Amateur Astronomy Goes Social p. 36

THE ESSENTIAL GUIDE TO ASTRONOMY

SKY & TELESCOPE

The Women Who Created Modern Astronomy p. 28

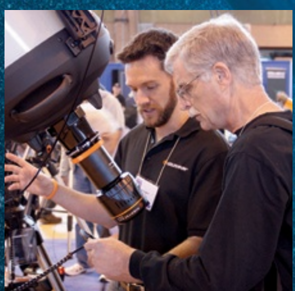
Observe Better with Imperfect Eyes p. 68

AUGUST 2013

What We Know About Alien Worlds

The Exoplanet Revolution p. 18

A Good Year for the Perseid Meteors p. 50

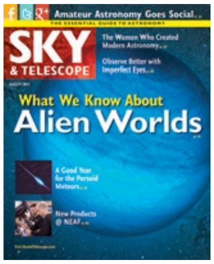


New Products @ NEAF p. 60

Visit SkyandTelescope.com

SKY & TELESCOPE

August 2013 VOL. 126, NO. 2



On the cover: Astronomers are closing in on the nature and prevalence of planets in the Milky Way.

COVER IMAGE: ESO / L. CALÇADA / P. DELORME / R. SAITO / VVV CONSORTIUM

FEATURES

OBSERVING AUGUST

ALSO IN THIS ISSUE

There's more to find online @ SkyandTelescope.com

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

AKIRA FUJII

SKYWEEK
Watch our weekly PBS segment to find out what's currently up in the sky.
skyweek.com

WEEKLY NEWSLETTER
Have the latest astronomy news delivered to your inbox.
SkyandTelescope.com/newsletters

ONLINE MARKETPLACE
Sell your personal used equipment for only $5 per ad listing.
SkyandTelescope.com/marketplace

Find us on Facebook & Twitter

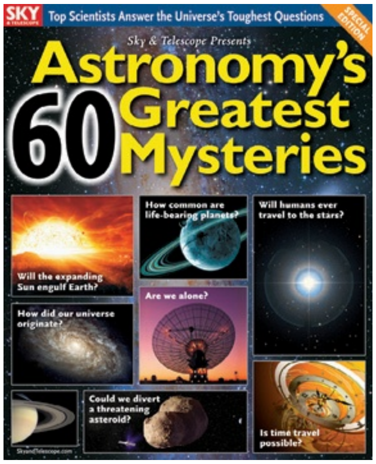
SKY & TELESCOPE (ISSN 0037-6604) is published monthly by Sky & Telescope Media, LLC, 90 Sherman St., Cambridge, MA 02140-3264, USA. Phone: 800-253-0245 (customer service/subscriptions), 888-253-0230 (product orders), 617-864-7360 (all other calls). Fax: 617-864-6117. Website: SkyandTelescope.com. Periodicals 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.

A Special Science Issue

EVERY YEAR for many years, *S&T* has published two special annual issues aimed largely at the amateur astronomy community. These magazines, *SkyWatch* and *Beautiful Universe*, have been rock-solid performers because they help fill a niche not met by other publications. We're currently working hard on editions that will come out later this year, so be on the lookout for our announcements.

But this year we decided to try something new by publishing a science-oriented special issue in addition to our amateur annuals. This 100-page magazine, titled *Astronomy's 60 Greatest Mysteries*, will be on sale on newsstands, through **www.shopatsky.com**, and by phone order at about the same time this August issue arrives in subscriber mailboxes.

This issue has similarities with the Q&A format in Sara Seager's "Exoplanets Everywhere" cover story. It features short articles that provide the most up-to-date information and insight on the most pressing questions facing astronomy, its related sciences, and space travel. We picked questions that are of interest to the scientific community and public alike: How and when did Saturn's rings form? How common is life on other planets? Are we alone? How do stars explode? Why are some galaxies shaped like spirals? What is dark matter? How did our universe come to be? Are there hidden dimensions of space? Is it possible to travel backward in time?



I can't thank our distinguished authors enough for doing such a fabulous job of packing fascinating and sometimes mind-bending discussion into accessible stories that can be read in just a few minutes. Dozens of scientists contributed, including exoplanet hunter Geoff Marcy, Britain's Astronomer Royal Martin Rees, and award-winning sci-fi author and astrophysicist Gregory Benford. And the issue is beautifully illustrated with colorful photos and artwork.

My colleagues and I are excited by every issue of *S&T*, and every annual edition, app, globe, DVD collection, and product that bears the *Sky & Telescope* name. But I feel a special connection with *Astronomy's 60 Greatest Mysteries* because it's quite different from anything we have ever produced. And we gave it the same level of care and attention to detail as if it were an issue of *S&T*. If you want new insight into where things stand at the very forefront of human knowledge on some of the most profound mysteries in science, and what major discoveries might lie just ahead, check it out! ✦

Robert Naeye
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 **Robert Naeye**
Senior Editors **Dennis di Cicco, Alan M. MacRobert**
Associate Editor **Tony Flanders**
Imaging Editor **Sean Walker**
Assistant Editor **Camille M. Carlisle**
Web Editor **Monica Young**

Editor Emeritus **Richard Tresch Fienberg**
Senior Contributing Editors **J. Kelly Beatty, Roger W. Sinnott**

Contributing Editors **Jim Bell, Trudy Bell, Greg Bryant, Paul Deans, Thomas A. Dobbins, David W. Dunham, Alan Dyer, Tom Field, Ted Forte, Sue French, Steve Gottlieb, David Grinspoon, Paul J. Heafner, Ken Hewitt-White, Johnny Horne, E. C. Krupp, Emily Lakdawalla, David H. Levy, Jonathan McDowell, Rod Mollise, Donald W. Olson, 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
VP / Publishing Director **Joel Toner**
Advertising Sales Director **Peter D. Hardy, Jr.**
Advertising Services Manager **Lester J. Stockman**
VP, Production & Technology **Barbara Schmitz**
Production Manager **Michael J. Rueckwald**
IT Manager **Denise Donnarumma**

VP / Circulation **Nicole McGuire**
Circulation Director **Deb Westmaas**
Assistant Marketing Manager **Adriana Maldonado**
Consumer Marketing **Nekeya Dancy, Hannah di Cicco, Bryan Griffith, Joseph Izzo, Ian Lahmer, T. J. Montilli**

NEW TRACK MEDIA LLC
Chief Executive Officer **Stephen J. Kent**
Executive Vice President / CFO **Mark F. Arnett**
Corporate Controller **Jordan Bohrer**
Office Administrator **Laura Riggs**

Editorial Correspondence: *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. 2133. 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: 386-597-4387.
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.

Hidden Gems

I enjoyed James Mullaney's recent article on neglected deep-sky wonders (April issue, page 66), and noted that more than half of them were south of the celestial equator. It's natural that the Southern Hemisphere would be neglected, since much of it is out of sight for northern observers — plus, about 80% of the world's population lives between 20° and 60° north latitude. But it is good to draw attention to these objects.

For readers desiring additional information, *Hartung's Astronomical Objects for Southern Telescopes* (now out of print) mentions all Mullaney's southern objects. That 1995 edition is a revised version of the book first published by amateur astronomer E. J. Hartung in 1968. The other source of excellent (if wordy) quotes for many of these objects is John Herschel's Cape observations from 1834 to 1838, which is still available at **http://tinyurl.com/capeobs**. His description of NGC 2477 (h3103) matches Mullaney's perfectly!

Anyway, well done on advertising these objects — there should be more of it.

David Malin
Sydney, Australia

Next Stop Mars? Not So Fast

Lately, there have been many headlines touting the possibility of humans traveling to Mars. There's a big problem with this. The single most important and exciting scientific discovery that could be made on Mars is that life once evolved there, or perhaps even still lives there. Based on the explorations to date, finding evidence of possible life is not an easy proposition. It probably isn't lying around on the surface and may exist only in relatively rare and restricted subsurface environments, perhaps even in the caves Robert Zimmerman discusses in his article (April issue, page 18). The search for Martians has only begun, and it has a long way to go.

S&T: LEAH TISCIONE

Robotic spacecraft sent to Mars are carefully cleaned and partially sterilized to minimize the biological cargo they carry. Humans, on the other hand, are much filthier. We carry and routinely shed absurdly large amounts of bacteria, dead cells, and residues from our meals. Whether landers have already contaminated the Red Planet with terrestrial biology is an open question, but humans would certainly do so. Even if none of our microbial cohort successfully colonizes Mars — and we should not put that past them — the burden of "dead" biological material humans would shed would still be huge. Detecting native Martian biology in the face of large amounts of human contamination would be extremely difficult. Humans should not travel to the surface of Mars until the question of Martian life, current or past, has been thoroughly explored. This will not be true for many decades at least.

Mark Holm
Monroeville, Pennsylvania

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.

The Great Comet that Wasn't

I very much enjoyed the article "Remembering Comet Kohoutek" by Dean Regas (April issue, page 32). It brought back many fond memories of observing that infamous comet.

But there is one statement in the article that I think is incorrect. Regas states that, "With only a month until perihelion, observers still needed telescopes to find the 10th-magnitude comet." To be sure we still needed telescopes, but the comet was much brighter than 10th magnitude.

Having participated in the observing program sponsored by the Astronomical League, I still recall the Kohoutek timeline vividly. At the time I was observing from Chicago's southwest side, and from that location there was no way a 10th-magnitude diffuse object would have been visible in the short-focus, 8-inch Newtonian I had — especially at the comet's low altitude in the predawn skies. Yet, three full weeks before the date in question, the comet was plainly visible in the scope (though not brilliant), resembling a blunt arrowhead. By one month before perihelion, the comet had brightened considerably and had evolved into a Q-tip with a degree or two of tail.

At the conclusion of the League program the president, the now-late Robert Fried, published the composite results from the 29 participants. The data suggest the comet was already at magnitude 9 two months before perihelion, and at magnitude 6 one month before.

Paul Lorenz
Vail, Arizona

Editor's Note: *The conflict between the article's and the League's magnitudes is probably from the difference between nuclear magnitude and real magnitude. Unfortunately we didn't clarify which of the two magnitudes we were talking about in the article, but a nuclear magnitude of 10 is still consistent with the League's observations. On October 30, 1973, for example, the nuclear magnitude was 12 — which is notably fainter than the League's 9th-magnitude result. So* *on November 30th the comet appeared to be magnitude 6, but the nuclear magnitude would have been fainter.*

As a teenager in the early spring of 1973, I heard of the potential for a very bright naked-eye comet and wrote a letter to the Smithsonian Astrophysical Observatory requesting an ephemeris for the new object. A week later, I was delighted to find in my mailbox a large envelope containing a five-page news release, "Comet Kohoutek (1973f): Prospects for Observations," by Brian G. Marsden.

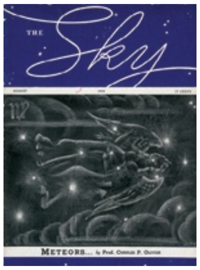
As Regas's article notes, Marsden himself was the first to suggest the comet might be spectacular. But Marsden also shares the blame with the news media for labeling Kohoutek as the "Comet of the Century." In the final paragraph of his release, he wrote:

> Comet 1973f was brighter than Comet Bennett 1970 II when the latter was observed at comparable distances from the sun in early 1971. Since Comet 1973f has a perihelion distance that is only about a quarter that of Comet Bennett, it should become much brighter; and if it develops a dust tail, it could be the most spectacular comet of the century.

Joe Rao
Yonkers, New York

75, 50 & 25 Years Ago

Roger W. Sinnott

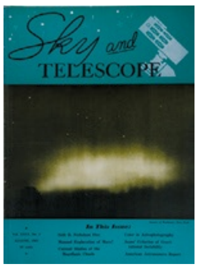


August 1938

Ritchey Telescope "The 40-inch reflector is the latest instrument to be made available for work in the Naval Observatory. . . . The instrument in substantially its present form was turned over to the Observatory in 1934 by its designer and maker, George W. Ritchey, after three years devoted to its construction. It is of the Ritchey-Chrétien type, arranged like a Cassegrainian. . . .

"Tests by knife-edge and by plates taken with the telescope show the figuring of the mirrors is good, and good quality images over the entire 90-minute field are now obtained."

Apart from Ritchey himself, astronomers remained wary of the design's hyperbolic mirrors and curved focal surface. It was considered for the Palomar 200-inch and rejected. But the success of this 40-inch changed minds, especially after it was moved from Washington, D.C., to Flagstaff, Arizona, in 1955. Many of today's largest reflectors — including the Hubble Space Telescope — are Ritchey-Chrétiens.

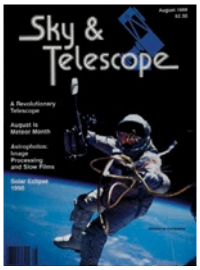


August 1963

Onward to Mars "Can we send a man to Mars and return him safely to Earth? When can we expect to do it? Eight hundred engineers and scientists met in Denver, Colorado, on June 6th and 7th to discuss these questions and heard the answer, 'Yes, in the 1970's.'. . .

"[A] five-man crew on a 420-day mission must carry nearly 3,000 pounds of food, even with present-day electrochemical waste processing, and with algae or bacteria as a food supplement. . . . Algae can be used in a photosynthetic gas exchanger to consume carbon dioxide and produce oxygen. In addition, at least one third and eventually perhaps half of the crew's food can be supplied by harvested algae."

First, we had to get to the Moon — and did, in 1969. Algae research led to the development of a supplement now found in baby food and yogurt. But we're still a long way from going to Mars.



August 1988

Pluto's Atmosphere "After decades of speculation and debate, it now appears certain that Pluto has an atmosphere. Astronomers collected the evidence on June 9th, when the cold, distant world occulted a star in Virgo. No fewer than eight observing teams in Australia, Tasmania, and New Zealand witnessed the star's light disappear and reappear gradually over several seconds, not abruptly. One group, from the Massachusetts Institute of Technology (including *Sky & Telescope*'s J. Kelly Beatty), watched from NASA's Kuiper Airborne Observatory."

The timings of the eight teams also revealed Pluto's puny size, downsizing it several hundred kilometers from previous estimates.

MISSIONS | Kepler Down and Probably Out

NASA / WENDY STENZEL

"I am just devastated. My hands are trembling and my heart is aching," planet hunter Geoff Marcy wrote *S&T*. He wasn't alone. On May 15th, NASA announced that its Kepler Space Telescope — which has discovered a profusion of extrasolar planets transiting their stars — had ceased to work and was unlikely to recover.

The problem was the same one that has plagued several other space astronomy missions: failure of reaction wheels, the gyroscope-like flywheels that keep the telescope precisely pointed. Kepler has four of them; three are required for pointing. One failed in July 2012. A second started showing signs of trouble in January, then became stuck for good.

A slim possibility remains that one of the dead wheels can be unstuck. Alternatively, mission controllers may be able to glean some lower-grade observing time by using the two remaining reaction wheels in conjunction with the spacecraft's thrusters until their fuel is used up. Mission controllers won't give up for several months. But, NASA announced, "it's unlikely that the spacecraft will be able to return to the high pointing accuracy that enables its high-precision photometry."

Kepler has been one of the most dazzlingly successful missions in space astronomy. It has found about 3,500 planet candidates, most of which are probably real. Even more are surely in the pipeline of data still to be analyzed, which should take another two years. Kepler outlived its original 3½-year mission by six months, and it more than fulfilled its primary goals. It established that most stars of most types have planets, and that small worlds like Earth are abundant throughout the galaxy (page 18).

But it failed just when things were getting really interesting: when true Earth analogs, in 1-year orbits, were about to come in reach. This was taking longer than expected because most stars turned out to have more "microvariability" than the Sun, adding unexpected noise to Kepler's precision brightness measurements. This meant Kepler would need to collect data for several more years to coax out enough rare, very slight transit dimmings produced by true Earth analogs to ensure that they were real. Those were the biggest prize: familiar, friendly worlds in Sun-like stars' habitable zones.

Says Marcy, "Our analysis shows that we will be able to detect Earth-size planets just inward of the habitable zone, and also planets a bit larger than Earth within the habitable zone. So we plan to nail down the frequency of Earth-size planets within the habitable zone by measurements of planets at the doorstep. We will be working seven days a week, day, evenings, and weekends, to extract the Earths from the existing data. Still, I'm so sad."

Kepler has a successor mission: TESS, the Transiting Exoplanet Survey Satellite, which coincidentally won funding the month before. Kepler pointed at a single field of sky in Cygnus and Lyra. TESS is being designed to watch for planets transiting at least three times as many stars: brighter, nearer ones all across the sky. It is scheduled for launch in 2017.

■ **J. KELLY BEATTY & ALAN MACROBERT**

STARS | “Suicide Pact” for T Pyx?

A famous recurrent nova may whittle itself down to nothing in as little as 100,000 years, rather than build itself up to a supernova cataclysm as expected, say Joseph Patterson (Columbia University) and 13 amateur coauthors in a report posted March 4th to the online research repository arXiv.org.

T Pyxidis is a white dwarf–red dwarf binary that erupts every 12 to 50 years or so as a recurrent nova. Hydrogen falls from the red star onto the white dwarf, building up as a thin layer on its surface. Eventually the layer becomes dense enough to erupt in a hydrogen-fusion explosion, brightening the system from magnitude 15 to about 6.5 for a few weeks.

Normally in such a binary, the white dwarf gains more mass from its companion between explosions than it blows off during them. When it grows to 1.4 solar masses this way, the star’s entire bulk explodes in a carbon-fusion reaction as a Type Ia supernova. If T Pyx did that anytime soon, it would shine at magnitude –9, a hundred times brighter than Venus.

But amateur-aided observations now suggest a darker fate for T Pyx. Instead of bulking up, the white dwarf seems to be losing *more* mass in each explosion than it gains in between.

This surprising result comes from about 15 years of precision photometry by amateur observers in the globe-spanning Center for Backyard Astrophysics, which Patterson coordinates. When a binary system loses mass, its orbital period increases. CBA astronomers determined the system’s orbital period before and after its most recent outburst in 2011. The period increased from 1.829507 to 1.829606 hours, a change of 0.0054%.

That may seem tiny, but Patterson was amazed. The change was seven times larger than predicted and corresponds to a Neptune’s worth of mass gone — five times more than what the white dwarf apparently drew down from the red star in the decades before its 2011 outburst. If this keeps happening, the white dwarf will eventually be worn away to nothing.

Not everyone buys this picture. “It just absolutely flies in the face of theoretical expectation,” says Edward Sion (Villanova University). In 2010 he concluded that the white dwarf is steadily *gaining* mass and may be only 10 million years from going supernova. “I’m not saying Patterson’s group is wrong,” he says, “but we have to be very cautious.” He warns that Patterson’s calculated accretion rate doesn’t explain all the observations.

No matter the outcome, CBA observers have advanced the scientific debate by measuring T Pyx’s mass loss. As Patterson notes, “It was lovely to see an important result coming directly from good ol’ Kepler’s laws applied to a huge swath of data from backyard telescopes.”

■ **MARK ZASTROW**

DAVID A. HARDY / STFC

An artist’s rendition of a recurrent nova. A relatively normal red star orbits a tiny but heavier white dwarf — so closely that a bit of the red star spills over the edge of its zone of gravitational influence, pouring a thin stream of hydrogen down onto the white dwarf’s surface.

IN BRIEF

Remains of Comet Shoemaker-Levy 9. Nearly 20 years after the world watched chunk after chunk of Comet Shoemaker-Levy 9 crash into Jupiter, traces of it are still in view. Using two instruments aboard the infrared Herschel Space Telescope, a team led by Thibault Cavalié (Laboratory of Astrophysics, Bordeaux, France) mapped water in Jupiter’s stratosphere. Any water there should be short-lived. The team found a lot of it, mostly in the southern hemisphere where the comet hit. They conclude that the comet must have delivered at least 95% of the water seen. They and others have also found traces of the comet’s hydrogen cyanide (HCN) remaining in Jupiter’s atmosphere.

■ **J. KELLY BEATTY**

A bridge between M31 and M33. Seven tenuous clouds of hydrogen trace a bridge of matter between our two closest big neighbor galaxies: M31 in Andromeda and M33 located 15° from it in neighboring Triangulum. They’re about 2.5 and 2.6 million light-years from us, respectively, but only about 700,000 light-years from each other. The streamer could be debris pulled out by a past close encounter, or a bit of the primal cosmic cobweb of dark matter around which galaxies condense. Such filaments continue feeding tenuous hydrogen onto galaxies today.

■ **CAMILLE M. CARLISLE**

Digitizing Harvard’s century of sky. Harvard College Observatory is progressing in its long-planned project to digitize its famed collection of more than 500,000 glass sky-survey plates. These were taken from about 1890 to 1990 to capture events happening across most of the sky. About 10% of the scanning and analysis work is now finished, and the observatory has released a first data set of 2.9 billion brightness measurements. A typical star of blue magnitude 12 or 13 offers a century-long light curve of roughly 1,500 measurements to as good as 0.1 magnitude.

The project, named Digital Access to a Sky Century at Harvard (DASCH), relies in part on volunteer labor by members of the Amateur Telescope Makers of Boston, but whether it is completed will depend on continued finding by the National Science Foundation. If the money comes through, DASCH project leader Jonathan Grindlay hopes to finish by 2016.

■ **MONICA YOUNG**

IN BRIEF

Testing relativity even better. A massive neutron star and its close white dwarf companion have provided the best laboratory yet to test some of general relativity's obscure predictions in extreme conditions. Once again, Einstein's century-old theory of gravity as an aspect of spacetime is passing with a perfect score.

