naeye was *Sky & Telescope's* Editor in Chief from 2008–2014. Previously he was Senior Editor at *Sky & Telescope* and Senior Science Writer for the Astrophysics Science Division of NASA's Goddard Space Flight Center. Robert is the author of two books: *Through the Eyes of Hubble: The Birth, Life, and Violent Death of Stars* and *Signals from Space: The Chandra X-ray Observatory.*

David Tholen, Ph.D. is an astronomer at the Institute for Astronomy of the University of Hawaii (IfA), who specializes in planetary and solar system astronomy. Dr. Tholen and his students have discovered many near-Earth asteroids, the most famous being Apophis, which will make an extremely close approach to the Earth on April 13, 2029.

Michael Wysession, Ph.D. is Associate Professor of Earth and Planetary Sciences at Washington University in St. Louis. An established leader in seismology and geophysical education, Professor Wysession is noted for his development of a new way to create three-dimensional images of Earth's interior from seismic waves. These images have provided scientists with insights into the makeup of Earth and its evolution throughout history. He has received the Innovation Award of the St. Louis Science Academy and the Distinguished Faculty Award of Washington University.

SOUTHERN SPLENDORS

Pablo Cirielli

The pristine skies over El Leoncito National Park in Argentina sparkle with southern-sky delights. Crux, the iconic Southern Cross, dangles lower left of center, with the dusty Coal Sack just below it. The large, colorful Carina Nebula, at upper right, sits between the dense clusters NGC 3522 (to its left) and NGC 3114 (right), along with the open cluster below it known as the Southern Pleiades (IC 2602).

Details: *Canon EOS 60D DSLR camera with 100-mm lens used at f/4 and ISO 800. Stack of 32 images; total exposure: 3.1 hours.*

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

▸ PERSEID PUTS ON A SHOW

Dwight Gruber

A long, bright Perseid meteor splits the Milky Way's star clouds in this extreme wide-angle view taken August 12th from Oregon's Mayer State Park.
Details: *Nikon D800E DSLR camera at ISO 400 with 14-to-24-mm f/2.8 zoom lens set to 14 mm. Total exposure: 30.5 minutes.*