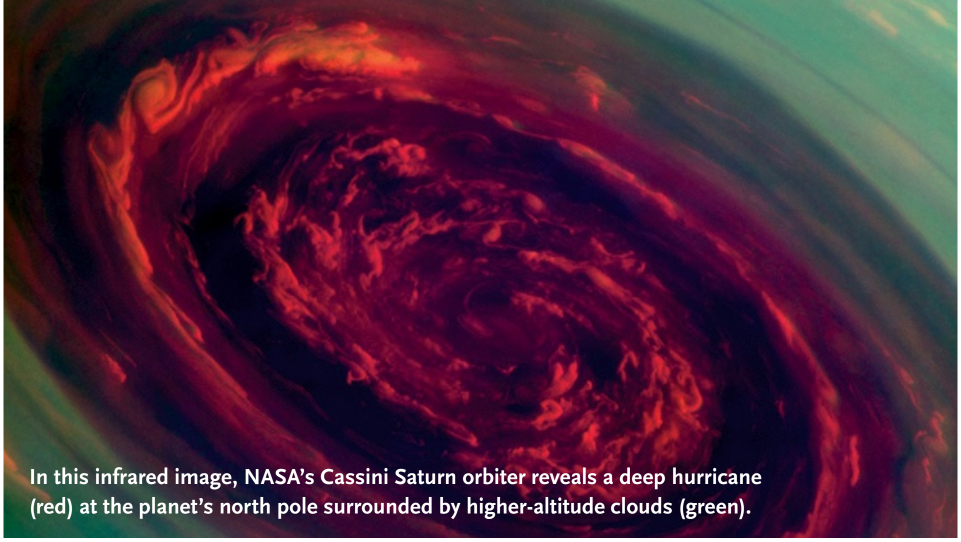
The pulsar PSR J0348+0432 in Taurus is an unusually massive neutron star with 2 solar masses, an important discovery in its own right. Whirling closely around it every 2.46 hours is a white dwarf with less than a tenth as much mass. The system is losing orbital energy to gravitational waves at just the rate that relativity predicts. Moreover, the difference in the two bodies' masses enables checking of relativistic effects that are hard to measure in more evenly matched pulsar binaries. John Antoniadis (Max Planck Institute for Radio Astronomy, Germany) and his colleagues find the system's orbital period shrinking by 8.6 ± 1.4 microseconds per year, indicating no sign of any new physics.

■ CAMILLE M. CARLISLE

Earth and Moon shared water. The water we drink and the water in ancient Moon rocks came from the same primitive-asteroid feedstock, report Alberto Saal (Brown University) and his colleagues in *Science Express*. Water from both the Earth and Moon shows the same proportion of deuterium (hydrogen-2 or "heavy hydrogen") as the water that's in primitive carbonaceous chondrite meteorites. These haven't changed since the earliest days of the solar system.

This finding links the Earth and Moon more robustly than ever. Astronomers once thought that Earth gained its water later in its history from late-arriving comets, but the water in most comets has a D:H ratio that's too high. And since the Moon apparently formed from superheated matter splashed out during an enormous impact on Earth, the thinking now is that the traces of water that ended up inside the Moon must have come from Earth. In other words, our young planet was already wet when it got clobbered very early in the solar system's history.

■ J. KELLY BEATTY



In this infrared image, NASA's Cassini Saturn orbiter reveals a deep hurricane (red) at the planet's north pole surrounded by higher-altitude clouds (green).

NASA / JPL / SPACE SCIENCE INSTITUTE

SATURN | Ringworld Makes Waves

Saturn has been making news for a hurricane centered on its north pole, a "rain" of water ice from its rings, and digestive troubles in its interior.

• On April 29th the Cassini imaging team released the dramatic false-color view above, looking down at the planet's north pole. The rose-like feature is a deep view into a giant hurricane, which sits centered in the "polar hexagon" of higher-altitude cloud streams. Roughly two Earths across, the hexagon has been around at least since its discovery in 1981 by Voyager 2. It appears to be a fast-moving jet stream, though its stable, six-sided shape remains a mystery.

The hurricane is a surprise. Its eye spans some 1,250 miles (2,000 km), 20 times larger than counterparts on Earth. Winds race around the outer edge at 330 miles (530 km) per hour. It's unclear what's driving it or how long it has existed. On Earth, hurricanes are powered by heat drawn from tropical ocean water. But there's no ocean under the hurricane on Saturn, just more atmosphere. It probably survives on a rain-and-evaporation cycle involving just the small amount of water vapor in Saturn's hydrogen atmosphere.

• Closer to Saturn's equator, another investigation finds evidence that water vapor from the rings is streaming into the top of the planet's ionosphere. This was suspected for decades, especially after Cassini found in 2004 that the rings are immersed in a tenuous water "atmosphere." James O'Donoghue and his colleagues describe (in the April 11th *Nature)* their infrared observations with the Keck I telescope, which revealed odd bright and dark bands at the middle latitudes of both hemispheres. These bands suggest that ionized water molecules from the rings travel down magnetic field lines into Saturn's ionosphere, where they "quench" a certain infrared emission that otherwise ought to arise. The effect is weakest at latitudes that map back along the magnetic field lines to the Cassini Division and the Colombo Gap, where icy ring particles are sparse.

• Planetary scientists have long known that Saturn emits about 2.5 times as much heat as it receives from the Sun. What generates the extra energy? For decades, scientists supposed that helium might be settling downward through the planet's hydrogen-rich interior, slowly "raining out" toward the core in the form of liquid droplets over the age of the solar system. These droplets would liberate gravitational energy as they descend.

But Jérémy Leconte and Gilles Chabrier suggest in the April 21st *Nature Geoscience* that Saturn's glow is leakage of heat still left over from the planet's formation 4.6 billion years ago. They think that a deep layer of stagnant gas has bottled in lots of ancient heat, releasing it only slowly. While helium rainout likely still happens, the authors doubt that it can account for all of Saturn's excess infrared mission.

Jupiter and Neptune also radiate about 1.7 and 2.6 times as much heat as they receive from the Sun, respectively. Uranus, a curious planet in many ways, generates next to none. ✦

■ J. KELLY BEATTY


SAO
astronomy.swin.edu.au
SWINBURNE ASTRONOMY ONLINE
Fully online postgraduate degree programs
Join students from around the globe!
Programs range from a 6-week short course to a Masters degree.
Celebrating 10 years of online education. SAO is fully accredited and run by Australia's Swinburne University.
Focus on fundamental astronomy.
Taught by research astronomers.
Designed for educators, science communicators, amateur astronomers, and anyone with a love of astronomy.
www.astronomy.swin.edu.au/sao
image: NASA, ESA, and C R O'Dell (Vanderbilt University), M. Meixner and P. McCullough (STScI).
SWIN BUR NE
CENTRE FOR ASTROPHYSICS AND SUPERCOMPUTING


SIMPLY THE BEST.
HERE'S WHY...
Highest overall performance of any filter in its class
Maximum light transmittance
Best optical glass substrate in the industry
Exclusively designed dielectric coatings & protective anti-reflection coatings on both sides
Optimum nebula emission bandwidth & maximized photo/visual contrast
Largest clear aperture of any consumer filter & no image distortion from off-axis light
"Squarewave" response reduces FWHM bandwidth
Strictest quality control standards in the industry
Individually inspected & tested with light transmittance proudly inscribed on each filter
PREMIUM QUALITY FILTERS AND ACCESSORIES
COMET FILTER
Increases contrast and reveals the delicate ionized tail of gaseous comets, allowing you to see their full extent.
1.25" - $119.95
2" or Cassegrain Rear Cell - $239.95
THE ULTRA HIGH CONTRAST FILTER (UHC)
The ULTIMATE dark sky nebula filter. Reveals the faintest of objects under both light polluted and dark skies.
1.25" - $119.95
2" or Cassegrain Rear Cell - $239.95
THE OXYGEN III FILTER
Legendary performance allowing near photographic views of diffuse, planetary and extremely faint nebulae.
1.25" - $119.95
2" or Cassegrain Rear Cell - $239.95
LUNAR AND PLANETARY FILTERS
Increased contrast on Lunar and Planetary details. Optimized for both visual and photographic applications. Visit lumicon.com for details.
1.25" - $23.95
2" - $35.95
MULTIPLE FILTER SELECTORS
Switch back-and-forth between filters without having to thread and unthread them from your eyepieces or diagonal. Leaving one of the slots open lets you compare views with and without your Lumicon filters. Made from solid aircraft aluminum.
(Filters Sold Separately)
1.25" - $142.95
2" - $160.95
Visit WWW.LUMICON.COM for a complete list of superior quality filters, accessories and photographic equipment.
SHOP ONLINE AT WWW.LUMICON.COM OR CALL 1.800.420.0255
TO ORDER: Please call us or visit our website for a complete list of authorized Lumicon premier dealers worldwide.
Prices do not include shipping and handling or applicable state taxes.
LUMICON
THE WORLD'S BEST FILTERS
PROUDLY MADE in the USA (Not China)
follow us
LUMICON INTERNATIONAL 80 West Easy St., Simi Valley, CA 93065 . US 800.420.0255 . 805.520.0047


NEW FEATURES!
• Increased payload 7.7 lbs.
• Adjustable AZ base
SkyTracker™
Camera Mount for Astrophotography
iOptron®
iOptron
SkyTracke
#3302W
Reg. $448
For a limited time only -- $399
Includes polar scope, Altitude dial and new features!
Ball Head and Tripod also available.
www.iOptron.com
B&H Photo
1.800.606.6969
www.bhphotovideo.com
High Point Scientific
1.800.266.9590
www.highpointscientific.com
OPT
1.800.483.6287
www.opttelescopes.com
Telescopes.com
1.800.303.5873
www.telescopes.com
Canadian Telescopes
1.888.527.7207
www.canadiantelescopes.com

David Grinspoon

It's Not About Pluto: Exoplanets Are Planets Too!

Recent discoveries have exposed the absurdity of the IAU's planet definition.

IT'S MID-2013 and I can't believe I'm still writing about this. But we need to agree on a definition of "planet" that's not embarrassingly wrong and doesn't ignore the exoplanet revolution. There is dissatisfaction in the universe, a disturbance in the force, because people know that the current "official" definition from the International Astronomical Union (IAU) is incomplete at best and nonsensical at worst. In fact, the reasons why we need a better one loom larger every day.

Exoplanets are being discovered at a furious pace (page 20) and the fact that the current "official" definition defines only planets orbiting our Sun becomes more glaring as our solar system's planets shrink to a completely negligible portion of all there are. Meanwhile, NASA's New Horizons spacecraft is speeding at about 34,000 miles per hour toward its July 2015 rendezvous with Pluto, which will look very planetary — a round and varied world with a thin atmosphere and its own retinue of

Artist Luis Calçada depicts the surface of Pluto, with the moon Charon hovering in the sky. When New Horizons images Pluto up close in 2015, it will probably become obvious that Pluto should be considered a planet.

ESO / LUIS CALÇADA

moons. Schoolchildren and other astute members of the public will again ask, “Why is this not a planet?” Hopefully by then our community will have settled on some slightly more coherent answers.

You can explain to the kids that we discovered many other Plutos out there. They’ll respond, “But why can’t they all be planets? And why do you call it a dwarf planet if it’s not a planet?” Good questions.

Unlike “life,” “planet” is not an inherently difficult thing to define. Life is vexing because we only have one example and we don’t know to what extent our limited earthbound outlook might be biasing us to mistake our biosphere’s quirks for universal qualities. Someday, when we have discovered many living worlds, we’ll be able to revisit our definition of life with a broader perspective.

With planets we have crossed that threshold and now we know that our star is not unique in hosting a gaggle of orbiting worlds. In fact, most stars have them. At the same time, new discoveries within our solar system revealed the retinue of objects orbiting the Sun to be larger and more complex than we imagined. Pluto, it turned out, had company in the Kuiper belt, including some fairly large objects. It made no sense to consider Pluto to be a planet and not also admit these newly discovered planets to the club.

So it was certainly reasonable to reconsider the meaning of “planet.” In August 2006 the IAU was bent on solving the perceived Pluto problem. But partisans on both sides — those wanting to protect Pluto and those eager to knock him off — made it a strangely emotional debate, warping the process.

Some scientists, certain that kids could not handle learning a lot more than 9 planets, thought that the line should be drawn at something larger than Pluto. (Some of these people have apparently never actually talked to kids.) Perhaps overly attached to the solar system of their youth, they preferred to react to the discovery of a lot more planets by changing the definition of “planet” to keep the number more or less the same as what they learned in grade school.

After several proposals and votes, the 300 or so exhausted remaining stragglers at the end of a very long IAU meeting in Prague adopted the final proposal. As an alternative, they could have suffered the embarrassment of no agreement.

But in their haste to deal with the Kuiper belt revolution, they punted on the exoplanet revolution. The IAU defined solar system planets separately and left unresolved the question of what exactly might qualify as a planet in other stellar systems; in other words, they ignored essentially the entire universe. Every time anyone now refers to exoplanets as planets (which includes every article ever written about exoplanets), they simply ignore the IAU definition.

Furthermore, the way the IAU dealt with Pluto-like objects made the new definition of “planet” unworkable for exoplanets. Beyond the surreal implication that a dwarf planet is not a planet, the main problem is that the criterion for determining what is a real planet and what is a dwarf involves observing the small-body population in the neighborhood of a candidate planet. But this won’t work for exoplanets, since we cannot know the small-body population in the vicinity of these newly discovered “things that might be planets.” Making matters even more ridiculous, Earth would be considered a planet in one location, but a dwarf if you moved it into the Kuiper belt, where it couldn’t possibly clear out this vast region of space.

Just as Galileo realized that the other known planets are the same kind of body as Earth, we now know that our Earth is but one among a much larger class of similar objects. Indeed, one of the most transcendent revelations made by science in our time, perhaps in all of history, is the fact that these wonderfully diverse objects around distant stars are indeed planets. That is the startling, beautiful, scientifically verified truth.

So it’s particularly silly, in the time of this exoplanet revolution, to proclaim a new definition that cannot be practically applied outside our solar system. After I tweeted this observation, I received a reply from a famous Pluto-assassinating astronomer who said, “I’d say [it’s] silly to have an exoplanet definition until we know more. Don’t make boxes first.” To this I replied, “We should call them ‘exothings’ then. Exoplanets implies we know they have characteristics in common with solar system planets.” But really, are we worried that these objects will turn out not to be planets? I’ll put money on predicting that when we do know more, those exothings will be ... planets!

So let’s fix this definition and put it to rest. I propose something simple like: *A planet is a gravitationally*

The IAU Planet Definition

At the end of the 2006 IAU General Assembly in Prague, the “members voted that the resolution B5 on the definition of a planet in the Solar System would be as follows:

A celestial body that (a) is in orbit around the Sun, (b) has sufficient mass for its self-gravity to overcome rigid body forces so that it assumes a hydrostatic equilibrium (nearly round) shape, and (c) has cleared the neighbourhood around its orbit.”

To read the IAU’s entire definition of “planet,” visit skypub.com/IAUplanet.

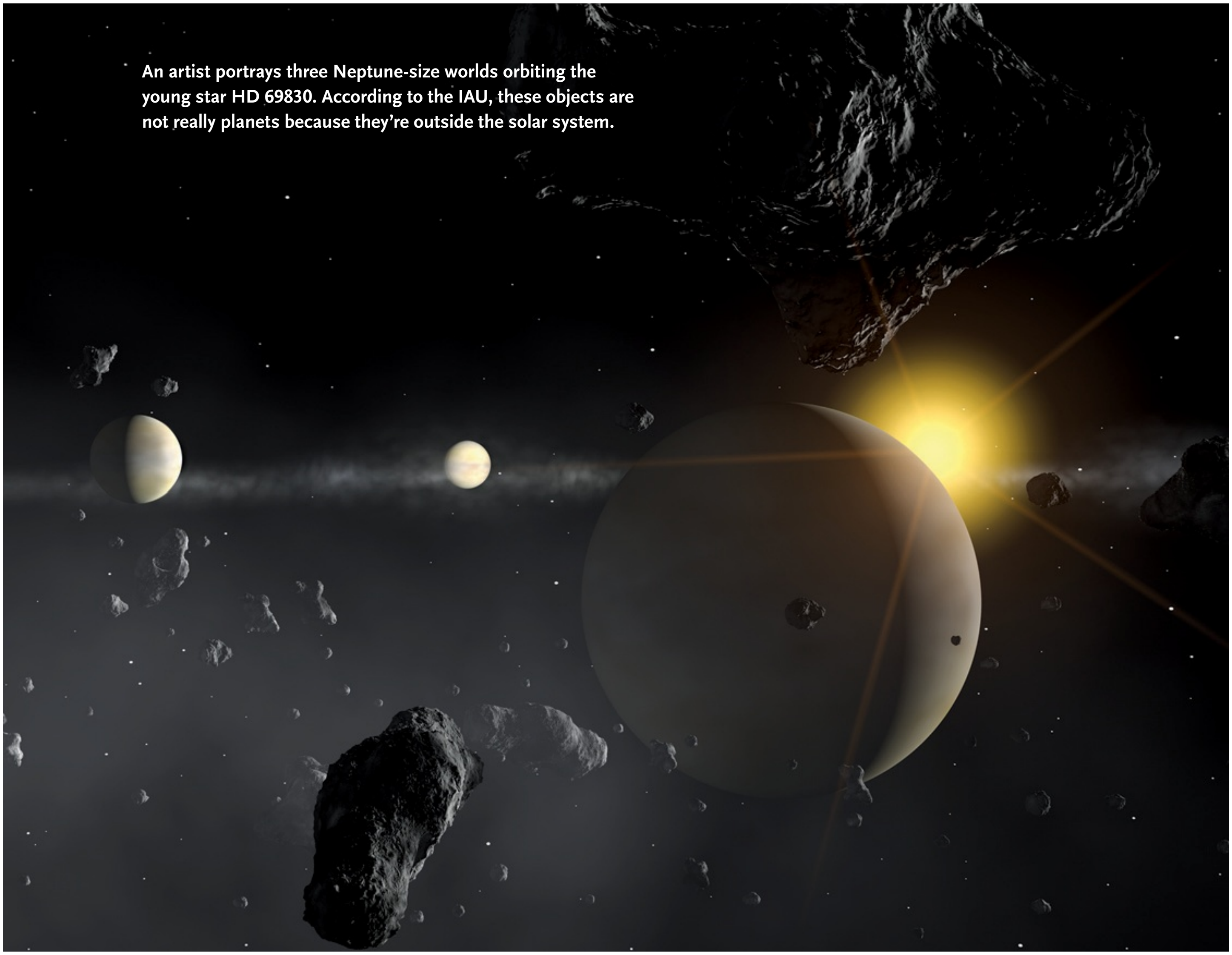
rounded object that is orbiting a star. To bound this definition on the large end, we can say that if an object has ever experienced nuclear fusion, it's a brown dwarf and not a planet. On the small end we can say that if it has not gravitationally dominated its surroundings then it goes in a subclass called dwarf planets. And "dwarfs" is just a subdivision of planets that already includes rocky planets, ice giants, and gas giants. When astronomers discover an exoplanet, we're often unsure which of these categories it goes in, but we know it's a planet.

Honorable mention must also be made of rogue planets, objects born in the comfort of a circumstellar disk, but in the gravitational tussling of sibling planets, somehow ended up being tossed out into the interstellar void. Are these rogues planets too? Sure, why not. Once a planet, always a planet.

And what about large moons such as Titan that would certainly be considered planets if they were independently orbiting a star? Good question, but we should just let moons be moons since it's clear what they are.

Someone will probably shoot this proposal full of holes and come up with a better one. And as we learn more we'll probably need to revise it. Planets are complex and incredibly diverse, and the exoplanet revolution is surely just beginning. But let's at least have a definition that incorporates where we are and what we know today. Now we know that planets exist in thrilling abundance, the next phase, which has already begun, is to find out what they're really like. And after that, the next step is to find out who's living out there. At that point we won't need a definition that's perfect, just one that won't make us the laughingstock of our galaxy. ✦

Contributing editor and noted book author ***David Grinspoon*** *is Baruch S. Blumberg Chair of Astrobiology at the Library of Congress. Follow him on Twitter at @DrFunkySpoon.*



An artist portrays three Neptune-size worlds orbiting the young star HD 69830. According to the IAU, these objects are not really planets because they're outside the solar system.

ESO

Exoplanets Everywhere

Sara Seager

A leading researcher answers the most pressing questions about our galaxy's enormous population of planets.

Illustration of sunset on Gliese 667 C's super-Earth planet: ESO / Luis Calçada

Exoplanet discoveries continue at an astonishing pace. When this issue went to press in late May, astronomers had announced more than 700 confirmed exoplanets in total, and NASA's Kepler space telescope had bagged more than 3,500 strong candidates.

One of Kepler's most exciting findings is a 1.5-Earth-diameter planet candidate in the habitable zone of its nearly Sun-like host star, and the mission has discovered a few dozen other potentially habitable worlds. Kepler's harvest of multiple-planet transiting systems has grown rapidly. Kepler has also found the first circumbinary planets — worlds orbiting two stars. And European astronomers may have found an Earth-mass planet orbiting Alpha Centauri B, a member of the triple-star system that is our Sun's closest neighbor (this planet has recently come under dispute).

In addition to all of these specific discoveries, astronomers are using the accumulating data from Kepler and other projects to close in on answers to the most fundamental questions about the prevalence, nature, and formation of planets in our Milky Way Galaxy. Here's what we can say right now about some of the most pressing questions of all.

▶ *How common are planets in our galaxy?*

Astronomers have long expected planets to be a natural outcome of star formation, built from the leftover gas and dust in protoplanetary disks that surround all types of stars except possibly the most massive. This concept is now substantiated by hard evidence.

Several studies weigh in on the commonality of planets in our galaxy. Planet surveys using the gravitational microlensing technique (page 21) achieved the first meaningful result about planet frequency, finding that each single solar-mass star in our galaxy hosts, on average, one or more planets in an orbital range of 0.5 to 10 astronomical units (1 a.u. is the average Earth-Sun distance).

Based on the rate that Kepler has found planets during its first three years of taking data, we can now confidently state that at least 70% of Sun-like stars have planets with orbital

periods of less than 85 days. The overall planet frequency for Sun-like stars will increase because we'll continue to analyze Kepler data taken over the past few years, which will enable us to find planets with longer orbital periods.

We also want to know the frequency of planets around the most common type of star: red (*M*) dwarfs. These low-luminosity stars have masses 10% to 50% that of the Sun and constitute about 70% of stars in the Milky Way. Although Kepler data have recently been used to claim that every *M* dwarf in our galaxy has at least one planet, more observations are needed to support this conclusion. But planets seem to be very common around *M* dwarfs.

Putting all the results together, we've learned that, on average, every star should have *at least* one planet. Kepler and radial-velocity surveys have together found dozens of multiple-planet systems, although the fraction of stars with more than one planet remains unknown. Given that our galaxy has at least 100 billion stars, it must have at least 100 billion planets that are orbiting stars. Planets are just simply everywhere.