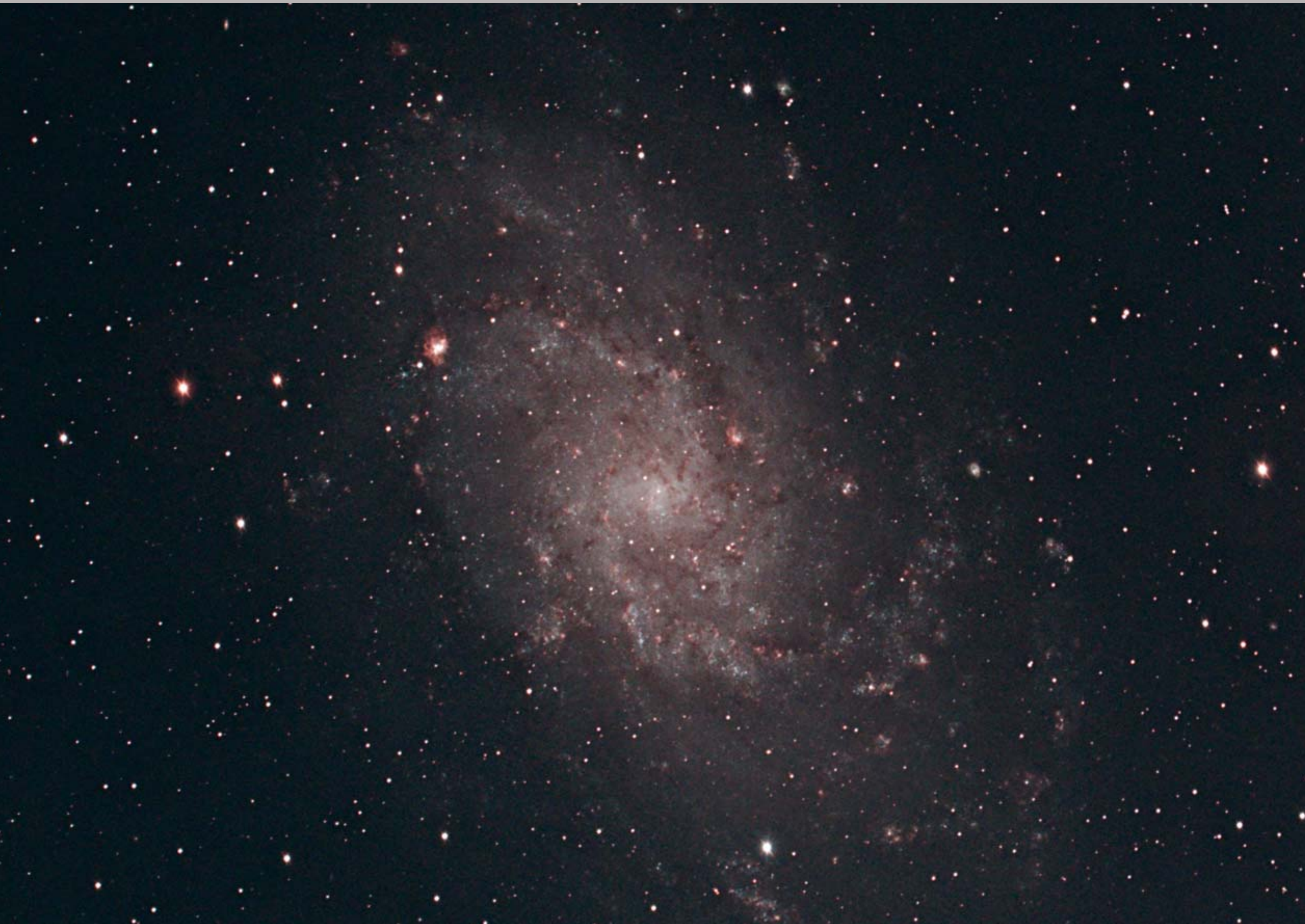
▾ TRIANGULUM'S PINWHEEL

Michael Sullivan

One of three massive spirals in the Local Group (joining the Milky Way and Andromeda), the Triangulum Galaxy is roughly 2½ to 3 million light-years away.
Details: *Celestron 14-inch Schmidt-Cassegrain telescope with Hyperstar and Starlight Xpress Trius-SX814C color CCD camera. Total exposure: 1 hour.* ✦

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

ATTENTION, SKETCHERS! *Send your best astronomical renderings to gallery@SkyandTelescope.com (include "sketch" in the subject line), and if we get enough submissions we'll showcase them in a future issue.*



SKY & TELESCOPE

Market Place

Your essential source for astronomical products

ACCESSORIES

VariMax Eyepiece Projection Adapters

With *VariMax*™ you can use your bigger, better eyepieces for Eyepiece PROjection photography!

HOT PRODUCT 2015 SKY & TELESCOPE

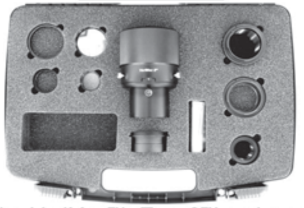
VariMax (1.25") $149
VariMax II (2.0") $179

2" UltraWide Prime Focus Adapters

Our *TRUE-2*™ 2" UltraWide Prime Focus Adapters offer 10mm more clear Aperture than any 2" T-Ring adapter!

True-2 (2.0") $79.00

DSLR Pro-Kits™



The *VariMax*™, *True-2*™ and more supplied in a Custom storage case.

Pro-Kit Silver (w/VariMax) $349.
Pro-Kit Gold (w/VariMax II) $379.

Fast $8 Shipping!
PRIORITY MAIL
UNITED STATES POSTAL SERVICE
Expert Advice!

SCAN HERE
Visit our Site!

Use Discount Code "SKY" for 10% off!