▶ *What is the distribution of exoplanets based on their masses/sizes and planet-star separations?*

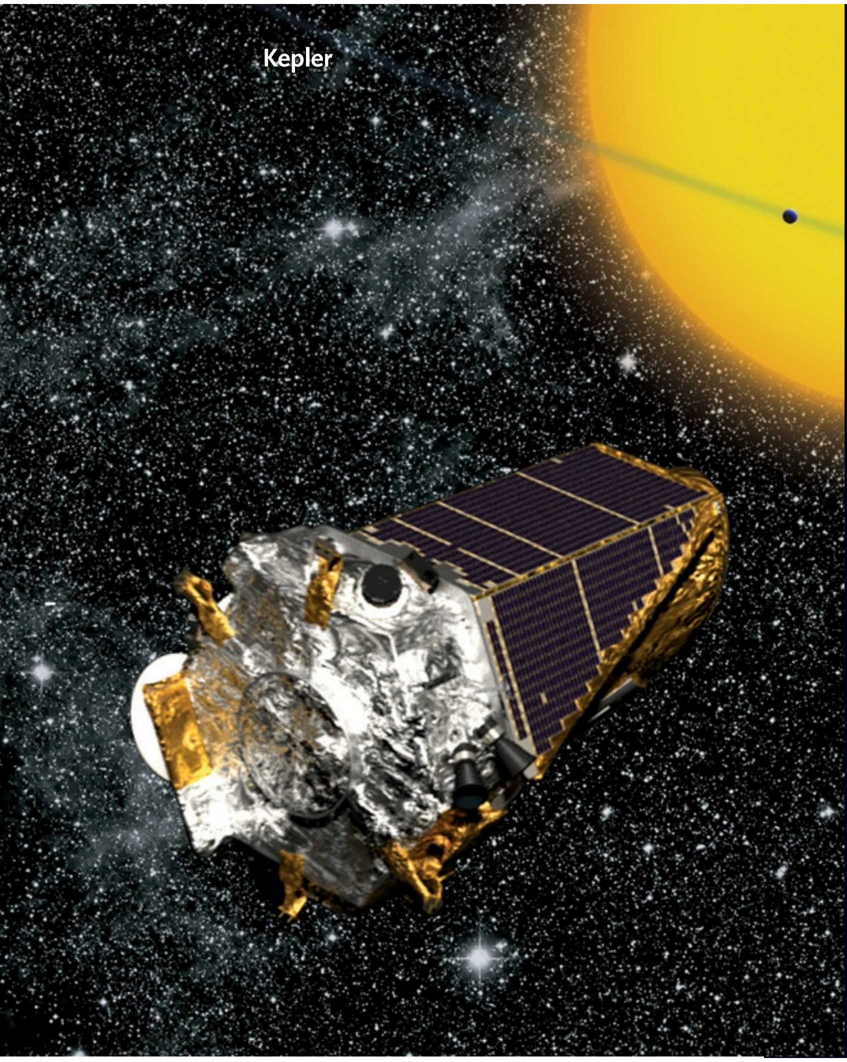
Our current knowledge of exoplanet populations comes from Kepler, radial-velocity detections, and microlensing surveys. Kepler has observed more than 150,000 stars, enabling it to discover enough planets that we can begin to answer this key question. Kepler finds that main-sequence *G* and *K* stars (which are similar to the Sun) have the following planet frequencies: 17% for planets with 0.8 to 1.25 Earth radii in orbits with periods less than 85 days; 25% for super-Earths (1.25 to 2 Earth radii) with periods less than 150 days; and 25% for mini-Neptunes (2 to 4 Earth radii) with periods less than 250 days. Radial-velocity studies corroborate the Kepler findings for planets with periods less than 50 days.

Fortunately, microlensing surveys are sensitive to planets that are far from their stars. These studies have found that for orbital distances of 0.5 to 10 a.u., 17% of stars host planets with 0.3 to 10 Jupiter masses. Cool Neptunes (10 to 30 Earth masses) and super-Earths (5 to 10 Earth masses) are even more common: their abundances per star are 52% and 62%, respectively, but these percentages come with large uncertainties.

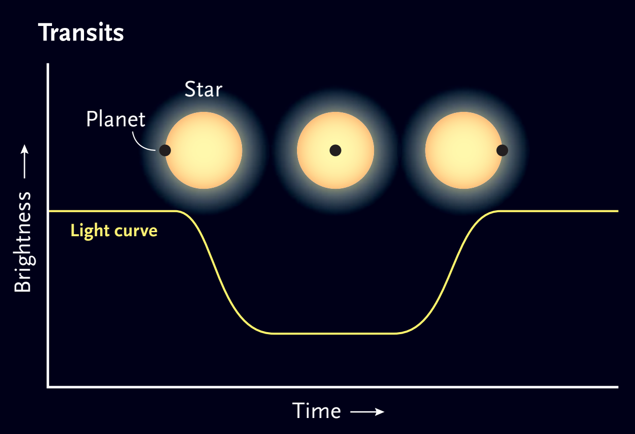
While we patiently accumulate more exoplanet data, we can safely say that small planets outnumber large planets in the galaxy. In fact, the occurrence rate soars for planets of smaller sizes and lower masses.

▶ *How common are planetary systems with architectures similar to our solar system, with small planets close in and gas giants farther out?*

We don't have a firm answer yet because it's difficult to detect planetary systems with our solar system's architecture. For now, we have to define a "solar system analog" as a planetary system with outer giant planets because Kepler



NASA / KEPLER / WENDY STENZEL



TRANSITS NASA's Kepler mission and other space- and ground-based telescopes have observed about 270 exoplanets by catching them transit (cross in front of) their host star. This method works best for finding close-in planets and worlds with large diameters. It provides an accurate measurement of a planet's diameter, but it doesn't directly yield mass. Only a small fraction of planets will transit their stars as seen from Earth's line of sight, but transiting planets offer the possibility of detailed studies to measure a planet's atmospheric composition and its orbital inclination relative to the star's equatorial plane.

KEPLER Launched in 2009, Kepler (*left*) is a 1-meter wide-field telescope in an Earth-trailing orbit that has continually observed the same field of stars to catch transiting exoplanets. It appears that the mission has ended (page 10), which will make it more difficult for astronomers to determine the frequency of Earth-size planets in the habitable zones of Sun-like stars.

has not taken data for enough time to detect exact Earth- and Venus-sized planets in Earth- and Venus-like orbits.

The most recent results on this question come from microlensing surveys, which can detect planets orbiting stars at large distances. About 20% of planetary systems have two outer giant planets — but this statement comes with large uncertainties. Radial-velocity surveys have identified a handful of Jupiter-mass planets orbiting at 5 a.u. (Jupiter's orbital distance) from a Sun-like star, but a careful statistical analysis has not yet been done for the roughly 3,000 stars that have been studied. We can make an educated guess that only between 1% and 20% of planetary systems are likely to be similar to our solar system.

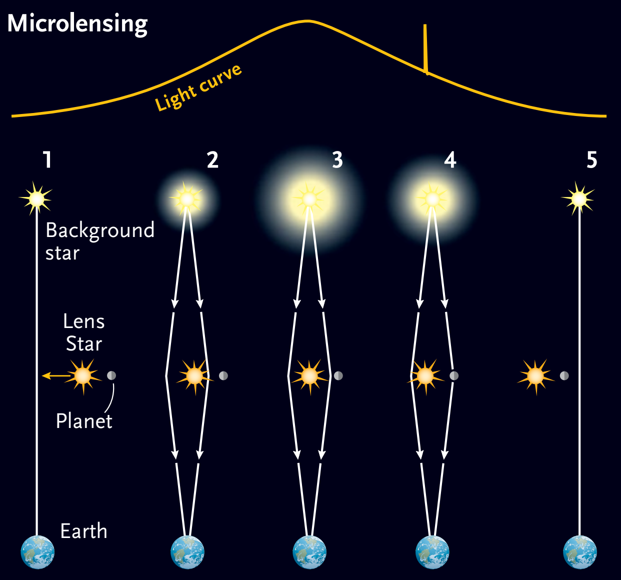
▶ *Are worlds in multi-planet systems mostly coplanar, like the planets in our solar system?*

We don't have enough information to answer this question for most known exoplanetary systems, but we can address it for Kepler's multiple-planet systems, whose worlds must be coplanar or they would not transit the host star. Using some clever tricks, astronomers have found that 85% of Kepler's multi-planet systems are coplanar to within 3°. Several other studies from radial-velocity searches reach a similar conclusion that planets in multiple systems usually have very low mutual inclinations. This implies that the planets formed together inside a disk and did not suffer major gravitational perturbations that would have increased their orbital inclinations.

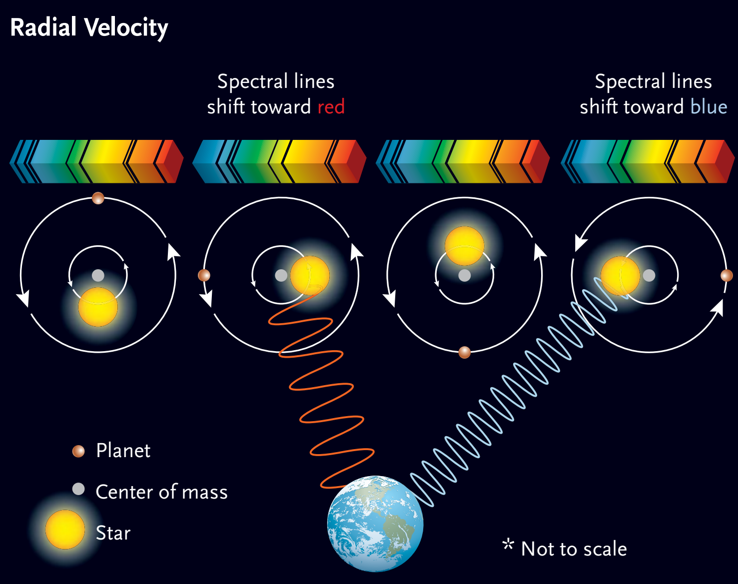
▶ *Why are so many planets in highly elongated orbits, unlike the worlds in our solar system?*

In the late stage of planet formation around some stars, too many large bodies remain to peacefully coexist. The planets suffer close encounters and "scatter" off one another, meaning that strong gravitational interactions can boost the eccentricity (elongation) of planetary orbits. This picture is supported by the fact that Jupiter-mass behemoths in systems with no other detected planets generally have highly eccentric orbits. These worlds appear to be the survivors of scattering events in which one or more

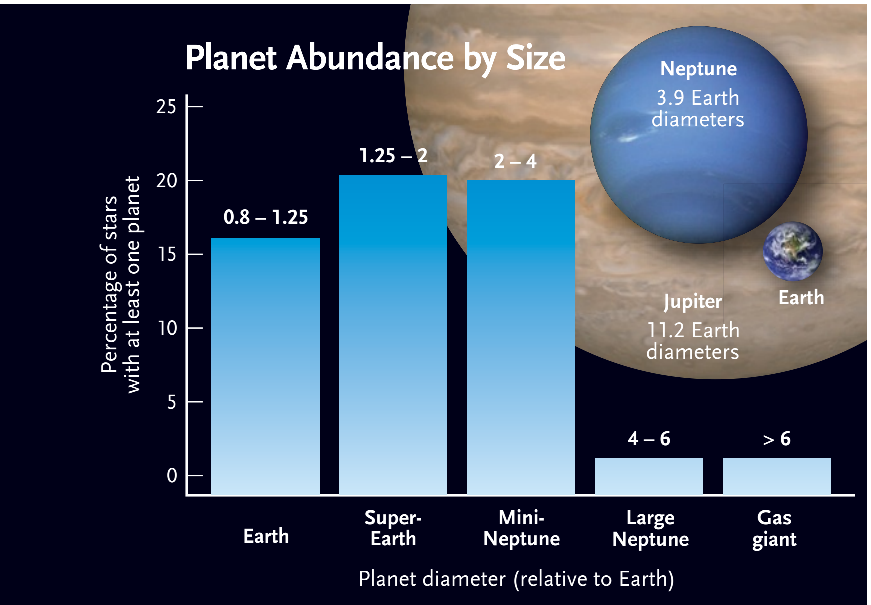
S&T: LEAH TISCIONE (3)



MICROLENSING Einstein's general theory of relativity provides a method for finding planets far from their host stars. The theory predicts that light from a distant star can be gravitationally lensed toward Earth as an intervening star slowly drifts in front of and then away over the course of several weeks. If a sufficiently massive planet orbits the lensing star, its gravity will briefly add to or depress the lensed light. The method requires a near-perfect alignment, astronomers can only make rough estimates of the planet's mass and distance from its star, and follow-up studies are extremely difficult. Astronomers have discovered 20 planets using this method, and have used the results to assess the galaxy's population of planets orbiting stars at large distances.

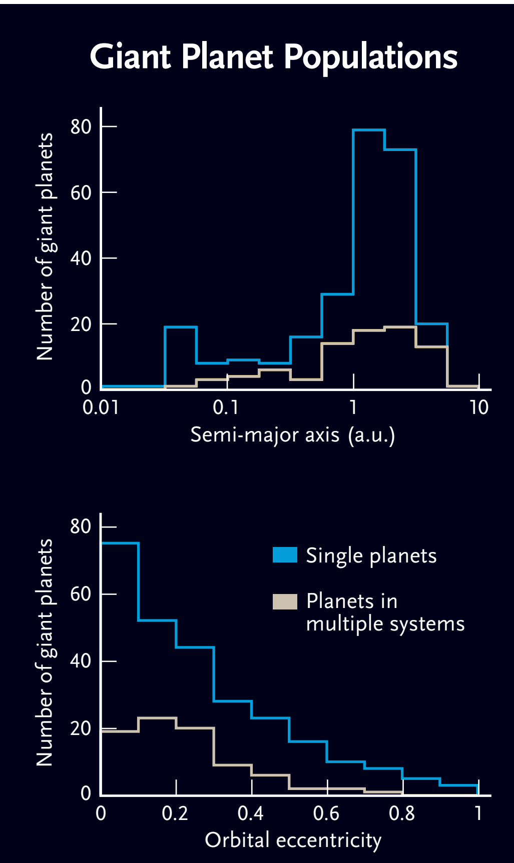


RADIAL VELOCITY Astronomers using the radial-velocity method have discovered more than 400 of the 700 confirmed exoplanets. This technique measures a star's motion toward and away from Earth as it gravitationally responds to one or more orbiting planets, and thus measures a planet's minimum mass (but not its size). This method is more sensitive to high-mass planets and worlds close to their parent star. It can just barely detect Earth-mass planets, and only if they have small orbits. If a planet transits its host star, radial-velocity observations can reveal the world's true mass, and in combination with the diameter measurements from the transits, astronomers can calculate the planet's density, which is a vital clue to composition.



PLANET FREQUENCY For worlds orbiting very close to their parent stars, Kepler has found many more small planets than large planets despite the fact that large planets are easier to detect. Interestingly, worlds between Earth and Neptune in size are very common even though none exist in our solar system.

S&T: LEAH TISCIONE, SOURCE: FRANCOIS FRESSIN (CFA)



GIANTS Radial-velocity surveys have found interesting differences between systems with just one detected giant planet and those with multiple giants. *Top:* Single giants tend to be found either very close to their stars or at distances beyond 1 a.u.; those in multiple systems are more evenly distributed in orbital distance. The drop-off in planets beyond 1 a.u. is due to survey limitations, not a lack of planets. *Bottom:* Single giants are more likely to have high-eccentricity orbits, probably because they survived scattering events that ejected their systems' other original planets.

S&T: LEAH TISCIONE; SOURCE: ANDREW HOWARD (UNIV. OF HAWAII)

planets were ejected into interplanetary space. Planets in multiple systems tend to have lower eccentricities, meaning they probably avoided the game of planetary pinball. Not surprisingly, almost all hot Jupiters (Jupiter-mass planets orbiting their host stars 5 to 10 times closer than Mercury orbits the Sun) have extremely low-eccentricities because tidal interactions with their nearby host stars will circularize their orbits over long timescales.

▶ *How common are hot Jupiters, and how did they end up in their close-in orbits?*

Hot Jupiters are largely responsible for jump-starting the field of exoplanet research. In 1995 the hot Jupiter 51 Pegasi b was the first exoplanet discovered to orbit a Sun-like star. Hot Jupiters have large sizes and masses and have a high probability to transit their star, which make them relatively easy to detect by the transit and radial-velocity techniques. With only a few exceptions, hot Jupiters are the exoplanets with atmospheres currently accessible for observations.

Despite their favorable characteristics for discovery and follow-up study, hot Jupiters are a fairly rare type of planet. Statistical studies point toward an occurrence of only 0.5% to 1% per Sun-like star. Astronomers don't think hot Jupiters formed at their current locations because there's not enough material in planet-forming disks that close to a star. The hot Jupiters most likely formed much farther out and migrated inward to their present locations (May issue, page 26).

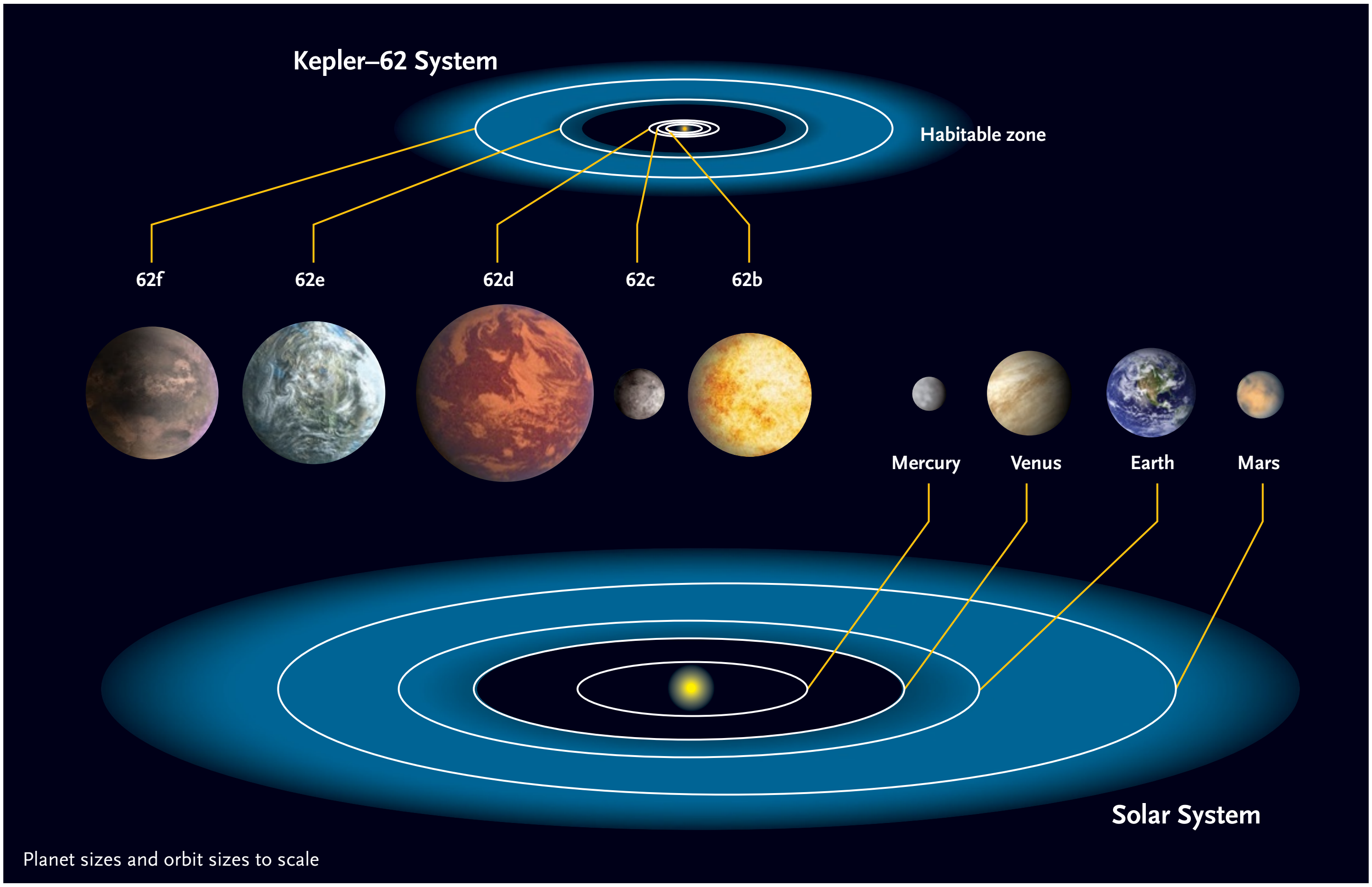
▶ *What physical processes push or drag hot Jupiters inward?*

The two mechanisms that receive the most attention are disk migration and scattering. In disk migration, the planet interacts with the disk material, which robs the planet of angular momentum, causing it to slowly spiral inward. In scattering, a planet gravitationally interacts with another planet or a companion star, causing the inward motion. An interesting clue is that some hot Jupiters have very strange orbital inclinations, orbiting their star in the opposite direction to the star's rotation or in polar orbits. These planets were probably scattered into their current locations.

▶ *What accounts for the wide diversity of exoplanet systems?*

Planet formation has a random element that involves many different processes. For example, numerous planetesimals will form in a protoplanetary disk, but nature doesn't predetermine which one will end up growing to dominate its surroundings.

The diversity of planetary systems may also, in part, reflect a diversity of planet-formation mechanisms. Most planets probably form from the bottom-up mechanism, in which planets accrete around a rocky core. But some gas



S&T: LEAH TISCIONE; SOURCE: NASA / AMES / JPL-CALTECH

COMPACT SYSTEM Kepler has found five planets in the Kepler-62 system. Four of the five are bigger than Earth, yet all orbit within 1 a.u. of the host star. Adding just one planet to this packed configuration would destabilize the entire system and lead to planet scatterings. Kepler-62's planets might have formed in an unusually massive disk.

giants might form in a top-down fashion, in which a large pool of gas inside a disk quickly collapses gravitationally to form a Jupiter-mass planet.

The diversity of systems may also be related to the mass of different protoplanetary disks, which vary widely even for stars of the same type. For example, Kepler has found remarkable systems with two to six planets orbiting within 1 a.u. of the host star. Theorists have suggested that the planets in these compact systems formed at their current locations in disks containing more material than the disk that existed around our Sun.

The diversity of planetary systems should also be affected by planet-migration mechanisms, where planets move through the disk and end up in orbits very different than the ones in which they formed. Astronomers still debate whether planet-planet scattering or planet-disk interactions are more important for shaping the architectures of planetary systems.

▶ *How many "rogue planets" are roaming loose in interstellar space, unattached to stars?*

There are likely a comparable number of planets drifting loose in the Milky Way Galaxy as there are planets orbiting stars: at least 100 billion. Conditions in a young planetary system are often turbulent and unstable, and planets (especially low-mass worlds) can be expelled by strong gravitational interactions with giant planets. We see residual evidence today of these dynamically chaotic early times with the large number of planets on elongated orbits and other planets orbiting far out of their host star's equatorial plane.

Microlensing studies have reported a large population of free-floating giant planets, finding that they are almost twice as common as typical stars. The findings are based on microlensing detections of planetary-mass objects with no signs of a host star, combined with the measured relative rate of lensing caused by stars or planets, microlensing event probability, and microlensing detection efficiency. There's still a possibility that the microlensing method has instead found planets that are so far from their host stars (greater than 10 a.u.) that the host star wasn't detected. But we have supporting evidence that the detected planets are indeed free floating.

▶ What are NASA's and ESA's plans to follow up on Kepler?

A heated competition was just concluded for an exoplanet mission under NASA's Explorer Program, which has a $200 million cost cap. Two missions were considered in the astrophysics category, with NASA selecting TESS (Transiting Exoplanet Survey Satellite). This program, led by my MIT colleague George Ricker, will perform an all-sky survey for transiting super-Earths orbiting bright stars. Launch is scheduled for 2017.

The European Space Agency (ESA) has selected a transit-finding telescope for launch in 2017. CHEOPS (CHAracterising ExOPlanets Satellite) will use high-precision photometry on bright stars to search for transits of planets discovered by the radial-velocity technique but that are not known to transit. ESA is also studying EChO (Exoplanet Characterisation Observatory), a space telescope designed to study exoplanet atmospheres.

NASA has recently announced a study of two different space telescope concepts to image exoplanets directly. These missions would have a cost cap under $1 billion, which may be possible to build within the next decade despite the austere budget environment. They would take pictures of large exoplanets while developing critical technology for the more ambitious task of imaging Earth-size planets and taking spectra to look for signs of biosignature gases.

HOT JUPITER In this artistic rendition, the hot Jupiter HD 209458b roasts in the searing heat of its nearby host star. Although this planet is almost certainly far too hot to support life, observations taken during transits have revealed the ingredients for life — carbon dioxide, methane, and water vapor — in its upper atmosphere.

If large numbers of stars have Jupiter-mass planets, as appears to be the case, our galaxy must be littered with scads of ejected low-mass planets because small planets are more readily flung from developing systems than are giant planets.

▶ *How common are planets in binary-star systems?*

Kepler has recently discovered at least a half-dozen circumbinary planets. The Kepler team estimates that about 1% of binary stars with close separations have a giant planet in a nearly coplanar orbit, yielding a galactic population of at least several million circumbinary planets. Astronomers have yet to detect small planets in circumbinary orbits, so no statistics yet exist for these systems. In addition, no reliable statistics yet exist for planets orbiting a single star in which the single star is part of a binary-star system, although a number of such planets have been found in radial-velocity surveys.

▶ *What are the prospects for finding moons around some of these planets?*

The prospects for finding moons around giant planets is quite high and Kepler once again provides the most promising information. A moon will betray its presence by its gravitational effect on the planet by slightly altering the duration and timing of the planet's transits (*S&T:* July 2009, page 30). Astronomers are poring over Kepler data to look for satellites, but so far they can only preclude the existence of Earth-sized moons around 7 planets that have undergone multiple transits. The occurrence rate for moons will become much clearer in the next few years.

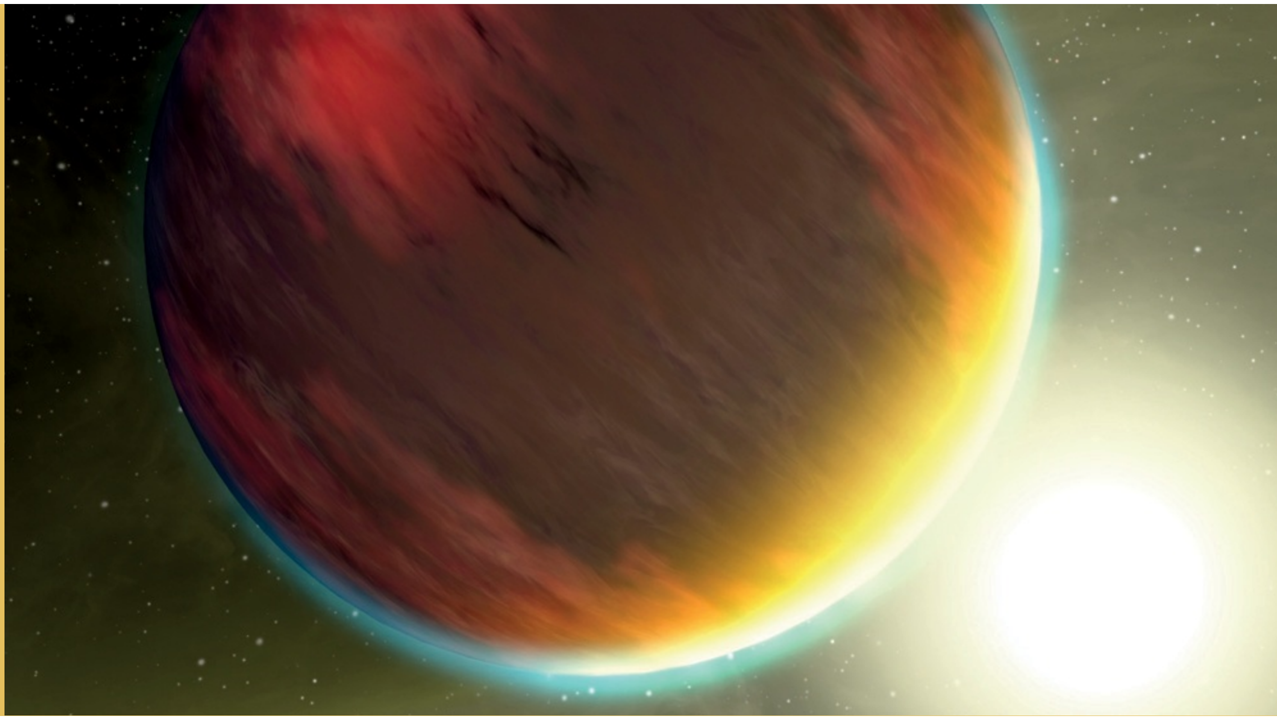
Some astronomers wonder if the moon of a giant planet could be habitable if the planet has the same intense radiation belts as Jupiter. Such radiation might be too harsh for surface life, but underground and oceanic life would be protected.

▶ *How common are Earth-sized planets in habitable zones?*

This is the $600-million-dollar question that Kepler was built to answer. Its most recent data release included dozens of planet candidates in the habitable zones of stars. Although Kepler has probably finished its observations, scientists will still be analyzing its data for years to come, so expect important discoveries in the future.

A recent study focusing on Kepler planets in the habitable zone of *M* dwarfs found an occurrence rate of 0.015 Earth-size planet per star (1 per 67 stars). The researchers further infer that the nearest transiting Earth-size planet in the habitable zone of a cool star is within 95 light-years of us and that the nearest non-transiting habitable-zone planet is within 23 light-years.

Radial-velocity studies have identified about a half-dozen potentially habitable planets within a few tens to hundreds of light-years. But habitable planets have such low masses and their radial-velocity signatures are so weak that many of these planets might not even be real. Astronomers may be reaching the limit of radial-velocity studies for low-mass planets. We may have to get used to ambiguous planet detections by complex data-analysis steps that extract a weak signal very deeply embedded in



NASA / JPL-CALTECH / TIM PYLE (SSC)

noise. Or we'll need to find a way to build a series of large ground-based telescopes to collect far more signal.

Making matters more complex, astronomers are still trying to determine what the habitable zone is. We're realizing that the habitable zone is much broader than we expected and that the habitable zone could be very planet-specific. From Earth, for example, we've learned that greenhouse gases are very powerful, with major climate concerns over adding just tens of parts per million of carbon dioxide. A super-Earth might have an atmosphere more massive than Earth's, with an accompanying strong greenhouse warming. Some super-Earths should have hydrogen-rich atmospheres, and molecular hydrogen can be a very strong greenhouse gas in some cases — warming planet surfaces far from host stars. Due to warming effects of greenhouse gases, the actual habitable zone will vary for each planet, and could range from 0.5 to 10 a.u. for Sun-like stars.

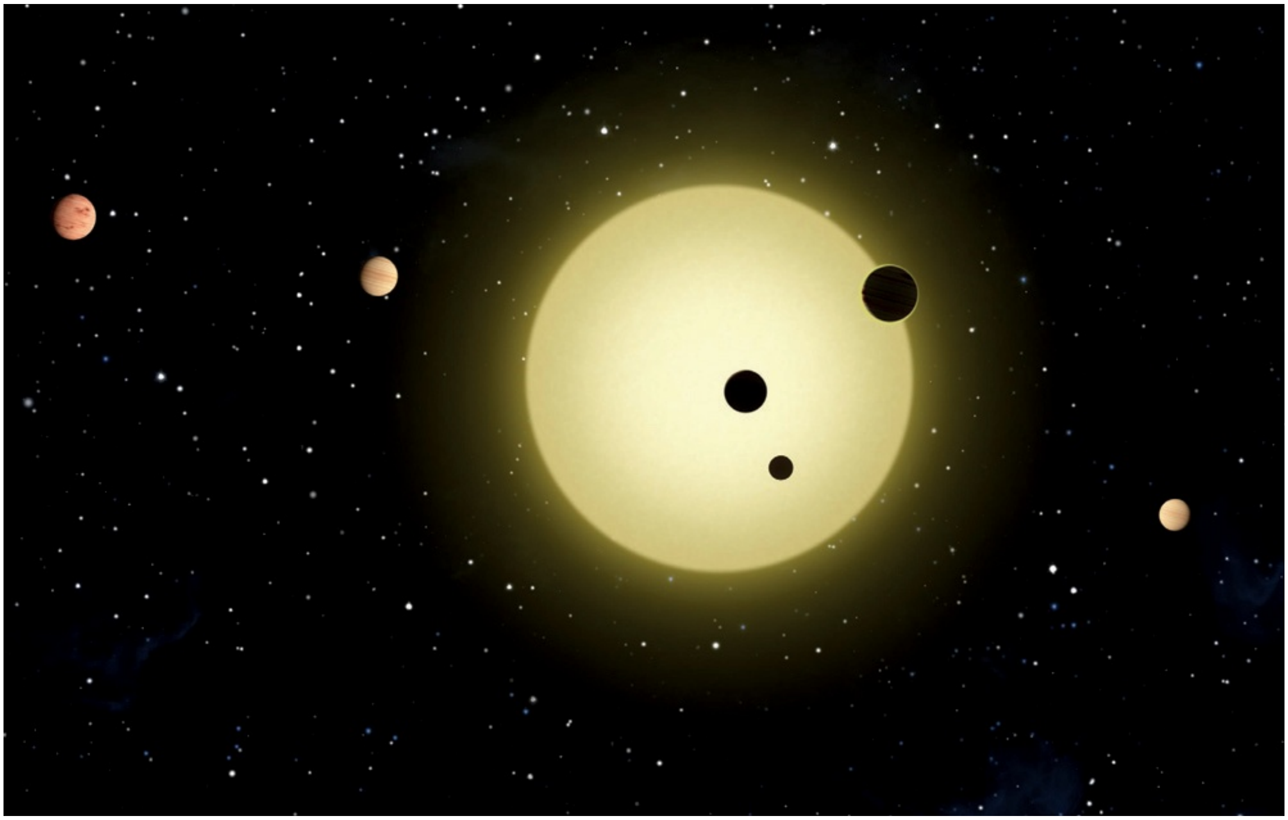
▸ What kind of supportive roles can amateur astronomers play?

Amateurs can support the hunt for exoplanets by helping sift through data or by making telescope observations. With just a computer and internet connection, 250,000 amateurs around the world are participating in Planethunters.org to identify transits in the public Kepler data. These citizen scientists have already found 20 promising planet candidates and one confirmed planet.

Amateur astronomers using a small telescope equipped with a CCD camera can help with searches for transiting exoplanets and searches for microlensing planets. For transit observing, the optimum strategy is to monitor stars with known exoplanets that are not yet known to transit. Although the probability for an individual planet to transit is low, each transiting planet around a bright star is so scientifically valuable that we should follow up all these planets for transit signals. The following two websites list transit times and discuss required equipment and software: http://transitsearch.org and http://brucegary.net/book_EOA/x.htm.

Amateur astronomers can help with microlensing observations by filling in at longitudes where professional astronomers lack coverage. This support enables complete coverage for the duration of planetary microlensing events, which last on the order of half a day. Such coverage is necessary to derive planet parameters such as mass and separation.

For the Microlensing Follow-Up Network (microFun) consortium, visit www.astronomy.ohio-state.edu/~microfun.


NASA / TIM PYLE

SIX-PLANET SYSTEM Artist Tim Pyle depicts the six known planets in the Kepler-11 system. They range between 2 and 4.5 Earth diameters, and they all orbit their Sun-like star inside the distance at which Venus orbits our Sun. The six planets also orbit the star in nearly the same plane (just like our solar system's major planets), which explains why all six have been seen to transit.

▶ *How common are life-bearing planets?*

With Earth as our only example of a planet known to harbor life, we currently have no data to enable us to answer this profound question, although Kepler's findings that small planets are extremely common give us reason for optimism. We're also encouraged by the fact that the ingredients for life — in the form of organic molecules — have been observed in interstellar space. With at least 100 billion stars in our Milky Way Galaxy and more than 100 billion galaxies in our observable universe, extraterrestrial life surely exists somewhere. We just hope that a life-bearing exoplanet exists within 30 light-years of the Sun so future telescopes will be able to study their atmospheres and enable us to make inferences about biology beyond Earth (*S&T:* August 2010, page 20).

To watch a video interview with author Sara Seager, visit skypub.com/seagerinterview.

▶ WHAT TYPES OF STARS ARE MOST LIKELY TO HOST PLANETS?

Studies show that stars with a high abundance of heavy elements are more likely to host giant planets (*S&T:* April 2011, page 22). This is strong evidence that most Jupiter-mass worlds form by accreting gas around a rocky core. Small planets are being found around stars with a broad range of heavy-element abundances. — ***Robert Naeye***

▶ *What are the biggest lessons we have learned from all the exoplanet discoveries to date?*

Astronomers have discovered planets of almost all detectable masses, sizes, orbits, and system configurations. Planet formation involves random processes, and planets can migrate from their original orbits. We have learned that for exoplanets, anything is possible within the laws of physics and chemistry. ✦

Sara Seager *is a professor of planetary science and professor of physics at that Massachusetts Institute of Technology. In addition to her research on exoplanets, her team is building a series of CubeSat nanosatellites, including ExoplanetSat, a space telescope with an 8.5-cm lens to search for transiting exoplanets around the nearest Sun-like stars.*

The Women Who Created Modern Astronomy

Three Harvard "computers" established our current understanding of the stars.

John Dvorak

ALL IMAGES FROM THE HARVARD COLLEGE OBSERVATORY UNLESS OTHERWISE CREDITED

Astronomers have long classified stars with a puzzling sequence of letters: *O*, *B*, *A*, *F*, *G*, *K*, and *M*. Not only are the letters out of alphabetical order, but most are missing. Yet random as it seems, this classification system forms the basis for our understanding of the stars.

The original sequence ran in a more logical order from *A* to *P*, but as letters were dropped, consolidated, and reordered, the sequence came to order the stars by their mass and temperature, from the most massive, white-hot *O* stars to the dim, red *M* dwarfs.

But the astronomers who studied the stars a century ago didn't have the benefit of knowing the stars' physical characteristics. As photography revolutionized observations, three talented, underpaid, and under-recognized women distinguished stellar types based solely on subtle hints in their spectra. In doing so, they laid the foundations of modern stellar astrophysics.

Early Classifications

In 1814 Joseph von Fraunhofer pointed his spectroscope at the Sun, wondering whether he might glimpse the same bright orange line he had detected while examining his lamplight. Instead, he saw hundreds of dark lines marring the solar spectrum. The lines remained a mystery until German physicist Gustav Kirchhoff, working with chemist Robert Bunsen, proposed that the dark lines revealed the Sun's composition as elements in the solar atmosphere each absorbed spectral slivers of sunlight.

Astronomers around the world rushed to apply Kirchhoff's conclusion to the stars. One of the first and most enthusiastic astronomers to do so was Father Pietro Angelo Secchi of the Vatican Observatory. With a large glass prism placed over the objective lens of the Vatican's 9-inch equatorial telescope, Secchi peered through the eyepiece. He thought he might see a variety of spectra as countless as the stars themselves, but instead the stars fell into a few basic types.

Facing page: Williamina Fleming stands at the center of a group of Harvard human computers circa 1890. Two women are using magnifying glasses to examine glass plates; a third woman is using a microscope. The light curve of variable star Beta Aurigae hangs on the back wall. _Below, left to right_: Father Pietro Angelo Secchi, Lewis Rutherford, William and Margaret Huggins, Giovanni Battista Donati, and Henry Draper all aimed to classify the stars.

By 1877 Secchi had examined the spectra of about 4,000 stars, painstakingly drawing some of them by hand. Ultimately, he divided them into five types. Blue-white stars such as Vega and Sirius made up Type *I*. These stars showed only a few wide, dark bands, which Secchi knew were due to hydrogen absorption. He used Type *II* for yellow stars, including Capella and the Sun, whose spectra display many fine lines. Types *III* and *IV* contained red stars; how their lines graded into bands distinguished the two types. Secchi also added a fifth type to account for stars with bright rather than dark lines in their spectra.

Secchi's work was soon widely applied, but he wasn't alone in classifying the stars. Lewis Rutherford in the United States, William and Margaret Huggins in England, and Giovanni Battista Donati in Italy each used different equipment and observing techniques to examine and classify the stars. The initial study of stellar spectra was based solely on visual inspection, so it was difficult, if not impossible, to compare separate works.

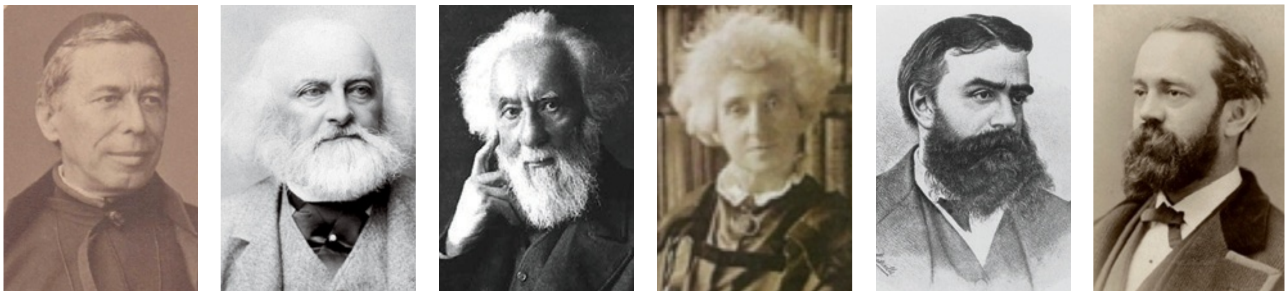
Enter astrophotography — and a wealthy New Yorker.

The Draper Memorial Fund

The first person to photograph the dark lines of a stellar spectrum was Henry Draper, who by reputation, as well as in fact, had the best combination of astronomical and photographic equipment in the U.S. On August 8, 1872, he photographed Vega through a 28-inch Cassegrain telescope of his own design and manufacture, showing four prominent hydrogen lines. No one would match this achievement for four years, by which time Draper had photographed the spectra of several dozen more stars.

In 1882 he resigned his professorship at New York University to devote himself to taking photographic spectra and classifying the stars. But that dream came to an abrupt end later that year when Draper died suddenly of lung disease at the age of 45, leaving his widow, Anna Palmer Draper, to take up the cause.

Anna Draper had worked closely with her husband, recording observations, mixing chemicals, and preparing photographic plates. Anna and Henry had even chosen the glass for the 28-inch mirror together during a shopping expedition they called their "wedding trip." Now, after his death, she intended to continue their work by establishing a new institution, one devoted entirely to the collection and study of stellar spectra. Edward Pickering,



Edward Pickering poses with the Harvard computers on May 9, 1913. The second woman to the right of Pickering is Annie Jump Cannon.

a close friend and director of the Harvard College Observatory, suggested that if she were to fund a laboratory at Harvard, the work could commence immediately.

Anna Draper established the Henry Draper Memorial on February 14, 1886, in honor of her husband. The memorial fund helped keep Harvard College Observatory at the forefront of astronomical research for more than half a century, and the end result would be several large catalogs of stellar spectra still in use today. But for the work to proceed, someone had to devise a better way of classifying the stars.

From A to Q

As was common in that era, there was a clear division of labor by gender at the observatory. Roughly half a dozen men did the physically demanding work of operating the telescopes and taking the photographs, while the women, who in the 1880s were about equal in number to the men, worked exclusively during the day, examining the photographs and cataloguing what they saw.

Even before the Draper Memorial had been established, Edward Pickering was already photographing the stars, and a woman named Williamina Fleming had developed a reputation for her keen eye when inspecting the glass plates. Fleming started out working as a maid in Pickering's house before Pickering noted her quick mind and hired her full-time in 1881, at the age of 24, for "copying and ordinary computing." Before long, Pickering had given Fleming the job of classifying stellar spectra.

The photographic spectra for *The Draper Catalogue* were taken with essentially the same setup Secchi used. A glass prism placed over the objective lens of a refracting telescope allowed the spectra of an entire field of stars to be recorded on a single photographic plate. Each plate measured 8 × 10 inches, covering an area of the sky equal to twice the bowl of the Big Dipper. A five-minute exposure revealed the spectra of hundreds of stars.

At first, Fleming tried to apply Secchi's five stellar types, but she discovered that she was seeing much more detail than Secchi. She kept the same sequence Secchi had used, that is, blue-white, yellow, and red stars, but she subdivided Secchi's five types into 13 classes, indicated by upper-case letters. The letters *A*, *B*, *C*, and *D* were used for Secchi's Type *I*, *E* through *L* for Type *II*, *M* for Type *III*, *N* for Type *IV*, and *O* for Type *V*. She omitted the letter *J* because it could not be easily distinguished from the letter *I* in German publications. Fleming also added additional classes: *P* for planetary nebulae and *Q* for stars with spectra not included in the other classes.