TelescopeAdapters.com

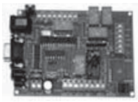
TRACKING for DOBS

*** High power observing and group viewing**
***Astro-imaging with NO field rotation**
call write or e-mail for free brochure

EQUATORIAL PLATFORMS 530-274-9113
15736 McQuiston Lane Grass Valley CA 95945
tomosy@nccn.net www.equatorialplatforms.com

ACCESSORIES

Foster Systems
Serving astronomers and observatories worldwide



Roll off Roof & Dome Controllers

- ASCOM compliant interface
- Automatic or Manual ops.
- Power monitoring and mgt.
- Weather monitor integration
- Dew Management

From $247
With Software

Visit us at www.fostersystems.com

***Howie Glatter**'s Laser Collimators & Accessories*
tuBlug ™ and Blug™ Barlowed collimation aids
SkyPointers™ & brackets - Glatter Mirror Sling kits

The Parallizer™

2"-1.25" adapter for Perfect Parallel Alignment
Howie Glatter 3850 Sedgwick Ave. Bronx, N.Y. 10463
Tel/Fax (718) 796 3203
www.skypointer.net www.collimator.com
e-mail: howieglatter@mindspring.com

New Seletek
Tarsier

Most advanced *autonomous*
digital focusing system

- Stepper or d.c. motors
- Can perform automatic temperature compensation
- LCD screen - Totally configurable
- Saves focus "goto" points

Launch price $145, shipping included
Get it now from lunaticastronomical.com

AAG CloudWatcher ($495): your observatory safeguard, now with optional wind speed meter.

More info: **www.lunaticoastro.com**

ACCESSORIES

Bob's Knobs

Meade, Celestron, Intes, Takahashi . . . and more!

6976 Kempton Rd.
Centerville IN 47330
765-855-5109 USA

www.bobsknobs.com

MEADE SCT UPGRADES
Improve focus, clutch, drives, light thru-put, mounting, carrying & balancing.

EZ BINOC MOUNT KIT
Outdoor mount handles all size binoculars.
View standing, sitting or reclining. $106.95

PETERSON ENGINEERING

www.petersonengineering.com 401-245-4068

HOT PRODUCT 2011 SKY & TELESCOPE

Now Build your own custom adapter at

www.preciseparts.com

305 253-5707
info@preciseparts.com

PRECISEPARTS
CUSTOM PARTS FOR ASTRONOMY

Shelyak INSTRUMENTS

Alpy
modular spectroscope

easy to use

Stars won't look the same

www.SHELYAK.com

BOOKS

"AT LAST: THE SKY GUIDE WE'VE BEEN WAITING FOR!"
From Richard Berry's Foreword

Annals of the DEEP SKY
A Survey of Galactic and Extragalactic Objects
JEFF KANIPE & DENNIS WEBB
Volume 1
$24.95

Annals of the DEEP SKY
A Survey of Galactic and Extragalactic Objects
JEFF KANIPE & DENNIS WEBB
Volume 2
$24.95

"IT WILL SURELY BECOME A SEMINAL WORK IN THE WORLD OF ATMS."
From Dennis di Cicco's Foreword

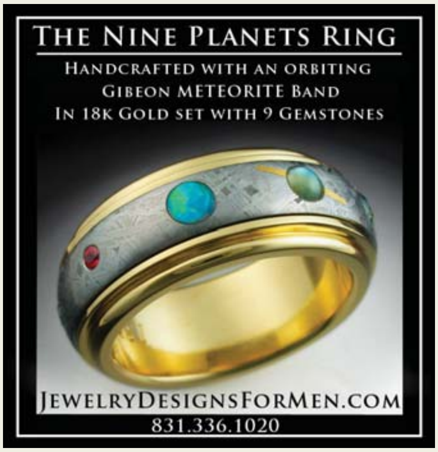
Engineering, Design and Construction of STRING TELESCOPES
Albert Highe
$39.95

FROM WILLMANN-BELL
Get full details at Willbell.com

COMPUTER SOFTWARE

Deep-Sky Planner 6
HOT PRODUCT 2014 SKY & TELESCOPE
Comprehensive planning & logging software
www.knightware.biz

MISCELLANEOUS



THE NINE PLANETS RING
HANDCRAFTED WITH AN ORBITING GIBEON METEORITE BAND
IN 18K GOLD SET WITH 9 GEMSTONES
JEWELRYDESIGNSFORMEN.COM
831.336.1020