After years of work, during which Fleming examined 28,266 spectra recorded on 633 photographic plates for

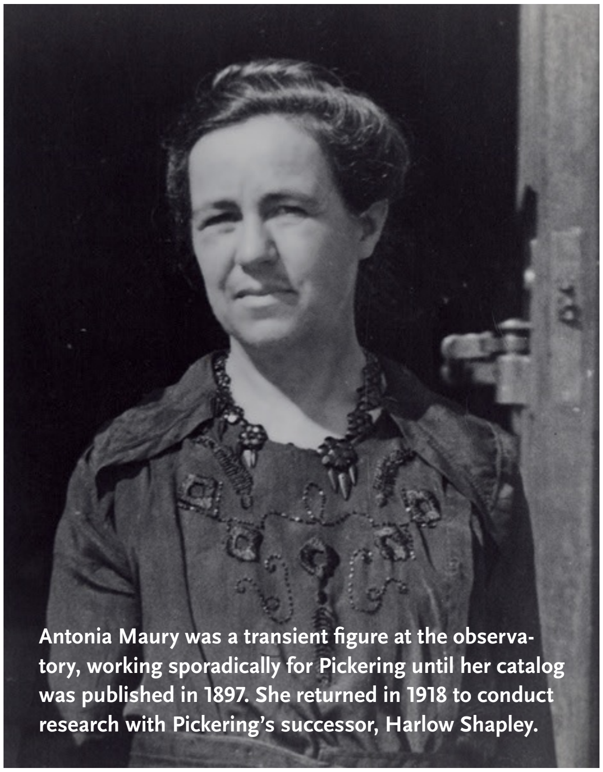
10,351 stars, the Harvard College Observatory published its first catalog of photographic stellar spectra in 1890. Yet even before this work was published, another catalog was being prepared.

B Before A

On the glass plates Fleming studied, the spectra measured ½-inch long and 1⁄32-inch wide. She lengthened the spectra by a factor of five using a magnifying loupe, allowing her to see many more lines than she could with her unaided eye. Moreover, additional lines would be revealed if spectra could be made at higher dispersion.

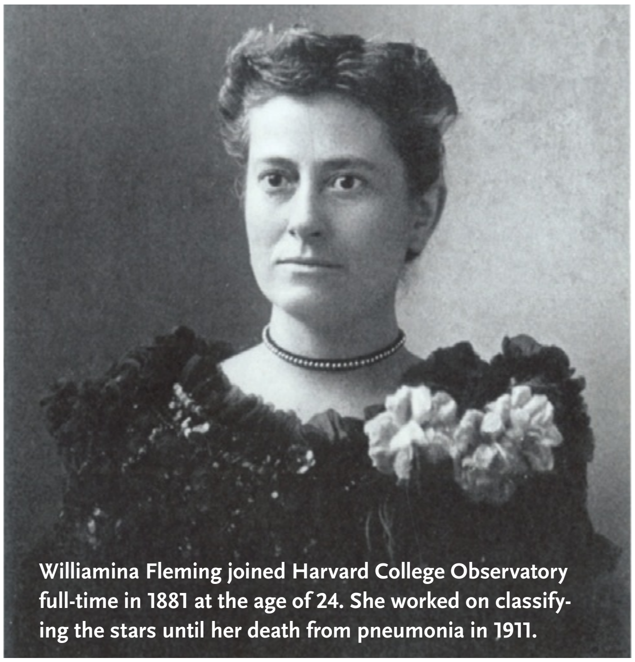
Soon new plates were being taken with as many as four prisms attached to the telescope. With the addition of each prism, the light of individual stars spread over a larger area, producing longer, clearer spectra for the brighter stars. The resulting photographs recorded an amazing amount of detail. Henry Draper had recorded only four dark lines in the original photograph of Vega; now hundreds more were revealed. After ordering a second set of photographic plates with high-dispersion stellar spectra, Pickering hired another woman to study them.

Antonia Maury, the late Henry Draper's niece, had just graduated from Vassar College, where she studied astronomy under Maria Mitchell, the most famous woman scientist in the U.S. at the time. When Maury applied to the observatory for a position, Pickering was at first reluctant to hire her, writing that the type of work done by women at the observatory was too routine for a college graduate. But Maury persisted, anxious for the opportunity — one of the few available to women in astronomy in the late 19th century. She was hired in June 1888 and began making important contributions almost immediately.

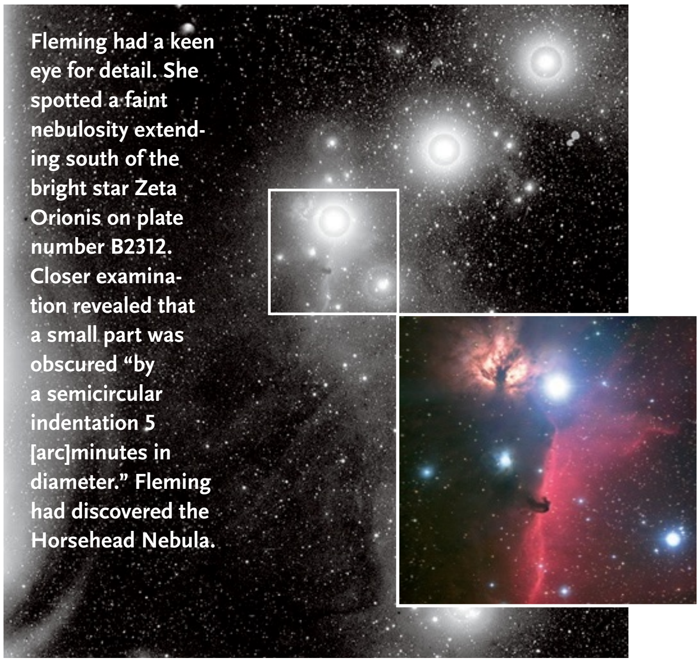


Antonia Maury was a transient figure at the observatory, working sporadically for Pickering until her catalog was published in 1897. She returned in 1918 to conduct research with Pickering's successor, Harlow Shapley.

Under Pickering's direction, Fleming had followed an empirical approach to classifying stars; she considered the presence or absence of specific lines, such as the hydrogen lines, in a stellar spectrum. But she disregarded what a spectrum might reveal about a star's physical characteristics. Maury disagreed with this method. She was deeply interested in the meaning of stellar spectra, and she especially wondered about the importance of the Orion lines.



Williamina Fleming joined Harvard College Observatory full-time in 1881 at the age of 24. She worked on classifying the stars until her death from pneumonia in 1911.



Fleming had a keen eye for detail. She spotted a faint nebulosity extending south of the bright star Zeta Orionis on plate number B2312. Closer examination revealed that a small part was obscured "by a semicircular indentation 5 [arc]minutes in diameter." Fleming had discovered the Horsehead Nebula.

NIGEL SHARP / NOAO / AURA / NSF

In Fleming's classification, an *A* star displayed only hydrogen absorption lines in its spectrum, while a *B* star also displayed prominent Orion lines, named after the absorption lines found in many stars near the Orion constellation and later discovered to come from the element helium. Maury examined plates showing spectra with many more lines than the ones Fleming had studied, so Maury could see subtle differences between stars that were in a single class in Fleming's system. Using a microscope instead of a glass lens, Maury realized that a decrease in the intensity of Orion lines was accompanied by a gradual increase in the intensity of the hydrogen lines. The only way to smooth this transition was to place *B* stars before *A* in Fleming's original sequence.

Maury published her catalog of stellar spectra in 1897, introducing a new classification system with 22 groups, six more than Fleming had used. Numbered in Roman numerals from I to XXII, the sequence ran parallel to Fleming's alphabetic sequence, except for classes *A* and *B*, which were reversed. Maury also introduced three subdivisions, *a*, *b*, and *c*, for spectra with medium, wide, and narrow lines, respectively.

Pickering thought the introduction of subdivisions unnecessary, but Maury defended her scheme, arguing that it represented a fundamental property of the stars. In the end, she was right. Danish astronomer Ejnar Hertzsprung discovered years later that Maury's *c*-subdivision separated normal red stars from luminous red giants, a discovery he attributed to Maury's sharp eye in distinguishing stellar spectra. To ignore the *c*-subdivision, he said, would be to classify fish with the whales.

Maury was clearly far in advance of her time, but she disagreed with Pickering over her role at the observatory, and whether the observatory should be involved in the interpretation of stellar spectra. In 1891 she left Harvard College Observatory for several years to accept a series of

Left: The Harvard College Observatory houses more than 500,000 glass plates taken between 1890 and 1990, including several thousand spectral plates. This photo shows the old storage system, before the plate stacks were modernized to protect a century of data from fire and earthquake damage. _Bottom_: This view from the southeast shows the Harvard College Observatory as it stood when Edward Pickering was director.

Left: **A portrait shows Annie Jump Cannon in full regalia after she was named the William C. Bond Astronomer at age 74, two years before her retirement. Cannon was the second woman to be appointed a professor on the Harvard faculty.** ***Right***: **Cannon, shown here in the 1930s, demonstrates how astronomers examined glass plates before electricity allowed the use of light boxes; glass plates were held in a wooden frame near a window to be examined with a magnifying loupe.**

teaching jobs, returning sporadically to finish her work on spectral classification. She and Pickering published the catalog in 1897 during a time when the importance of *O* stars was becoming apparent. Even as she left them in last place in Group *XXII*, she suggested the class might play a special role in understanding the overall sequence.

O Before B

When Pickering ran a statistical study on the stars in the 1890 catalog, he found that 99.3% fell into six classes — *A, B, F, G, K*, and *M*. So as Fleming prepared another catalog of stars in clusters such as the Pleiades, she and Pickering decided to eliminate most of the original stellar classes.

Many classes were in error or redundant. Stars in class *C*, those with double hydrogen lines, were dropped when those double lines did not appear on spectra taken at higher dispersion and with better photographic plates. And the spectra of *H, I,* and *K* stars were enough alike that all three classes were combined into class *K*. Classes *E* and *G* were similarly grouped together, "since the difference is probably in the intensity of the photographic image rather than in the stars themselves," Pickering wrote.

But that still left the mysterious *O* stars, which display both dark and bright lines. At one point, Pickering merged *O* stars with planetary nebulae in class *P*, because spectra in both classes showed bright lines. But after Pickering hired another woman to study stellar spectra, the *O* class was soon resurrected.

Annie Jump Cannon had been valedictorian of her class at Wellesley College. She studied under Sarah Whiting, one of the few women physicists in the country and a close friend of Pickering. Following a childhood interest, Cannon enrolled at Radcliffe College as a special student in astronomy before joining the observatory in 1896.

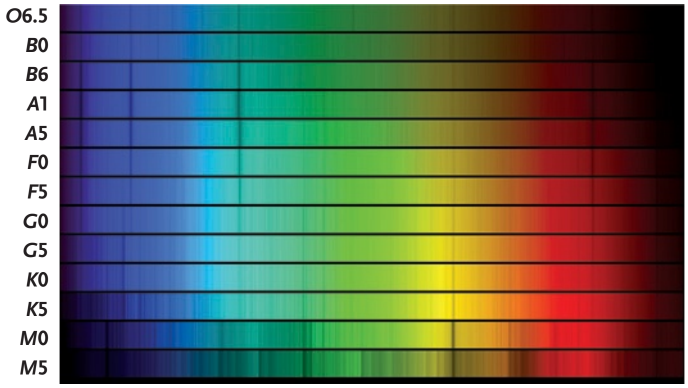
And Cannon would have a new set of plates to examine. After recording the spectra of stars visible from Cambridge, Pickering had sent telescopes, equipment, and people to South America and South Africa to produce a collection of plates for the southern sky.

Out of more than 10,000 stars in the 1890 catalog, only one was identified as class *O*; Maury published only 3 more. But Cannon discovered several in the southern sky.

Pickering, who also studied the glass plates, noticed two bright lines and several dark lines associated with the southern *O* star Zeta Puppis. The pattern of dark lines was reminiscent of the well-known Balmer series, lines caused by hydrogen absorption, but Zeta Puppis's dark lines lay at different wavelengths. Years later lab experiments would show that the lines of the so-called Pickering series are due to absorption from singly ionized helium. But long before that realization, Cannon saw that these lines would be key to placing *O* stars at the front of the spectral sequence.

Cannon was examining the highest-quality photographic plates yet, so she saw line patterns that wouldn't have been visible to Fleming or Maury. In addition, she had many more bright stellar spectra available for study. For these reasons, Cannon identified more subdivisions than Maury — prompting her to add a number from 0 to 9 to the lettered stellar classes — and she identified more transitional stars as well.

Of particular note was the 5th-magnitude star 29 Canis Major. Cannon recognized in its spectrum both the Picker-



NOAO / AURA / NSF

These stellar spectra, taken with the Kitt Peak National Observatory's 0.9-meter telescope, show stars with different classifications. The arrangement from *O*-type to *M*-type shows a continuum of changes in the visible spectrum at wavelengths from 400 to 700 nanometers.

ing series, which identified it as an *O* star, as well as the strong Orion lines normally associated with *B* stars.

"Thus it happened again that the natural order of the alphabet must be broken," Cannon wrote in "The Henry Draper Memorial" in 1915, "for *O* was then placed before *B* in the stellar sequence."

OBAFGKM

By 1901, the year Cannon published her first catalog of stellar spectra, astronomers were using nearly two-dozen stellar classification schemes. Admittedly, most were revisions or refinements of earlier work, including those developed at Harvard, but the many systems led to confusion.

For example, the star Procyon was Type *II* according to Secchi, Class *F* to Fleming, Group *XIIa* to Maury, and Class *F5* to Cannon. Other astronomers, using their own classifications, listed the star as Type *Ia*3 or Division *III* or as representing an entire class known as Procyonian. Obviously, a single system had to be adopted, but which one?

European astronomers were especially harsh in criticizing the Harvard work as having too many classes. "The most frightful confusion," was how Julius Scheiner, director of the Potsdam Observatory in Germany, assessed the Harvard system. He wondered whether, as better stellar spectra were obtained, astronomers would eventually put every star into a class of its own.

But Harvard had an advantage over the other observatories. By the beginning of the 20th century, the women of Harvard had classified at least 30,000 stars, more than five times as many as those classified using all other systems combined.

In September 1910, at an international meeting of astronomers held in Pasadena, California, Pickering led an afternoon session to discuss stellar classification. Of the 83 in attendance, 46 (including Fleming) came from American institutions, 9 from France and Germany, and 8 from Great Britain. Pickering was greatly relieved that Cannon's system received little opposition. The meeting gave "the strongest endorsement I could have desired," he wrote later in a diary.

But notable people were missing from the meeting, so a questionnaire was distributed to solicit a wider opinion. Of the 28 questionnaires returned from astronomers in seven different countries, only Scheiner voiced a strong opinion against adopting Cannon's system. But Scheiner became gravely ill and was unable to attend the next major international astronomy meeting in 1913, this time in Bonn, Germany. A resolution passed at the meeting tentatively adopted Cannon's system. Scheiner died four months later.

Finally, at the first General Assembly of the International Astronomical Union in May 9, 1922, the IAU passed a resolution to formally adopt Cannon's stellar classification system. The same resolution included a provision to use Maury's *c* subdivision for stars with narrow, sharply defined lines. With only minor changes, the Harvard classification is still in use today. ✦

John Dvorak *operates a telescope at Mauna Kea for the Institute for Astronomy, University of Hawai'i.*

To learn more about the digitization project that will make new use of Harvard's century's worth of glass plates, visit skypub.com/DASCH.

Classifying Failed Stars

In 1995 astronomers discovered the first bona fide "brown dwarf," an object cooler than the coolest *M* star. Incapable of sustaining hydrogen fusion, these "failed stars" continued to turn up in infrared surveys. It soon became clear that Cannon's stellar classification system would have to be extended. But with what letters? Only *H*, *L*, *T*, *Y*, and *Z* were available at the time — Cannon's system already used *O*, *B*, *A*, *F*, *G*, *K*, and *M*, and other letters could be confused with other astronomical conventions.

J. Davy Kirkpatrick (Caltech) and his colleagues argued in 1999 that *L* would be the best choice because it's closest to *M*. The discovery of even cooler brown dwarfs prompted the addition of *T* and *Y*. *Z* was rejected because it implies the last class, which, in the words of Adam Burgasser (University of California, San Diego), "is probably a bit presumptuous."

Astronomers regularly use these classifications as they conduct research, but the International Astronomical Union hasn't officially adopted the *LTY* extension yet. That gives schoolteachers time to come up with a follow-on to "Oh Be A Fine Girl/Guy, Kiss Me!"

— *Camille M. Carlisle*


The Original And The Best!
1000+ Under the Stars!
"First Light!"
- Ron W., 15" UC, Clummington, MA
"The 15" UC is absolutely amazing, everything worked perfectly."
• Portable Alt-Az • Superb optics
• Ultra-smooth easy operation
• Exceptional craftsmanship
• A scope for every serious observer: 12" • 15" • 18" • 20" • 25" apertures
Send For the Obsession DVD & Brochure
NEW UCs
Ultra Compact
15", 18", 22" - f/4.2
OBSESSION TELESCOPES™
PO Box 804s, Lake Mills, WI 53551 (920) 699-5571
www.obsessiontelescopes.com
See it on-line
Fits in any car


ADORAMA
MORE THAN A CAMERA STORE
adorama.com
42 West 18th St.
New York City, 10011
800.223.2500
Adorama's Un-Beatable Service
CLICK BY 6 IT SHIPS
SAME DAY SHIPPING
ON ORDERS PLACED BY 7PM MON-THU, FRIDAY BY 1PM EST
for details visit adorama.com
MEADE
LX80 Multi-Mount with 8" SC OTA
The Meade LX80 8" SC package includes a Meade Series 4000 26mm eyepiece, 8x50 viewfinder with quick release dovetail mount
NEW
STARTING AT
$1499.00
PREMIER SELECT CELESTRON DEALER
NexStar 8 SE
Schmidt-Cassegrain Telescope, Special Edition Package with Orange Tube & XLT Coatings
STARTING AT
$1199.99
GoodBuy 2012 Sale
From Your Friends at Tele Vue
Oct. 1st to Dec. 28th
10% Off Sale
Eyepieces, Powermates, Barlows & Paracorr!
Vixen Optics
35505 Polarie Star Tracker
Astrophotography Compact Mount.
$429.00
AstroTrac
TT320X-AG Tracking Mount
With Auto-Guiding port for Digial SLR Cameras includes Astro Trac Illuminated Polar Scope, 12 Volt Car Battery Adapter
Big Discounts
Telrad
Starry Night
FUJINON
Thousand Oaks Optical
STAR-SOUND
SBIG
ZEISS
EXPLORE SCIENTIFIC
Vixen Optics
Rigel Systems
KENDRICK ASTRO INSTRUMENTS
Apogee
tasco
LUMICON
SWAROVSKI
WE CARRY THE COMPLETE LINES OF: QSI, SBIG, Apogee and ATIK CCD's
Check our web site for a full line of:
• Photography,
• MP3 Players,
• Computers,
• Home Office,
• Printers,
• Video,
• Photo Lab,
• Etc.
SONY
Nikon
FUJIFILM
Panasonic
Canon
SAME DAY SHIPPING on orders placed till 7:00pm on Mon-Thur, Friday on orders placed till 1:00pm for all in-stock items. FREE SHIPPING on thousands of items! Plus, Adorama protects you more than ever with our 30-DAY MONEY BACK guarantee! Shop with confidence and rest assured. For complete details, call 800.223.2500 or visit adorama.com
Store Hours
Sunday 9:30am - 5:00pm
Mon-Th 9:00am - 8:00pm
Friday 9:00am - 2:00pm
Saturday Closed
BBB ACCREDITED BUSINESS


SPECIAL EDITION
Top Scientists Confront Astronomy's Toughest Questions
Sky & Telescope Presents
Astronomy's 60 Greatest Mysteries
On Newsstands Now
Will the expanding Sun engulf Earth?
How did our universe originate?
How common are life-bearing planets?
Are we alone?
Is time travel possible?

The New SOCIAL FACE of Astronomy

Join the revolution that's forging new connections between amateur astronomers. David Dickinson

Social media is swiftly changing the way our society interacts, a shift that has in turn transformed the astronomical community. A properly tailored social-media feed connects observers with real-time information about the latest comet discovery, satellite launch, or nova flare-up — even when much of what the social-media universe shares is no more consequential than cat pictures or what someone ate for breakfast.

We're getting our news from social media more than ever before, and as often as not, the news is coming from others like ourselves. We can even reinvent ourselves via social media. A Facebook, Twitter, or Google+ account grants anyone an instant, self-designed web presence; no site maintenance or hosting is required.

Of course, online communities have their share of drawbacks. Mark Twain supposedly said, "A lie will go round the world while the truth is pulling its boots on." Nowhere is this more apparent than the internet. Sorting through online news in general, and social media in particular, often means applying your own judgment to separate fact from fiction. Though many of the blog-

CATCHING A LAUNCH Author David Dickinson managed to shoot Space Shuttle *Discovery*'s takeoff on April 5, 2010, after his Twitter feed notified him that launch was imminent.

NASA / PAUL E. ALERS

GOING SOCIAL **Social-media connections translate to real life. A follower holds up her mobile device while listening to NASA Administrator Charles Bolden, left, and Kennedy Space Center director Robert Cabana speak at a NASA Social event on May 19, 2012, at Kennedy Space Center in Florida.**

gers participating in the fast-paced science-news cycle are professional scientists and astronomers, others have less regard for accuracy. Recycling old news or images is typical of internet fakery. For example, who hasn't received that e-mail this (and now apparently every) August from a well-meaning friend or family member saying, "Mars will be as big as a full Moon"?

One rule will help you spot most fakes: if it looks too good to be true, it probably is. The same discerning eye that can spot a 14th-magnitude nova soon learns to sort the gold from the gravel, picking out the bona-fide meteor fireball or satellite reentry videos from recycled footage of the 2001 reentry of *Mir*.

Even online forums and RSS alert services are giving way to social media. In 2007 I first heard Comet 17P/Holmes was brightening via an RSS news feed, just hours after a Japanese observer reported the observations. Five years later, my Twitter feed informed me of the September 21st UK fireball within minutes after it streaked across the sky. Contrast both of these cases with 1983's close passage of Comet IRAS-Araki-Alcock past Earth — many observers heard about it only weeks after it occurred.

Astronomy enthusiasts can take advantage of the lightning-fast social-media world with a few tips and tricks in hand.

Tweeting Astro News

Twitter is the ideal social source for fast-breaking news. You don't have to create an account to peruse the site, but you'll need to register to receive regular updates. You can search for a particular topic using "hashtags," keywords marked with the "#" symbol that help focus the conversation and filter out the noise. Popular examples of hashtags that astronomers might use include #Perseids, #astrophotography, and #comets. Anytime you use a hashtag in your own posts, think of it as broadcasting your message to a select group of (temporary) followers. You can also use the address symbol "@", say, @NASASocial, if you want to tweet a message not only to your own followers but also to the addressee.

Since all conversations on Twitter are public, everyone following you, or those tracking your hashtags, will see what you have to say. The only way to communicate privately is to send a direct message (DM), and you can only send DMs to people following you.