MOUNTS

Alt-Az Mounts and Tripods
"NO BALANCE REQUIRED"
*Extremely Rigid
*Silky Smooth even at 300 power
*Change eyepieces without re-balancing
*Designed from the start to use DSCs
(no external cables or encoders)
*No counter weights
or locks
*Quality at it's best
DiscMounts, Inc
HANDCRAFTED BY TOM PETERS
www.DiscMounts.com
954.475.8574

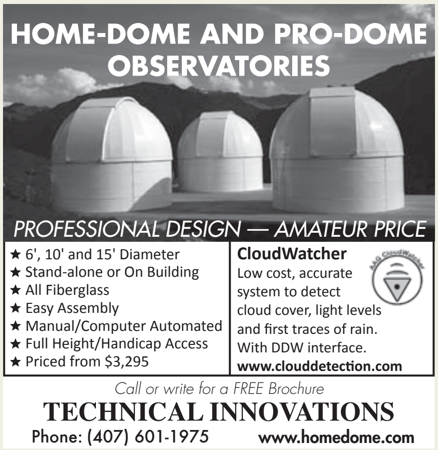
OBSERVATORIES / DOMES

Keeping it *"Beautifully"* Simple
Almost Zero Replacement... Robust quality for a Professional life cycle
Almost Zero Anxiety... The Astro Haven team is behind every product
AstroHaven ENTERPRISES
domesales@astrohaven.com
949.215.3777 www.astrohaven.com

NexDome
The NEXt Generation Observatory
NexDome.com

OBSERVATORIES / DOMES

DURANGO SKIES
OBSERVATORY SOLUTIONS
Consulting & Project Management
site plan design & review
equipment configuration
Observatory & Equipment Sales
domes
roll-off roof plans
telescopes
mounts & piers
CELEBRATING 10 Years 2005 2015
Installation & Training
assembly supervision
install & test equipment
operational & maintenance training
www.observatorysolutions.com



HOME-DOME AND PRO-DOME OBSERVATORIES
PROFESSIONAL DESIGN — AMATEUR PRICE
★ 6', 10' and 15' Diameter
★ Stand-alone or On Building
★ All Fiberglass
★ Easy Assembly
★ Manual/Computer Automated
★ Full Height/Handicap Access
★ Priced from $3,295
CloudWatcher
Low cost, accurate system to detect cloud cover, light levels and first traces of rain. With DDW interface.
www.clouddetection.com
Call or write for a FREE Brochure
TECHNICAL INNOVATIONS
Phone: (407) 601-1975 www.homedome.com

ORGANIZATIONS

only you can save the night
www.darksky.org

OPTICS

STAR INSTRUMENTS
Premier manufacturer of Ritchey-Chrétien and custom optics since 1976
All optics tested in autocollimation with instantaneous phase shifting interferometer
(770) 683-9177
www.star-instruments.com
starinst@star-instruments.com

OPTIC WAVE O.W.L. LABORATORIES
Optical Coatings
Parabolic Mirrors
Testing
Refiguring
www.OpticWaveLabs.com

REAL ESTATE

CLASSIFIEDS

ASTRONOMY PROPERTIES: Dark skies, great transparency, mild climate. Homes, Land, Observatories. Mountain top or valley. Website: portalrodeorealty.com Email: prrealty@vtc.net 877-291-5607 Karen Norrick Owner/Broker

FOR RENT: 3BR/2BA furnished home in ARIZONA SKY VILLAGE PORTAL, AZ. Spectacular observing/birding! irkitzman@gmail.comwww.arizona-dreaming.com 520-203-8500

NEW SOLAR HOME on 20 acres, 4 miles from Portal, Arizona. Quality PV system. 16” wide masonry construction. 1,134-sq-ft home plus 350-sq-ft guest house. 360-degree views. Dark skies. Privacy. $217,000. Phone: 505-470-3014; E-mail slushymeadows@gmail.com.

REAL ESTATE: Several astonishingly beautiful Southern Utah properties in remote areas near Capitol Reef National Park. Wonderful land and sky. Homes available as well as 10 to 40 acre parcels of land with long distance views and southern exposures. For more information visit www.bouldermountainrealty.com or call Cathy Bagley, Broker, Torrey, Utah 435-425-3200.

Classified ads are for the sale and purchase of noncommercial merchandise, unique items, or job offers. The rate is $1.50 per word; minimum charge of $24; payment must accompany order. Closing date is 10th of third month before publication date.

TELESCOPES

Inside This Issue

Specialty astronomy equipment dealers and manufacturers are an important resource for amateur and professional astronomers alike — patronize our advertising dealers in this issue and enjoy all the benefits of their expertise.

Product Locator

BINOCULARS

Meade Instruments Corp.
(Pages 3, 6-7)
Meade.com
800-919-4047 | 949-451-1450

CAMERAS

Finger Lakes Instrumentation, LLC
(Page 1)
FLIcamera.com
585-624-3760

EYEPIECES

Explore Scientific - Bresser (Cover 4)
ExploreScientific.com
888-599-7597

Meade Instruments Corp.
(Pages 3, 6-7)
Meade.com
800-919-4047 | 949-451-1450

Tele Vue Optics, Inc. (Cover 2)
TeleVue.com
845-469-4551

FILTERS

Finger Lakes Instrumentation, LLC
(Page 1)
FLIcamera.com
585-624-3760

Meade Instruments Corp.
(Pages 3, 6-7)
Meade.com
800-919-4047 | 949-451-1450

Tele Vue Optics, Inc. (Cover 2)
TeleVue.com
845-469-4551

FOCUSERS

Finger Lakes Instrumentation, LLC
(Page 1)
FLIcamera.com
585-624-3760

MOUNTS

iOptron (Page 5)
iOptron.com
866-399-4587

Meade Instruments Corp.
(Pages 3, 6-7)
Meade.com
800-919-4047 | 949-451-1450

Paramount (Cover 3)
Bisque.com
303-278-4478

PlaneWave Instruments (Page 53)
PlaneWave.com
310-639-1662

Tele Vue Optics, Inc. (Cover 2)
TeleVue.com
845-469-4551

OBSERVATORIES

Observa-Dome Laboratories (Page 63)
Observa-Dome.com
800-647-5364 | 601-982-3333

Oceanside Photo & Telescope (Page 13)
Optcorp.com
800-483-6287

PlaneWave Instruments (Page 53)
PlaneWave.com
310-639-1662

SOFTWARE

Prism America, Inc. (Page 63)
Prism-America.com

Software Bisque (Cover 3)
Bisque.com
303-278-4478

TELESCOPES

Astro-Tech (Page 73)
Astronomics.com
800-422-7876

Explore Scientific - Bresser (Cover 4)
ExploreScientific.com
888-599-7597

iOptron (Page 5)
iOptron.com
866-399-4587

Meade Instruments Corp.
(Pages 3, 6-7)
Meade.com
800-919-4047 | 949-451-1450

PlaneWave Instruments (Page 53)
PlaneWave.com
310-639-1662

Sky-Watcher USA (Pages 10-11)
SkyWatcherUSA.com
310-803-5953

Tele Vue Optics, Inc. (Cover 2)
TeleVue.com
845-469-4551

Dealer Locator

CALIFORNIA

Oceanside Photo & Telescope (Page 13)
Optcorp.com
800-483-6287

CALIFORNIA

Woodland Hills Telescopes (Page 61)
Telescopes.net
888-427-8766 | 818-347-2270

OKLAHOMA

Astronomics (Page 73)
Astronomics.com
800-422-7876

To advertise on this page, please contact Peter Hardy at 617-758-0243, or Ads@SkyandTelescope.com

Index to Advertisers

SKY
& TELESCOPE
SkyandTelescope.com
800-253-0245

IN THE NEXT ISSUE

Hot Products 2016

S&T gearheads spotlight the most exciting and innovative new products.

Where Will You Be in 2017?

Here's your guide to the what, when, and where of the first coast-to-coast U.S. total solar eclipse in nearly a century.

A 90-Minute-Long Corona

Help researchers along the 2017 eclipse track record details in the Sun's corona.