But keeping the conversation public is what Twitter's all about. You can follow anyone from professional astronomers to astronauts to science writers. It might be tough to ask a question in real life to figures such as science popularizer Neil deGrasse Tyson or Chris Hadfield, the commander of the International Space Station (ISS), but celebrities tend to be more approachable on Twitter. I've struck up relationships with professional astronomers and science writers, such as Mike Brown (@plutokiller), Phil Plait (@BadAstronomer), and Nick Howes (@NickAstronomer). And if you run into one of those characters who insists an alien Elvis abducted them last night, you can use the convenient Unfollow and Block features.

Updates on anything from gamma-ray bursts to newly released astrophysics papers can be found via Twitter (see page 41 for some suggestions). Users worldwide share information about sky events such as eclipses and meteor showers in real-time, and some observatories even automatically tweet every object they observe.

Twitter also serves as the base for astronomy projects, such as the meteor-tracking Twitter group Meteorwatch (@VirtualAstro). British science writer Adrian West started the innovative program so observers could tweet meteor activity in real-time. It's currently more of a public outreach initiative than a scientific endeavor, but it opens the possibility of data-mining Twitter for real-time meteor information, much like automated programs have tracked flu outbreaks and earthquake activity.

Satellite-tracking is another Twitter specialty. The automated ISS tracker @Twisst, for example, notifies you hours before an illuminated nighttime pass of the ISS becomes visible from your location. To set up the service, you'll need to add your general location to your Twitter profile. There's just one place where the tracker hasn't worked — when ESA astronaut and Twisst user André Kuipers was aboard the ISS, Twisst sent him a message saying, "We don't understand where you are right now!"

"When the ISS is visible over many populated areas, I send over 30,000 tweets per day," notes Dutch freelance journalist Jaap Meijers, who launched the service in 2009. "Last year, Twisst sent out a total of 6.5 million tweets."

Twisst is part of a growing community of satellite and space-launch trackers. Some users track upcoming reentries in an effort to spot satellites on their final

@NASASOCIAL NASA Deputy Administrator Lori Garver, in the yellow jacket, stands with NASA Social participants on May 18, 2012, underneath the engines of a Saturn V rocket. About 50 NASA Social followers attended activities surrounding the launch of SpaceX's Falcon 9 rocket in a demonstration mission to the International Space Station.

NASA / PAUL E. ALERS

passes. High-profile reentries of spacecraft such as the Upper Atmosphere Research Satellite and Russia's failed Phobos-Grunt mission sparked Twitter efforts to observe them worldwide.

NASA in particular has made good use of Twitter, tweeting from nearly 500 accounts and winning several Shorty awards ("honoring the best in social media") over the years. Nearly every mission from the Voyagers to New Horizons has an official account, including Curiosity, Juno, Dawn, and Messenger.

NASA also runs a program where social-media participation can earn you real-world access to space-related events. The first NASA Tweetup took place at the Jet Propulsion Laboratory in California in 2009, and the event was so popular that the concept, now called NASA Socials (@NASASocial), was expanded to include other forms of social media. Recent events include SpaceX's October 2012 and March 2013 Dragon launches to shuttle cargo back and forth from the ISS. When the second resupply mission experienced problems shortly after launch, news of the drama flooded through Twitter within minutes.

This example is just one demonstration of how social media has swiftly become an integral and permanent part of the news cycle. But for me, Twitter's most exciting facet is its open forum, which fosters a growing international observing community. By allowing me to share and receive real-time sat-tracking and occultation observations with people around the world, Twitter fulfills the internet's promise to "connect us all."

Astronomers on Facebook

Of course, Twitter isn't the only social game in town. Many people use social media's biggest site, Facebook, to keep in touch with family and friends, but it's also a great place to keep up with your local astronomy clubs.

JAAP MEIJERS

TWISSTERS This map shows the more than 50,000 @Twisst followers across the globe who receive updates on illuminated nighttime passes of the ISS.

DAVID DICKINSON (2)

CATCHING A LAUNCH The author attended a Tweetup centered on the launch of STS-132, which carried the *Atlantis* shuttle into space to dock with the ISS in May 2010. *Inset:* Tweetup participants took breaks from launch events in a tent supplied with an abundance of internet connections and outlets.

YOU MIGHT ALSO LIKE ...

LinkedIn: As a more professionally oriented version of Facebook, this site's primary strength lies in its ability to connect the curious public with professional astronomers, science writers, and other astronomy-related professions. The Amateur Astronomy group, a growing community of amateur and professional astronomers, is one place you can find healthy astronomy discussion.

Quora: This Yahoo-Answers-like site forms communities of individuals and experts who submit and/or answer questions on a certain topic, such as, "When will the last total solar eclipse occur?" or "Can I see planets during the daytime?"

As with many query-based forums, the site tries to maintain quality by asking users to rate answers on their effectiveness.

Photo-Sharing Sites: Flickr, Pinterest, and *Sky & Telescope*'s online photo gallery are becoming growing hubs for sharing astrophotos.

Before sharing photos via any website, though, one caveat is in order: posting photos is a great way to gain exposure and start discussion, but be careful you don't inadvertently release your image rights to the Wild West that is the modern internet. Flickr allows you to post images under a Creative Commons license, or you can opt to retain your rights. A simple alternative is to share only low-resolution photos.

If you're looking online for images to use, some caution might also be in order — not everything marked as Creative Commons or "free for reuse" is in fact free to share. Some photos include digital watermarks, but for those that don't, you can check a photo's pedigree using sites such as TinEye (**www.tineye.com**). Reverse-image searches are also a good way to flush out Photoshopped fakes.

TWITTER MUSINGS The author's own account, @Astroguyz, offers plenty of examples of how to share updates and images with followers. He includes plenty of hashtags so that non-followers can find his tweets too.

FACEBOOK UPDATES *Sky & Telescope* notifies readers of news and observing stories, new episodes of the *SkyWeek* television show, product sales, and editorial musings. To receive these notifications, "like" our page on Facebook.

Facebook shines in its ability to create a "website for the masses." Small organizations/businesses that in the past would have hired a designer to create a website now simply create a Facebook page instead. Many astronomy clubs have followed suit. If you just want a simple website stating "Here's where we are, what we do, and when we do it," a Facebook page is a great way to go. It's even possible to link Twitter to Facebook so that any tweets automatically post to Facebook as status updates.

A timely example comes from Padma Yanamandra-Fisher, a senior research scientist at NASA's Space Science Institute, who started a Facebook group earlier this year as part of the Comet ISON Observing Campaign (CIOC). The campaign seeks to promote amateur and professional collaborations during the comet's passage through the inner solar system in late 2013, and CIOC's Facebook page is a key outreach tool.

Virtual Star Parties with Google+

Google's most popular foray into social media, Google+, began in 2011, when Facebook and Twitter were already well established. But the platform is starting to catch up. Promoted as a social-media layering site, Google+ connects the search engine's multiple platforms, including YouTube and Gmail. But what most interests amateur astronomers is its unique Hangouts On Air feature, which helps potentially thousands of users get together for online star parties.

The Virtual Star Party, organized by CosmoQuest and run by *Universe Today*'s Fraser Cain, attracts viewers worldwide every Sunday night around 11:00 p.m. EDT. (The exact start time changes from week to week). It's a fun and rewarding experience whether you join as a spectator or telescope operator, and whether you watch the show live on Google+ or YouTube or catch up on old shows archived on YouTube. The event has grown so big that it even attracted Google's attention: watch Google's 3-minute documentary at **skypub.com/social-media**.

The approximately one-hour show features views through a mix of telescopes observing in real-time, overlaid with commentary from professional astronomers such as Pamela Gay, Nicole Gugliucci, and Thad Szabo. The organizers are looking for dedicated amateurs and professionals running the gamut in experience and equipment to participate, and they're always open to newcomers. Contact Fraser Cain (**info@universetoday.com**) if you'd like to add your observations to the show.

Like any platform, Google+ has a learning curve. I participated in three star parties before I got the hang of Hangouts, and I learned a few things along the way. The best audio configuration eliminates echo by separating the microphone from the speakers; I use an open microphone and a set of ear buds. And I make sure no other open microphones are receiving, such as those installed on webcams that some astronomers fit to their telescopes.

Google+ Hangout's free Toolbox extension allows users to track comments and personalize their appearance. You can polish your look by creating a custom Lower Third, which displays information about you and your equipment to the viewers. It'll appear backwards as you're using it, but don't worry, your audience will see it correctly.

Hangouts aren't just for star parties. Astrophotographers also use Google+ to share images and discuss techniques in real time. Several Virtual Star Party members stay online after the show to do just this. And many other outlets now feature regular Hangouts, among them the Planetary Society, *Universe Today*, CosmoQuest, and the SETI Institute.

In the brave new world of social media, you'll find many of the next generation of astronomy enthusiasts online. You'll often have to vet updates yourself, and you might need to look elsewhere for in-depth information. Nevertheless, creating and tailoring Google+, Facebook, and/or Twitter social-media accounts is a wonderful way to take part in fast-breaking observing updates and connect with astronomy aficionados worldwide. ✦

__David Dickinson__ is a science teacher, freelance science writer, and backyard astronomer living in Hudson, Florida. He tweets his astronomical musings as @Astroguyz and blogs at __www.astroguyz.com__.

VIRTUAL OBSERVING ***Universe Today*****'s Fraser Cain, left, runs CosmoQuest's Virtual Star Party on Google+. Other volunteers offering observations or commentary during the show include Gary Gonnella, Nicole Gugliucci, Scott Lewis, and Thad Szabo, appearing from left to right along the bottom of the screenshot.**

SETTING UP **The author live streams planets, the Moon, and bright double stars for Virtual Star Parties.**

DAVID DICKINSON

Who's Who in the Astronomy Twitter-verse

There are literally thousands of space- and astronomy-related accounts out there on Twitter. If you can think of a club, individual, or space mission, they probably have an account. The list that follows is a sampling of my personal favorites that I haven't already mentioned:

@AAVSO	A great source of notifications on novae and variable stars
@AstronomyFM	The 24-hour internet radio stream, Astronomy.FM, tweets a daily news update
@AstroPHYPapers	Tweets the latest astrophysics papers posted on www.arXiv.org, an archive of scientific preprints.
@EclipseMaps	Eclipse expert Michael Zeiler tweets about eclipses, astronomy, and science in general
@ESA	The European Space Agency tweets its latest activities
@IMOMeteors	Notifications from the International Meteor Observers
@NASA	Official news from the U.S. space agency
@NASASocial	A good follow for the latest on upcoming NASA Social events
@NeilTyson	Musings from astronomer and science popularizer Neil deGrasse Tyson
@nextlaunch	Notifies followers of upcoming space launches with live webcasts
@SkyandTelescope	*Sky & Telescope* shares the latest astronomy and observing news
@SpaceFlightNow	Timely updates on space missions worldwide
@SungrazerComets	Tweets the latest comet discoveries from SOHO and STEREO data
@TalkingSpace	Notifications from the outstanding podcast about space exploration

Three of this issue's observing articles cover the area of Aquila, Scutum, and Ophiuchus shown in this photograph.

In This Section

PHOTOGRAPH: AKIRA FUJII

AUGUST 2013

3 **DAWN:** Jupiter shines lower left of the crescent Moon (for North America).

3–4 **ALL NIGHT:** Asteroid 3 Juno reaches opposition, rising around sunset and setting around sunrise; see page 51.

4 **DAWN:** Faint Mars is upper left of the thin crescent Moon.

5 **DAWN:** An extremely thin crescent Moon may be visible below Mercury very low in the east-northeast starting 45 minutes before sunrise, as shown on page 48. Bring binoculars.

9 **DUSK:** Look for the thin crescent Moon below Venus low in the west about a half hour after sunset; see page 48.

11–13 **NIGHT:** The Perseid meteor shower peaks on the nights of August 11–12 and 12–13, with almost no Moon. Rates should be best after midnight; see page 50.

12 **EVENING:** Saturn shines above the waxing crescent Moon.

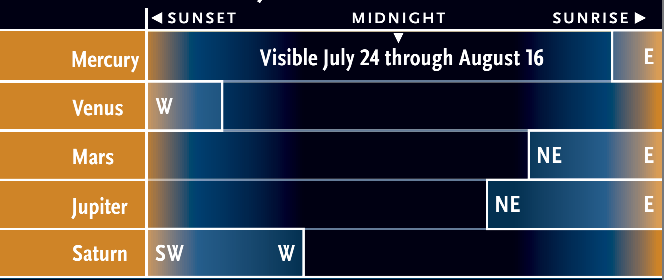
13 **DUSK:** Binoculars show the wide double star Alpha (α) Librae, also called Zubenelgenubi, very close to the right or upper right of the first-quarter Moon for North America. The Moon occults (hides) Alpha Librae for much of South America.

17–20 **DAWN:** Mars forms a short arc with similarly bright Pollux and Castor to its upper left.

31 **DAWN:** Jupiter shines left of the crescent Moon.

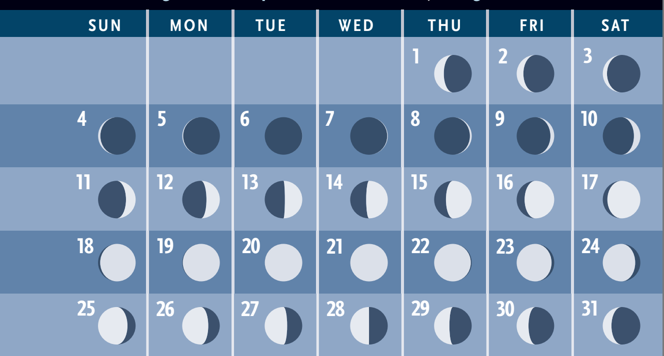
Planet Visibility

SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH



Moon Phases

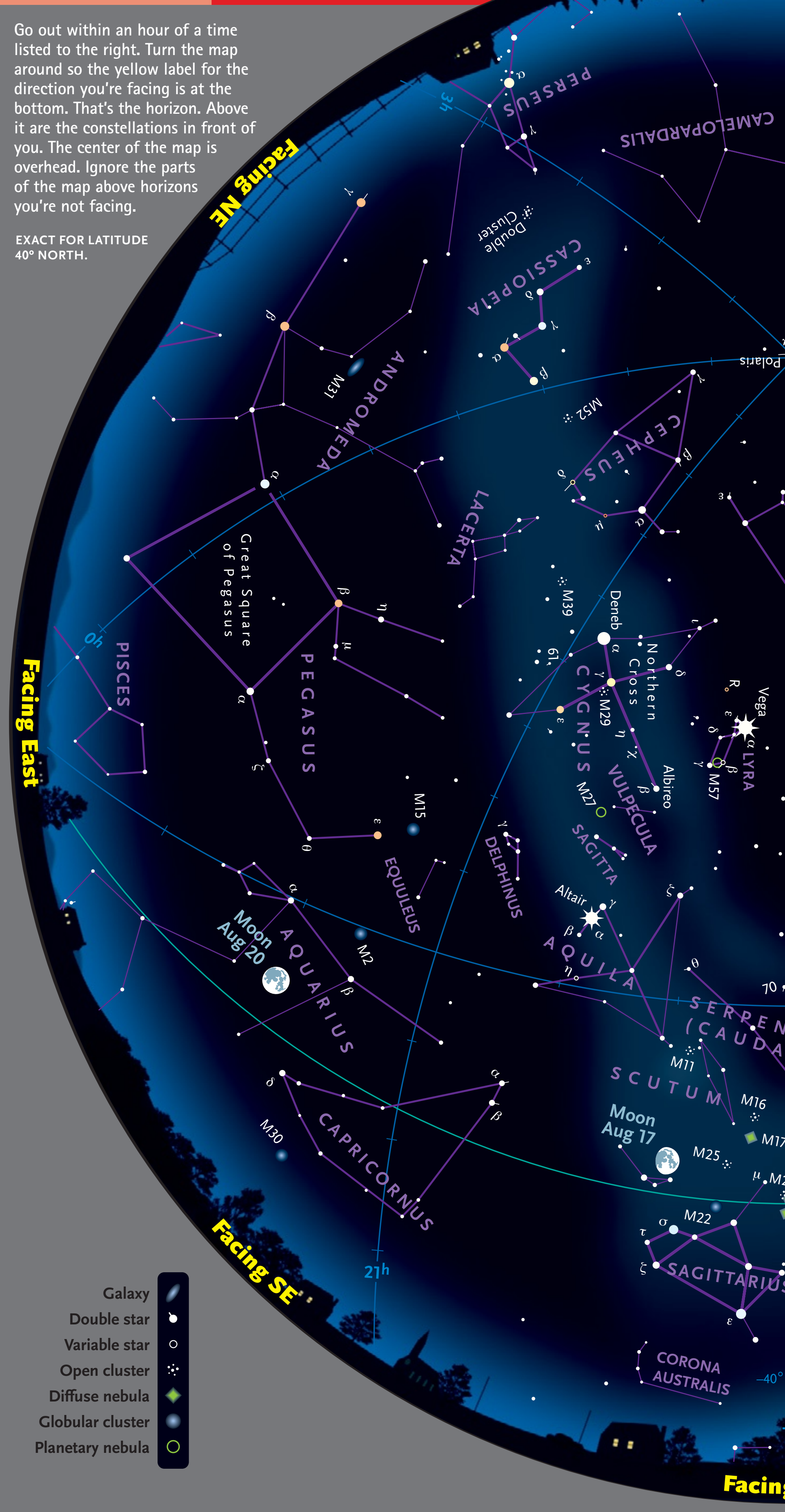
New August 6 5:51 p.m. EDT
First Qtr August 14 6:56 a.m. EDT
Full August 20 9:45 p.m. EDT
Last Qtr August 28 5:35 a.m. EDT

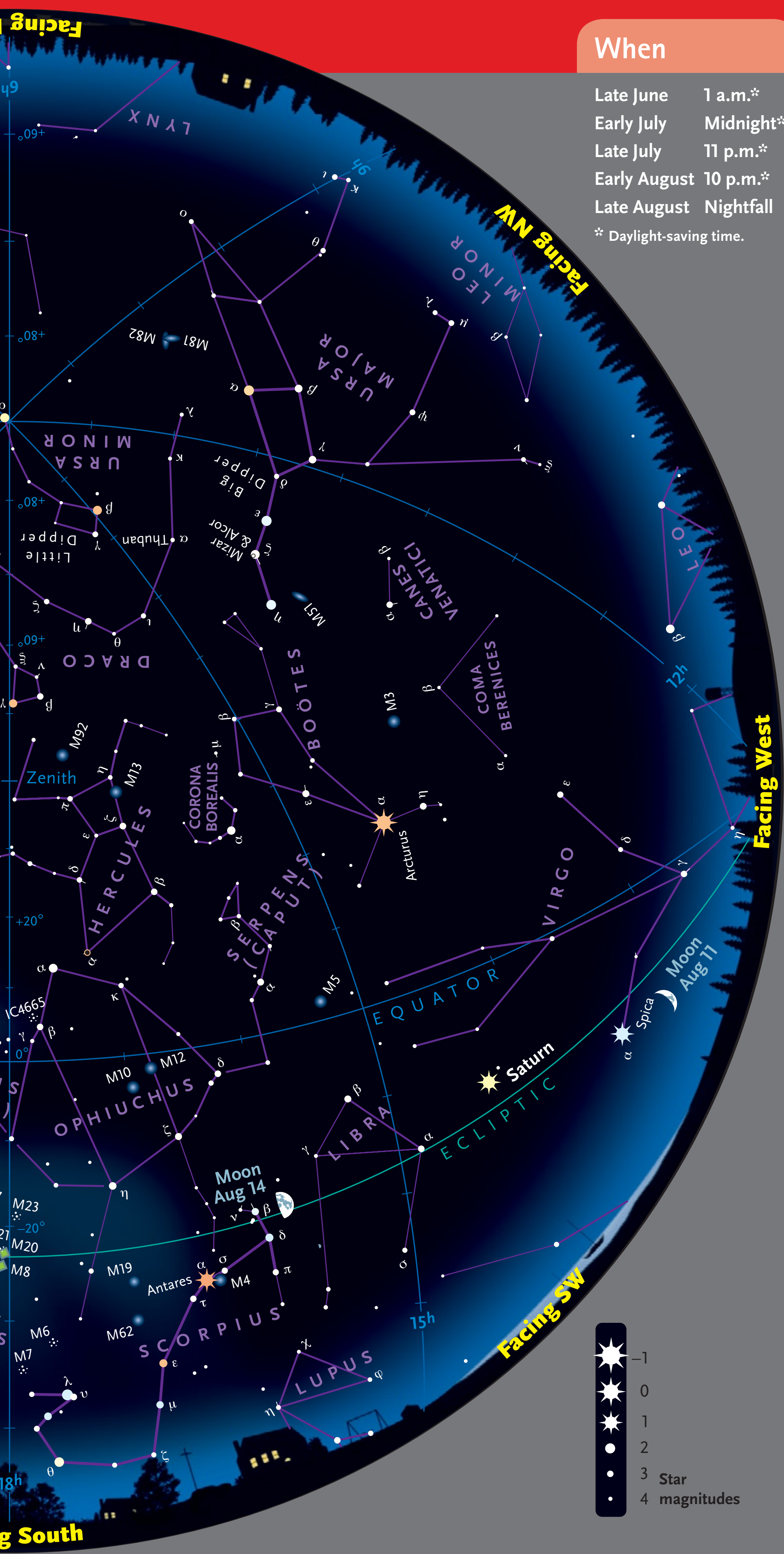


Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

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

* Daylight-saving time.

Gary Seronik
Binocular Highlight

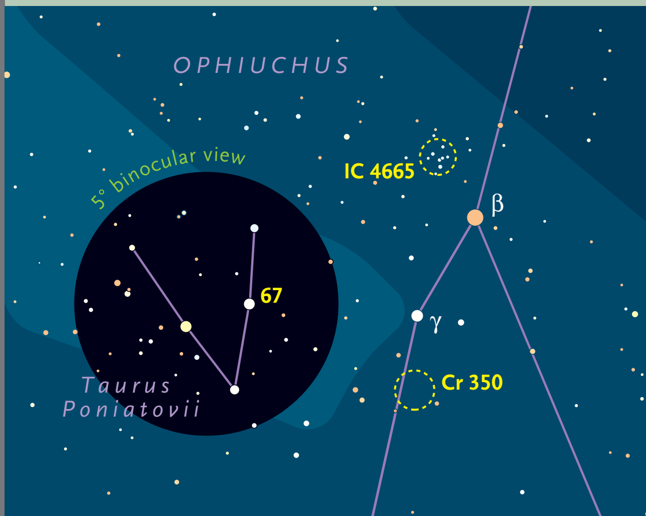
Finds in Ophiuchus

Ophiuchus, the Serpent Bearer, is well known for his treasure-trove of Messier globular clusters, but the constellation offers binocular observers plenty more. Indeed, even if we restrict ourselves to the patch of sky near 2.7-magnitude Beta (β) Ophiuchi, our haul will include a nifty asterism, a challenging double star, and a pair of loose open clusters.