Monsters in the Dark

The tale of giant ellipticals and cD galaxies

On Newsstands December 1st!

STATEMENT OF OWNERSHIP, MANAGEMENT AND CIRCULATION (required by Act of August 12, 1970: Section 3685, Title 39, United States Code). 1. Sky & Telescope 2. (ISSN: 0037-6604) 3. Filing date: 10/1/2015. 4. Issue frequency: Monthly. 5. Number of issues published annually: 12. 6. The annual subscription price is $42.95. 7. Complete mailing address of known office of publication: 90 Sherman Street, Cambridge, MA 02140. 8. Complete mailing address of headquarters or general business office of publisher: F+W Media, Inc., 90 Sherman Street, Cambridge, MA 02140. 9. Full names and complete mailing addresses of publisher, editor, and managing editor. Publisher, Phil Sexton, 10151 Carver Road, Suite 200, Blue Ash, OH 45252, Editor, Peter Tyson, 90 Sherman Street, Cambridge, MA 02140, Managing Editor, Peter Tyson, 90 Sherman Street, Cambridge, MA 02140. 10. Owner: F+W Media, Inc., 10151 Carver Road, Suite #200, Cincinnati, OH 45242. 11. Known bondholders, mortgages, and other security holders owning or holding 1 percent or more of total amount of bonds, mortgages or other securities: None. 12. Tax status: Has Not Changed During Preceding 12 Months. 13. Publisher title: Sky & Telescope. 14. Issue date for circulation data below: October 2015. 15. The extent and nature of circulation: A. Total number of copies printed (Net press run). Average number of copies each issue during preceding 12 months: 75,915. Actual number of copies of single issue published nearest to filing date: 72,800. B. Paid circulation. 1. Mailed outside-county paid subscriptions. Average number of copies each issue during the preceding 12 months: 54,371. Actual number of copies of single issue published nearest to filing date: 53,391. 2. Mailed in-county paid subscriptions. Average number of copies each issue during the preceding 12 months: 0. Actual number of copies of single issue published nearest to filing date: 0. 3. Sales through dealers and carriers, street vendors and counter sales. Average number of copies each issue during the preceding 12 months: 5,533. Actual number of copies of single issue published nearest to filing date: 5,550. 4. Paid distribution through other classes mailed through the USPS. Average number of copies each issue during the preceding 12 months: 0. Actual number of copies of single issue published nearest to filing date: 0. C. Total paid distribution. Average number of copies each issue during preceding 12 months: 59,904. Actual number of copies of single issue published nearest to filing date: 58,941. D. Free or nominal rate distribution (by mail and outside mail). 1. Free or nominal Outside-County. Average number of copies each issue during the preceding 12 months: 112. Number of copies of single issue published nearest to filing date: 89. 2. Free or nominal rate in-county copies. Average number of copies each issue during the preceding 12 months: 0. Number of copies of single issue published nearest to filing date: 0. 3. Free or nominal rate copies mailed at other Classes through the USPS. Average number of copies each issue during preceding 12 months 0. Number of copies of single issue published nearest to filing date: 0. 4. Free or nominal rate distribution outside the mail. Average number of copies each issue during preceding 12 months: 167. Number of copies of single issue published nearest to filing date: 0. E. Total free or nominal rate distribution. Average number of copies each issue during preceding 12 months: 279. Actual number of copies of single issue published nearest to filing date: 89. F. Total distribution (sum of 15c and 15e). Average number of copies each issue during preceding 12 months: 60,183. Actual number of copies of single issue published nearest to filing date: 59,030. G. Copies not Distributed. Average number of copies each issue during preceding 12 months: 15,732. Actual number of copies of single issue published nearest to filing date: 13,770. H. Total (sum of 15f and 15g). Average number of copies each issue during preceding 12 months: 75,915. Actual number of copies of single issue published nearest to filing: 72,800. I. Percent paid. Average percent of copies paid for the preceding 12 months: 99.5%. Actual percent of copies paid for the preceding 12 months: 99.8%. 16. Electronic Copy Circulation: A. Paid Electronic Copies. Average number of copies each issue during preceding 12 months: 660. Actual number of copies of single issue published nearest to filing date: 604. B. Total Paid Print Copies (Line 15c) + Paid Electronic Copies (Line 16a). Average number of copies each issue during preceding 12 months: 60,564. Actual number of copies of single issue published nearest to filing date: 59,545. C. Total Print Distribution (Line 15f) + Paid Electronic Copies (Line 16a). Average number of copies each issue during preceding 12 months: 60,843. Actual number of copies of single issue published nearest to filing date: 59,634. D. Percent Paid (Both Print & Electronic Copies) (16b divided by 16c x 100). Average number of copies each issue during preceding 12 months: 99.5%. Actual number of copies of single issue published nearest to filing date: 99.9%. I certify that 50% of all distributed copies (electronic and print) are paid above nominal price: YES. 17. Publication of statement of ownership will be printed in the December 2015 issue of the publication. 18. Signature and title of editor, publisher, business manager, or owner: Peter Tyson, Editor-in-chief and Community Leader. I certify that all information furnished on this form is true and complete. I understand that anyone who furnishes false or misleading information on this form or who omits material or information requested on the form may be subject to criminal sanction and civil actions.

Alex Gurshtein

Aquarius in a Loincloth

What worked for Hevelius decidedly did not for one Soviet postal official.

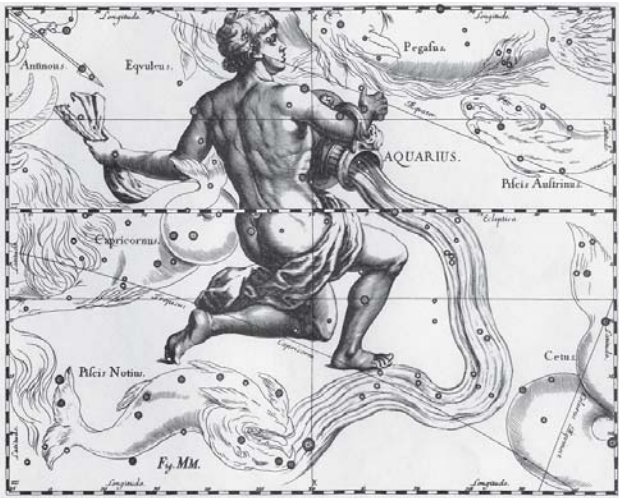
With the 30th anniversary this March of the Soviet Vega missions — a pair of spacecraft that investigated Venus before flying past Halley's Comet in March 1986 — I'm reminded again of an amusing event in the former USSR in which I played an indirect role. The event speaks volumes about a bygone era when the Soviet Union was both a planet-exploring powerhouse yet also distinctly less progressive on the public morals front.

It concerns the depiction of Aquarius on a Soviet stamp — one that shows the zodiacal water-bearer quite untraditionally swathed in a kind of loincloth.

For almost 60 years I worked where I was born, in Moscow. In the last decade of my Muscovite life, fate chose to place me on the Artistic Advisory Board of the Ministry of Communications of the USSR. Arising during Gorbachev's *perestroika*, the AAB offered nonbinding advice concerning the artistic merits of postage stamps, envelopes, and the like being prepared for publication. Its members were primarily artists; as an astronomer and a philatelist, I was the black sheep of this council. In any case, from time to time during AAB meetings, I bore witness to many curious incidents with Soviet stamps. To wit:

COURTESY ALEX GURSHTEIN

Hevelius' Aquarius (below) and Komlev's dressing-up (right). See more images, including the 2004 stamp, at http://is.gd/sovietstamps.



JOHANNES HEVELIUS

In the early 1980s, artist Gherman Alexeyvich Komlev received an order for three stamps dedicated to the Vega project. The stamps came out at different times and were printed in standard sheets as well as in miniature sheets of eight. To design the margins for one of these miniature sheets, Komlev drew inspiration from Johannes Hevelius' 1690 star atlas — which, as many amateur astronomers know, depicts Aquarius with bare buttocks.

And so it came to pass that the exposed behind of Aquarius, as Komlev sketched it, landed on the desk of the head of the Directorate for the Production and Distribution of Instruments of Postal Revenue. This body gave final approval to all Soviet stamp projects.