Let's begin with the asterism known as **Taurus Poniatovii**. As the name suggests, this group of five stars resembles the V-shaped face of Taurus, the Bull. It's quite a striking mini-constellation that fits comfortably in the 6° field of view of my 10×30 image-stabilized binoculars. If you have 15× binos, try splitting its best double star, **67 Ophiuchi**. Nearly lost in the glare of the 4.0-magnitude primary is an 8.1-magnitude glint only 55″ away. It's a tough but doable pair.

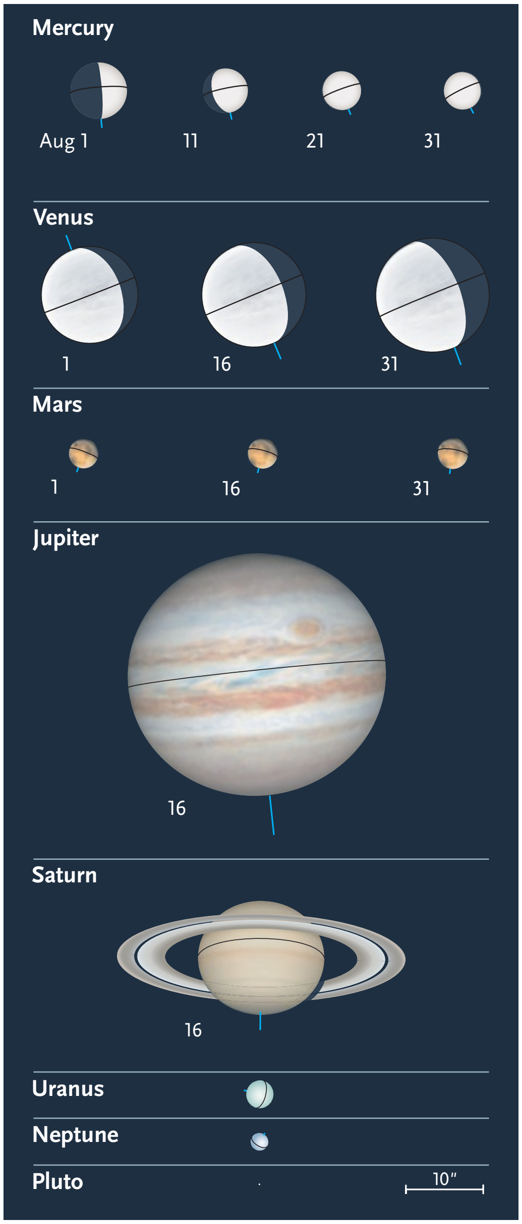
North of Beta is our easiest find, **IC 4665**. For anyone who thinks that all the best binocular sights have Messier or NGC numbers, this IC open cluster may come as a revelation. In my 10×30s, IC 4665 is a conspicuous and attractive gathering of roughly a dozen reasonably bright stars with a scattering of fainter ones mixed in between.

And if you think IC objects are obscure, aim your binos just south of Gamma (γ) Ophiuchi for **Collinder 350** (Cr 350). This is a very sparse collection of stars that hangs together best under dark skies in the wide field of view offered by 7× or 10× binos. Cr 350 is reasonably obvious in my 10×30s, and I can pick out several rows of stars, the most conspicuous of which runs northwest/southeast. However, the more restrictive field of view of my 15×70s actually makes the cluster more difficult to see! ✦



Watch a SPECIAL VIDEO

To watch a video tutorial on how to use the big sky map on the left, hosted by *S&T* senior editor Alan MacRobert, visit SkyandTelescope.com/maptutorial.

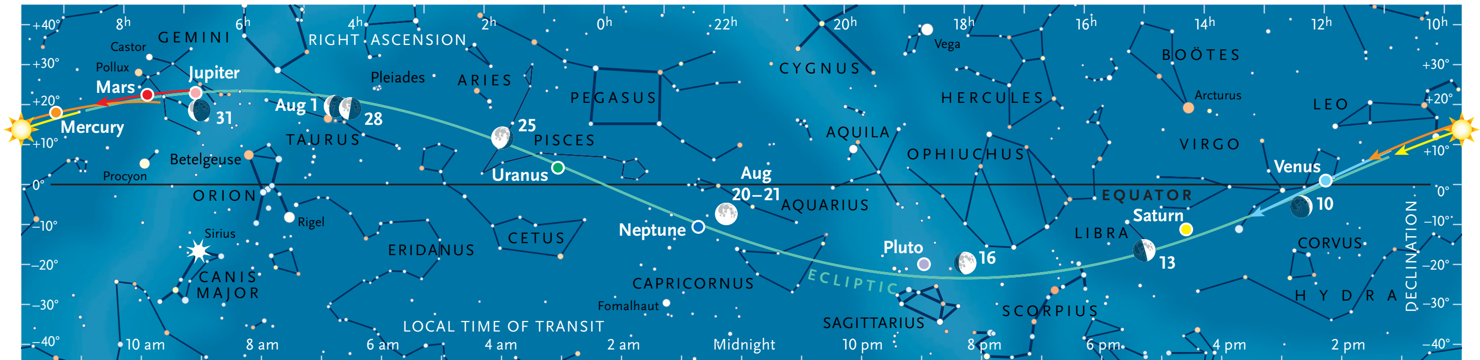


Sun and Planets, August 2013

	August	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$8^h 44.6^m$	+18° 05′	—	–26.8	31′ 31″	—	1.015
	31	$10^h 37.0^m$	+8° 44′	—	–26.8	31′ 41″	—	1.009
Mercury	1	$7^h 22.6^m$	+20° 32′	20° Mo	–0.1	7.3″	44%	0.917
	11	$8^h 26.8^m$	+19° 54′	14° Mo	–1.1	5.8″	80%	1.166
	21	$9^h 47.3^m$	+15° 11′	4° Mo	–1.8	5.1″	99%	1.330
	31	$11^h 01.2^m$	+7° 54′	6° Ev	–1.3	4.9″	98%	1.375
Venus	1	$10^h 52.6^m$	+8° 37′	32° Ev	–3.9	12.5″	83%	1.331
	11	$11^h 36.2^m$	+3° 38′	35° Ev	–3.9	13.2″	80%	1.267
	21	$12^h 19.0^m$	–1° 30′	37° Ev	–4.0	13.9″	77%	1.200
	31	$13^h 01.5^m$	–6° 37′	39° Ev	–4.0	14.7″	74%	1.131
Mars	1	$6^h 53.2^m$	+23° 35′	27° Mo	+1.6	3.9″	98%	2.398
	16	$7^h 35.7^m$	+22° 29′	31° Mo	+1.6	4.0″	97%	2.354
	31	$8^h 16.6^m$	+20° 45′	36° Mo	+1.6	4.1″	96%	2.297
Jupiter	1	$6^h 33.9^m$	+23° 03′	31° Mo	–1.9	33.0″	100%	5.980
	31	$6^h 59.2^m$	+22° 37′	54° Mo	–2.0	34.7″	99%	5.676
Saturn	1	$14^h 14.4^m$	–10° 59′	86° Ev	+0.6	16.9″	100%	9.857
	31	$14^h 21.2^m$	–11° 41′	59° Ev	+0.7	16.1″	100%	10.329
Uranus	16	$0^h 45.2^m$	+4° 05′	131° Mo	+5.8	3.6″	100%	19.363
Neptune	16	$22^h 24.8^m$	–10° 39′	169° Mo	+7.8	2.4″	100%	28.989
Pluto	16	$18^h 38.7^m$	–20° 01′	136° Ev	+14.1	0.1″	100%	31.756

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

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



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

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

Fred Schaaf

The Shield of King Sobieski

Scutum is the only modern constellation introduced for political reasons.

In the past two months' columns, we have looked at a small constellation brimming with wonders: Corona Borealis, the Northern Crown. On August evenings, its sightly semicircle of stars still shines high — in fact it's now directly above Arcturus in the west for observers at mid-northern latitudes.

Corona Borealis is small, but Scutum, the Shield, is much smaller — in fact, only four of the 88 constellations cover less of the sky. Nevertheless, Scutum's position smack-dab in the middle of the Milky Way band makes its star fields very rich. And Scutum's few individual wonders are so powerful that they're worth viewing on every clear summer night.

The shield of King Sobieski. The vast span of sky north of declination –25° stretching from right ascension 14^h east to 2^h contains only three modern constellations: Lacerta, the Lizard; Vulpecula, the Little Fox; and Scutum. All were invented by the famed 17th-century astronomer Johannes Hevelius.

Scutum is the only modern official constellation that was introduced for political reasons. Hevelius created it in 1684 as Scutum Sobiescianum, Sobieski's Shield, to honor his patron King John III Sobieski of Poland. But the official name has been shortened to just Scutum, removing the political reference.

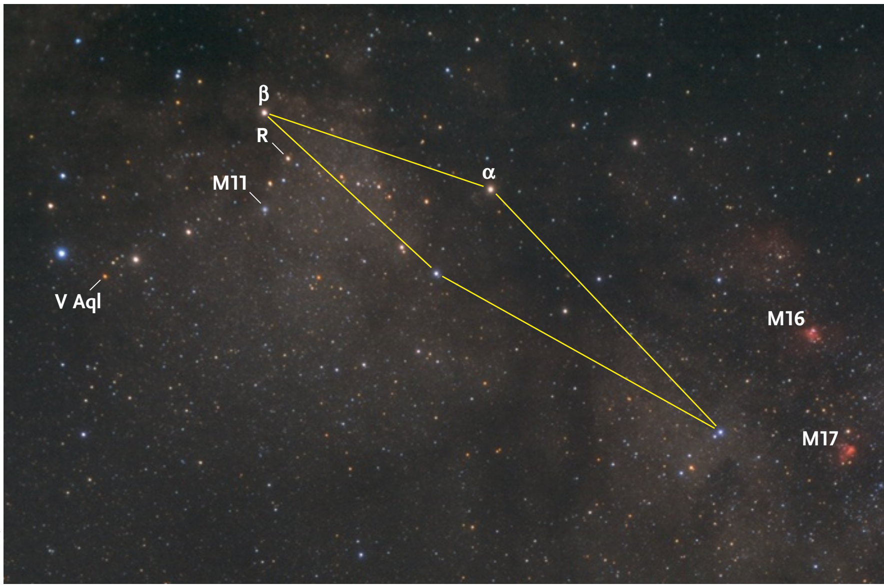
The stars of Scutum. Corona Borealis is faint, with only one star brighter (much brighter) than magnitude 3.7. But Scutum is fainter still. Alpha and Beta Scuti shine only at magnitudes 3.9 and 4.2, respectively. Alpha is an orange *K*3 III giant 200 light-years from the Sun, while Beta, a yellow *G*4 IIa bright giant, is roughly 900 light-years away.

Normally, all of Scutum's other stars shine at magnitude 4.7 or fainter. But in addition to the occasional novae that can flare up in any constellation, Scutum contains the remarkable variable star R Scuti. R is located only about 1° south of Beta Scuti and 1° northwest of the dramatic star cluster Messier 11. It was discovered by the English astronomer Edward Pigott in 1795, the same year he identified R Coronae Borealis, one of the variable stars mentioned in the June column. R Scuti's period is about 146 days, often varying from only about magnitude 4.8 to 6.0. But every fourth or fifth minimum the star plunges to about 8.0, and the extreme variability range is roughly 8.8 to 4.5 — nearly as bright as Beta Scuti.

A great star cloud and a great cluster. Scutum is filled with the Scutum Star Cloud, which Edward Emerson Barnard called "the Gem of the Milky Way." This roundish, approximately 8°-wide patch of bright Milky Way glow hangs about halfway up the southern sky for observers at mid-northern latitudes on August evenings. Barnard also identified some of his most impressive dark nebulae in this region.

But the climax of Scutum is a cluster roughly 5,500 light-years from Earth, well in front of the Scutum Star Cloud. I'm talking about Messier 11. The 19th-century observer William Henry Smyth famously compared a prominent part of M11 to a flight of geese, leading to the nickname Wild Duck Cluster. To me, M11 in a medium-size amateur telescope is an avalanche of stars throwing up a cloud of seeming nebulosity. The avalanche falls from the apex of the cluster's bright fan of stars, marked by the brightest — 8th-magnitude — yellow star near the apex. The seeming "nebulosity" is revealed by slightly larger amateur telescopes to be a cloud of about 500 stars brighter than 14th magnitude. ✦

The constellation Scutum's name is Latin for "shield," perhaps inspired by the shield-shaped Scutum Star Cloud that fills the upper left corner of this photograph. North is to the upper left. The carbon star V Aquilae is discussed on page 56.



AKIRA FUJII

Low Planets at Dusk and Dawn

Saturn is disappearing into the sunset, but Jupiter rises higher each morning.

All the bright planets are visible in August, but none are very well placed for telescope users who observe from mid-northern latitudes.

Venus continues to shine low in evening twilight. Saturn is fairly low as the sky darkens on August 1st, and it ends the month only a little higher than Venus. Jupiter rises well after midnight, Mars rises even later, and neither is especially high when the sky begins to brighten. Mercury is visible before dawn in early August but is lost from view by mid-month.

DUSK TO LATE EVENING

Venus sets about 1½ hours after the Sun all month. Although its elongation from the Sun is increasing, the angle between the ecliptic and the horizon is unfavorable for northern observers. The ecliptic's slope is shallow at sunset at the beginning of August, and shallowest in September. So from late June through October, Venus remains at about the same altitude at sunset, just 15° to 17° high (for observers around 40° north latitude).

What does change is Venus's azimuth at sunset, which moves from west to west-southwest during the course of August. Venus is also moving rapidly in front of the stars. It starts August 42° lower right of blue-white Spica and ends the month just 5° from that star.

Venus brightens slightly to magnitude –4.0 this month, and its disk grows a little, from 12.5″ to 14.7″. But the gibbous disk is still so small, and the planet so low, that telescope users will have trouble detecting that its phase is gradually shrinking to three-quarters lit.

Saturn begins August roughly 30° above the southwestern horizon when it comes into good view about 45 minutes after sunset. It shines at magnitude +0.6 about 12° upper left of slightly fainter Spica. Binoculars show that Saturn is creeping away from 4.2-magnitude Kappa (κ) Virginis, starting the month less than 1° southeast of star and ending 2½° away.

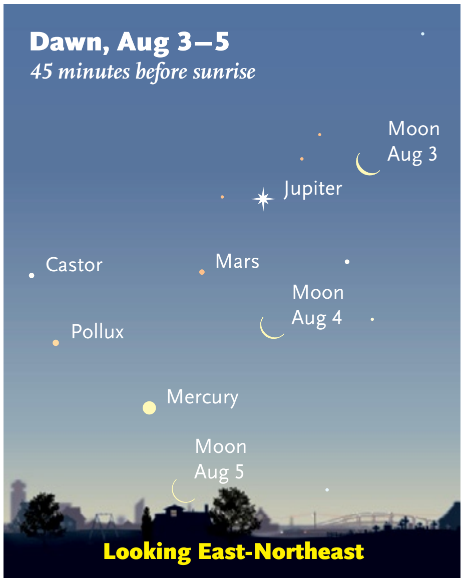
The gap between Saturn and Venus dwindles dramatically in August, from 53° to 18°. Saturn sets around midnight (daylight-saving time) as August starts. But by August 31st it sets just an hour after Venus and 2½ hours after the Sun.

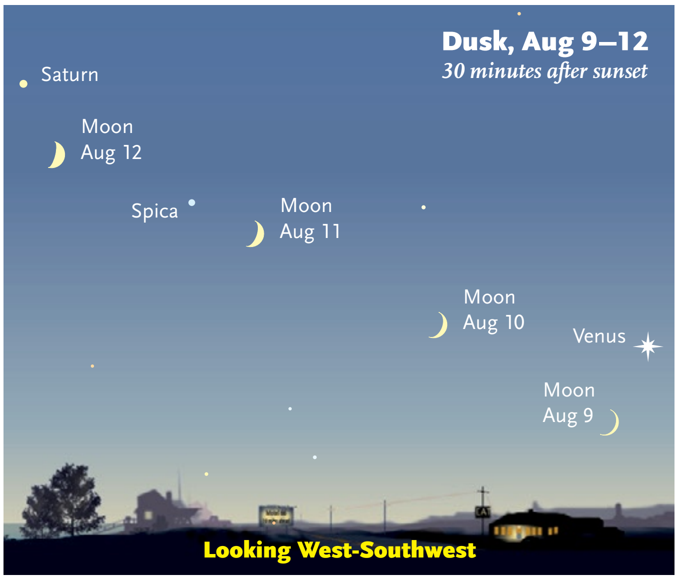
In early August Saturn is still high enough for a reasonably steady telescopic view at dusk. Saturn was at eastern quadrature (90° east of the Sun) on July 28th, so the planet's shadow is particularly prominent on its beautiful rings.

Pluto, in Sagittarius, is well-placed for observation in the early evening if you can see to 14th magnitude. See page 52 of the June issue for a finder chart.

LATE NIGHT

None of the bright planets are visible for several hours after Saturn sets. But two dimmer worlds reach opposition this August, and are therefore highest in the middle of the night. The asteroid **3 Juno** comes to opposition on August 4th, shining at magnitude 9.0 in extreme eastern Aquarius (see page 51). **Neptune** reaches opposition in central Aquarius on August 27th (the American evening of August 26th), when it shines at magnitude 7.8.

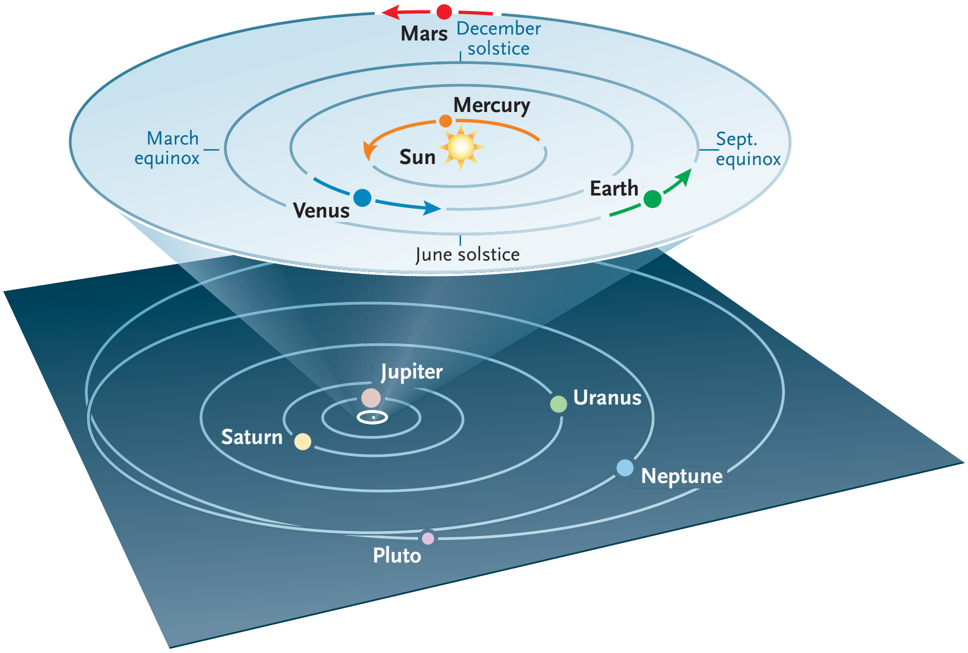




These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west); European observers should move each Moon symbol a quarter of the way toward the one for the previous date. In the Far East, move the Moon halfway. The blue 10° scale bar is about the width of your fist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

ORBITS OF THE PLANETS

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



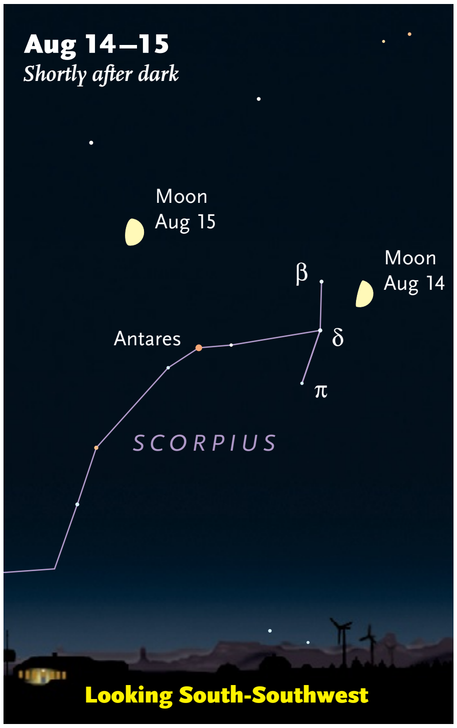
Even then, when Neptune is closest to us for the year, its light takes a full 4 hours to reach us (more precisely, 4.016 hours). No wonder its disk appears just 2.4″ wide in telescopes!

Uranus, in Pisces, trails its brother planet by almost 2½ hours in right ascension. But Uranus is now 15° north of Neptune, so it rises just 1½ hours later for observers at latitude 40° north, and it's much higher when it finally transits the meridian in the small hours of the morning. Uranus shines at magnitude 5.8 and its disk is 3.6″ across — six times brighter and 50% larger than Neptune.

Next month's issue will have finder charts for Uranus and Neptune. They're also available at **skypub.com/urnep**.

DAWN

Jupiter rises around 3:30 a.m. (daylight-saving time) as August begins, about 20 minutes before **Mars**. Both are in Gemini, still just 5° apart after their 0.8° conjunction on July 22nd. They're poorly placed for telescope users, less than 20° above the eastern horizon 45 minutes before sunrise on August 1st.



The situation changes significantly during August, as both planets rise earlier each morning (especially Jupiter), and sunrise comes later. On August 31st Mars is 25° above the eastern horizon 45 minutes before sunrise at latitude 40° north, and Jupiter is 18° upper right of Mars. Viewed against the "fixed" stars, Jupiter is moving slowly eastward into Gemini, while Mars races across the Twins and into Cancer during August. Mars passes Pollux — by a bit less than 6° — on the American morning of August 18th.