Now, the chief of the Directorate at the time was ignorant of mythology and astronomy — or perhaps he simply knew the preferences of upper-level authorities. But without hesitation, he declared that it was utterly unacceptable to expose the delicate morality of the Soviet citizenry to a nude male figure, even a half-turned one, and promptly demanded that the artist alter the design.

To avoid changing the entire, largely approved composition, the hapless Komlev quickly slapped a loincloth onto Aquarius. And in precisely this way the ancient water-bearer saw the light of day in December 1984, on a Soviet minisheet of eight Vega stamps.

Twenty years later, in 2004, the postal service of the new Russia finally realized a proposal I'd first made in my AAB days of publishing 12 stamps with the signs of the zodiac. Among sources for artist Vladimir Beltyukov was once again Hevelius' star atlas. But this time no one in Russia commanded covering up Aquarius' backside. How times change! ✦

__Alexander Gurshtein__ is an astronomer and historian of science at Colorado Mesa University. A former president of the IAU Commission on History of Astronomy, he helped initiate the International Year of Astronomy (2009).

Omne Trium Perfectum.

Paramount MYT
23 kg / 50 lb
$6,000

Paramount ME
109 kg / 240 lb
$15,000

Paramount MX
45 kg / 100 lb*
$9,000

Good things really do come in threes.

The Paramount robotic telescope mount combines precision mechanics with advanced control system electronics, all powered by the world's most capable software suite, to acheive unmatched performance, reliability and observing productivity. Whether you choose from the portable MYT, the transportable MX, or the legendary observatory-class ME, make the Paramount the foundation of your digital imaging endeavors.

**Mount capacity does not include counterweights.*

PARAMOUNT

PARAMOUNT ROBOTIC TELESCOPE MOUNT

THE ROBOTIC TELESCOPE MOUNT ENGINEERED TO GO WHERE YOU GO.

FIND YOUR SPACE BISQUE.COM

SOFTWARE BISQUE

862 Brickyard Circle Golden, Colorado 80403

Going the Galactocentric Distance

Theodora Mautz
2015 National Young
Astronomer Award Winner

Ms. Theodora Mautz is a high school senior and is this year's First Place Winner in the Astronomical League's National Young Astronomer Award. Her research question was: *"How do the galactocentric distances of Milky Way globular clusters affect their rotational velocities about the galactic center?"*

She extracted data on globular clusters, studying their rotational velocities around, and distances from, the center of our galaxy. She then generated a rotation curve, similar to the rotation curve for Milky Way disk stars created by astronomer Vera Rubin (an American astronomer who pioneered such work on galaxies). Her hypothesis was that there would be no relationship between the two variables, as Rubin found in the 1970s with stars in the Milky Way's disk, because she believed there to be pervasive dark matter content in the halo of our galaxy. Sure enough, after running two statistical analyses on the data, Theodora found there to be no relationship! Her results support the theory that there are large quantities of dark matter throughout the Milky Way halo, which is a really fascinating idea!

In addition to the First Place NYAA Award plaque, Theodora Mautz was granted lifetime access to the McDonald Observatory complex near Ft. Davis, Texas and she received an Explore Scientific ED Air-Spaced Triplet telescope like the one you see here!

Essential Series 102mm Apochromatic Refractor*[1]
$1,249.99

For more than two decades, the **Astronomical League** has held the annual National Young Astronomer Award competition to recognize the outstanding astronomical research of high-school-age students.

As proud sponsors of the Astronomical League's National Young Astronomer Award, **Explore Scientific**® would like to congratulate this year's exceptional honorees.

www.astroleague.org

* Shown with Twilight II Mount with Pier Extension - $499.99 and Bresser® 70° 25mm Eyepiece - $70, each sold separately.
[1] 8x50 Illuminated Finder Scope - $179.99, not included

EXPLORE SCIENTIFIC®

EXPLORE ONE · BRESSER® · NATIONAL GEOGRAPHIC · HUNTER'S SPECIALTIES

The official telescope of the
National Young Astronomer Award
explorescientificusa.com – 866.252.3811