Mars appears just 4″ across, tiny in telescopes, but Jupiter's 34″-wide globe is an interesting sight. The modestly bright star a few degrees from Jupiter this month is 3.0-magnitude Epsilon (ε) Geminorum, also known as Mebsuta.

On the final mornings of July, **Mercury** was a zero-magnitude object at greatest dawn elongation and as little as 7° below Mars. Swift little Mercury brightens rapidly during the first half of August but appears lower each morning. It's lost to naked-eye view around mid-month and reaches superior conjunction with the Sun on August 24th.

On August 8th Mercury passes 4° south of **Comet C/2012 S1 ISON**, but the comet is only 17° from the Sun and still probably only about 13th magnitude. When Mercury is again near Comet ISON on November 23rd (4.7° apart), the comet may be only a little fainter than the negative-magnitude planet!

EARTH AND MOON

The **Moon** is a waning crescent at dawn near Aldebaran on August 1st, upper right of Jupiter on August 3rd, lower right of Mars on August 4th, and (very thin and tricky to spot) below Mercury on August 5th, as shown on the facing page.

Returning to the evening sky, the waxing lunar crescent is below Venus at dusk on August 9th, near Spica on the 11th, and Saturn on the 12th. On August 13th North Americans see the Moon very near Alpha (α) Librae, also called Zubenelgenubi, and the Moon occults (hides) the star for much of South America.

At dawn on August 31st, the waning lunar crescent stands close to the right of Jupiter. ✦

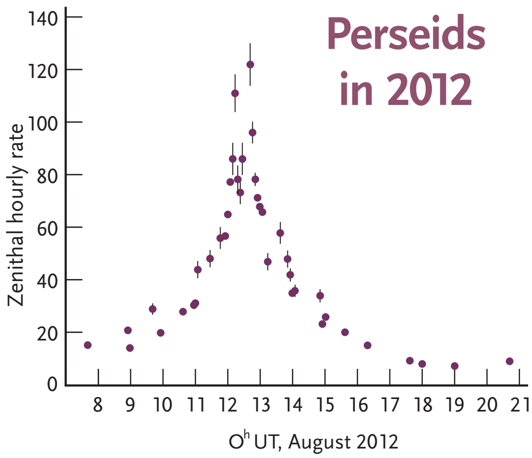
Dark Nights for the Perseids

Plan to be out meteor watching on the nights of August 11–12 and 12–13.

The Perseid meteor shower peaks this year when there's almost no Moon, making the late-night sky nice and dark for shooting-star spectators and counters. The thick waxing crescent Moon sets in mid-evening. Some Perseids do appear during the evening, but the shower is always better from about 11 or midnight until the first light of dawn. This is when the shower's radiant point, in northern Perseus, climbs high in the northeastern sky. Or to put it another way, this is when your side of Earth turns to face the oncoming meteors more directly.

Right: Hundreds of meteor observers counted Perseids last year using the standardized methods of the International Meteor Organization for intercomparison. They tallied 27,537 Perseids during 3,981 time intervals. As the resulting activity curve here shows, the shower remains active for several days before and after its peak. The "zenithal hourly rate" is the corrected number that someone would have seen if the shower's radiant were near the zenith in an unobstructed sky with 6.5-magnitude stars visible. Vertical bars show the statistical uncertainty for each combined data point.

SOURCE: INTERNATIONAL METEOR ORGANIZATION



A bright Perseid streaked across southern Cetus around moonrise last August 12th while Oshin Zakarian was exposing what he calls a "lucky shot" in the Alamut Valley of Iran.

OSHIN ZAKARIAN / DREAMVIEW.NET

Earth should go through the thickest part of the stream for many hours centered around 19^h Universal Time August 12th, which is 3 p.m. on that date Eastern Daylight Time. That means the shower splits the difference between the early-morning hours of August 12th and 13th for North America and Europe. So the number you count on each of those mornings, even in ideal conditions, may be somewhat off the International Meteor Organization's predicted peak of 100 visible per hour — even if you have no light pollution and the radiant is near the zenith. But surprises can always happen.

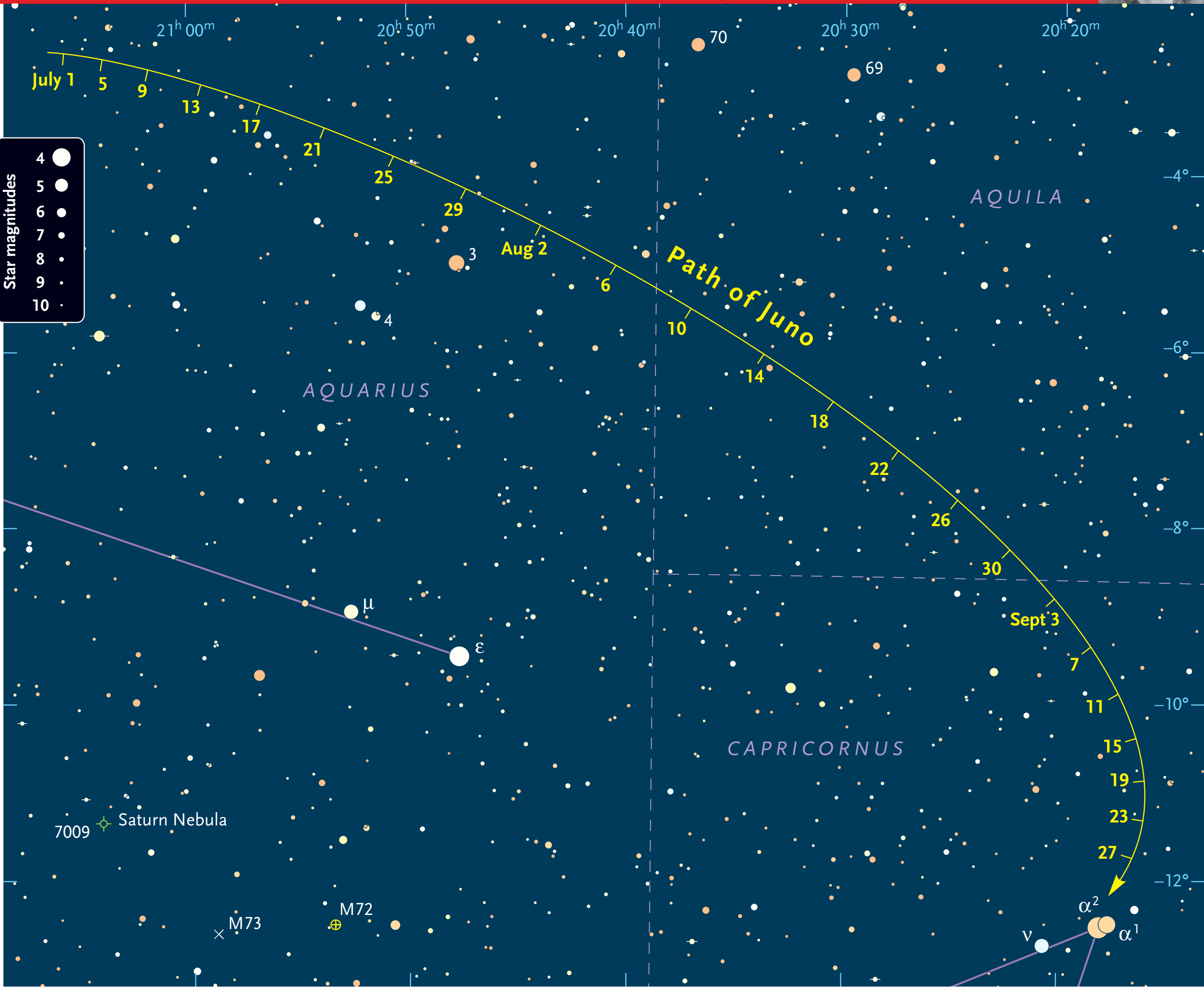
Two much weaker showers are also active at this time of year, the Delta Aquarids and Kappa Cygnids. And there are always a few sporadics too. Keep all these separate from Perseids in your notes.

Find a spot with an open sky view and no bright lights. Lie back in a reclining lawn chair, bundle up in a sleeping bag against mosquitoes and the late-night cold, and watch the stars. Expect an average of roughly a Perseid a minute under fine conditions, or fewer in light pollution.

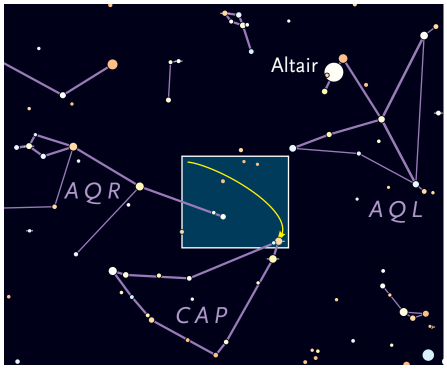
If you'd like to try making a reportable meteor count for the IMO, follow the methods at **imo.net/visual/major**. You can watch other observers' counts accumulate almost in real time at **imo.net**.

The Perseids are the ionization trails made by little debris bits from Comet 109P/Swift-Tuttle streaking into Earth's upper atmosphere at 37 miles (60 km) per second. The Perseids were especially dramatic in the 1990s around the time of Swift-Tuttle's most recent return, but they've since reverted to normal. The comet isn't due back until around 2122.

Alan MacRobert



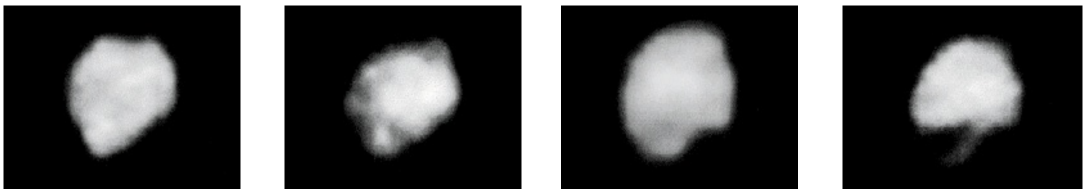
Juno on Late Summer Evenings



Of the "big four" asteroids — the first four discovered, from 1801 to 1807 — one doesn't really belong. That's 3 Juno, quite a bit smaller and fainter than 1 Ceres, 2 Pallas, and 4 Vesta. It's an irregular chunk about 160 miles (260 km) across, smaller than quite a few higher-numbered asteroids. Just by luck did the German astronomer Karl Ludwig Harding pick it up in 1804. No more asteroids were discovered until 1845.

Use the chart above to find Juno in late evening. It's magnitude 9.6 on July 1st, 9.0 for two weeks around its August 4th opposition, 9.2 by September 1st, and 9.6 on October 1st.

The chart plots stars to magnitude 9.7. The yellow ticks are at 0^h UT every four days.

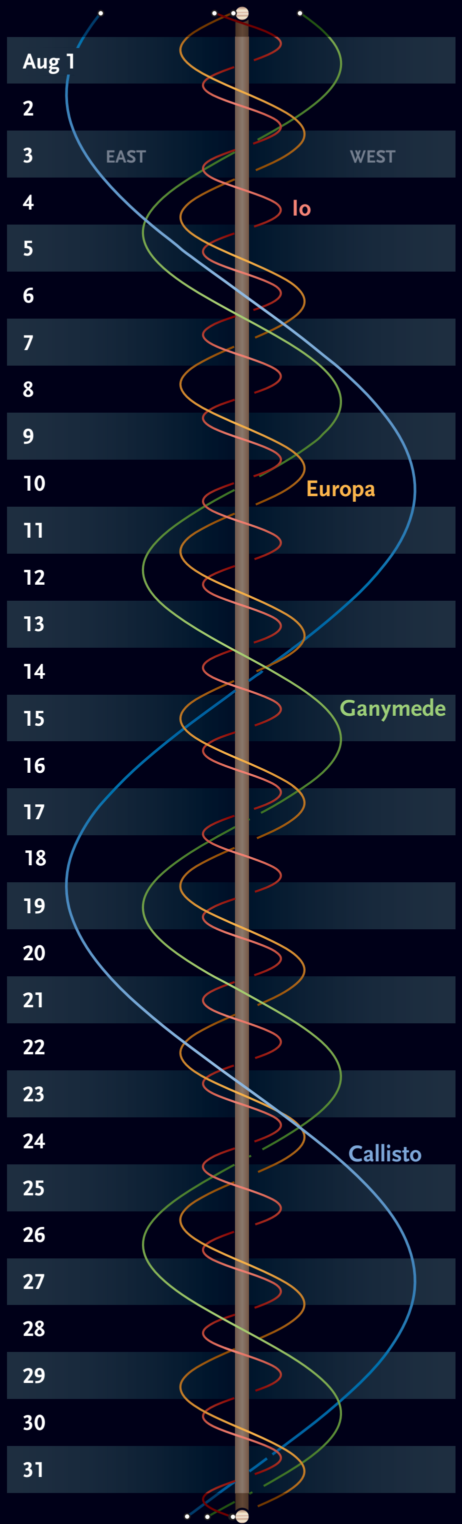


Adaptive optics on the Mount Wilson 100-inch telescope resolved Juno's rough shape a decade ago. Seen here are four profiles as the asteroid rotated with its 7.2-hour period.

SALLIE BALIUNAS / MOUNT WILSON OBSERVATORY

Are your telescope's motions jerky? De-grease the mount's metal bearings and apply ChapStick to them instead, for better smoothness. See ***skypub.com/chapstick****.*

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.

Action at Jupiter

Jupiter in August is visible only shortly before and during dawn, but some planetary observers like that time because the atmospheric seeing often settles into unusual sharpness during daybreak. At the beginning of August Jupiter is only about 16° high 45 minutes before sunrise (as seen from latitude 40° north), but by month's end it's 42° up at that time. Jupiter still appears relatively small as it swings around from behind the Sun, growing from 33 to 35 arcseconds wide in August.

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

Because Jupiter is observable now for so few of the 24 hours each day, very few of its satellite events can be seen from a given location. We'll start our big timetable of them next month.

Jupiter's Great Red Spot is always a prime attraction when it's in view, though it's usually pale orange-tan rather than "red" and much harder to see than the main cloud belts. Here are the times, in Universal Time, when it should cross Jupiter's central meridian. The dates, also in UT, are in bold. The Red Spot is observable for at least an hour before and after these times:

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

To obtain Eastern Daylight Time from UT, subtract 4 hours. The times above assume that the spot is centered at about 199° in Jupiter's System II of longitude.

A light blue or green filter slightly improves the contrast of Jupiter's reddish, orange, and tan markings. ✦

Mars Occults a Star

It's a lousy month for Mars, which is only 4″ wide and low before dawn (lower left of Jupiter). But an interesting event happens on the morning of August 18th, when Mars passes right next to or across a 7.1-magnitude star.

Mars occults the star for Alaska and far western Canada. Their nominal time of closest approach is around 5:42 a.m. Pacific Daylight Time (12:42 UT). The occultation itself will be very tough to observe, because each square arcsecond of Mars's sunlit surface will be much brighter: magnitude 4.3. Use very high power.

Telescope users elsewhere along the West Coast can at least look for the star (HIP 37579) drawing close Mars before daybreak. In other time zones the star will stand much farther off, since Mars is speeding eastward on the celestial sphere by 97″ per hour. That's one Mars diameter every 2½ minutes.

Minima of Algol

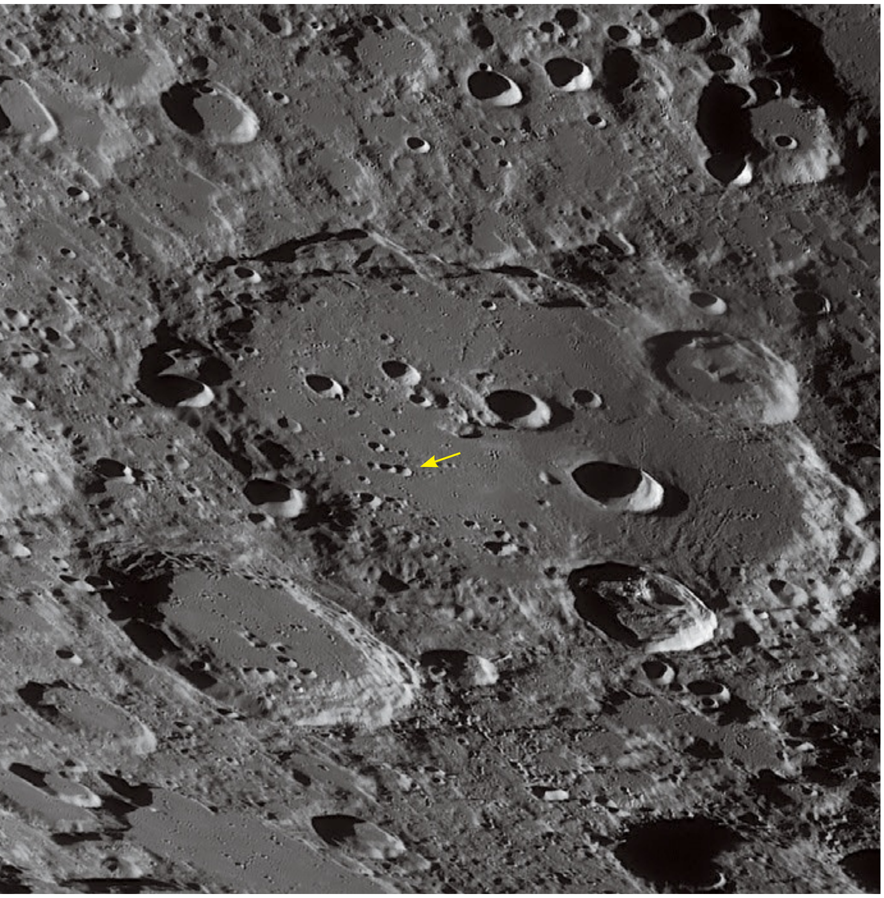
July	UT	Aug.	UT
3	16:29	1	8:36
6	13:18	4	5:25
9	10:07	7	2:13
12	6:55	9	23:02
15	3:44	12	19:51
18	0:33	15	16:39
20	21:22	18	13:28
23	18:10	21	10:17
26	14:59	24	7:05
29	11:48	27	3:54
		30	0:42

Hunting Secondary Craters

Track down thousands of these tiny trains.

Everyone who observes the Moon has admired the crater **Copernicus**, with its deep interior, terraced walls, and bright rays radiating out hundreds of kilometers in all directions. Chances are you've heard that Copernicus and other large lunar craters were formed by hypervelocity impacts of cosmic debris — comets and asteroids — that excavated these massive holes.

Although large, dramatic features such as Copernicus attract us, they're actually in the minority on the Moon. Copernicus is one crater, but it spawned *thousands* of others a kilometer (0.6 mile) or so in diameter when the ejected debris rained back down upon the lunar landscape, bombarding the surrounding terrain. Studies of high-resolution spacecraft images demonstrate that at the meter scale, there are millions of secondary craters for every large primary.


THIERRY LEGAULT

Recognizing secondary craters is an observing challenge because most are extremely small. You can easily spot the larger secondaries, such as the buckshot-like pattern of them east of Copernicus around the faint crater **Stadius**. Other Copernicus secondary craters lie along a bright ray in Mare Imbrium east of **Pytheas**. Closer examination of these Copernicus secondaries reveals that they are more complicated than similarly sized primary craters. That is because of two factors: their shapes and their configurations.

The ejecta that form secondary craters travel only about 10% as fast as the cosmic projectiles that excavated the primary craters. So instead of digging deep and beautifully circular craters, the impact of ejecta often creates elongated gashes.

Secondary craters also often form in clusters, loops, or lines. These craters are close together and form nearly simultaneously, so they and their ejecta often overlap. You can glimpse this effect in the 60-km-long line of Copernicus secondaries just inside Mare Imbrium, west of **Eratosthenes**. The craters overlap and ejecta wrap around them, making a herringbone pattern whose V shape points back toward Copernicus.

The maximum diameters of secondary craters are only about 5% of the diameters of their primary craters. If that ratio is scaled up to the sizes of impact basins, their secondaries would be about 20 to 40 km wide. Secondary craters that size are easy to find in the southern highlands near **Clavius**. In fact, on the floor of Clavius is a short chain of three barely overlapping secondary craters — the largest is 7 km wide — that point back to their likely source, the Orientale Basin.

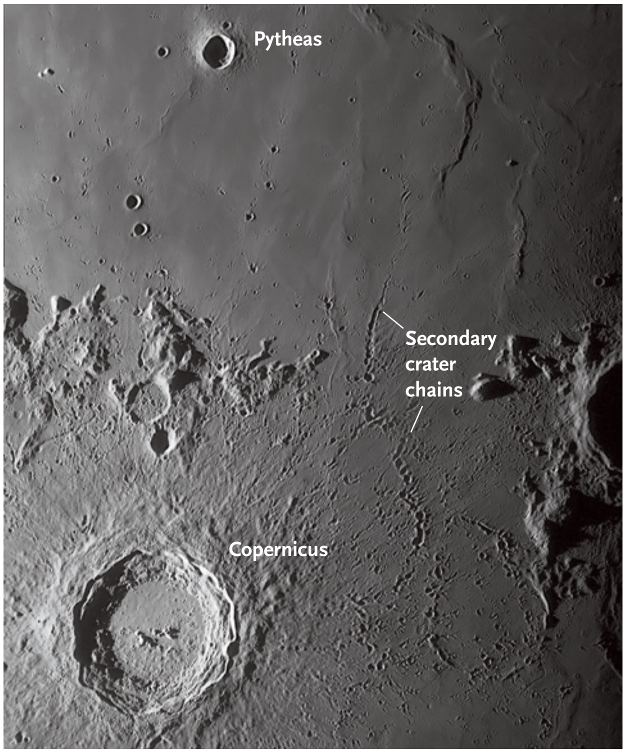
On the northwest rim of **Longomontanus** is a cluster of overlapping craters 10 to 20 km wide that is roughly aligned radially with the Imbrium Basin, 2,600 km to the north. A similar gaggle of overlapping craters on the western rim of nearby **Maginus** is probably another Imbrium secondary cluster. To the east, beyond Deluc and Lilius, are more overlapping craters 30 to 40 km wide that may be secondaries from the Nectaris Basin, nearly 1,500 km

The southern highlands are littered with ancient degraded secondary craters formed by the massive impacts that produced the major lunar basins. This small crater chain within Clavius roughly points back to its likely origin from the Orientale Basin.

to the northeast. One characteristic of these likely basin secondaries is that they all appear degraded. Because they were formed together, their rims cut into one another and their ejecta interfered.

You won't find basin secondaries on the large maria because the lavas erupted after the basins formed. But whenever you observe the lunar highlands, consider any clusters of 20- to 40-km-wide degraded craters as possible secondaries from basins that aren't even nearby.

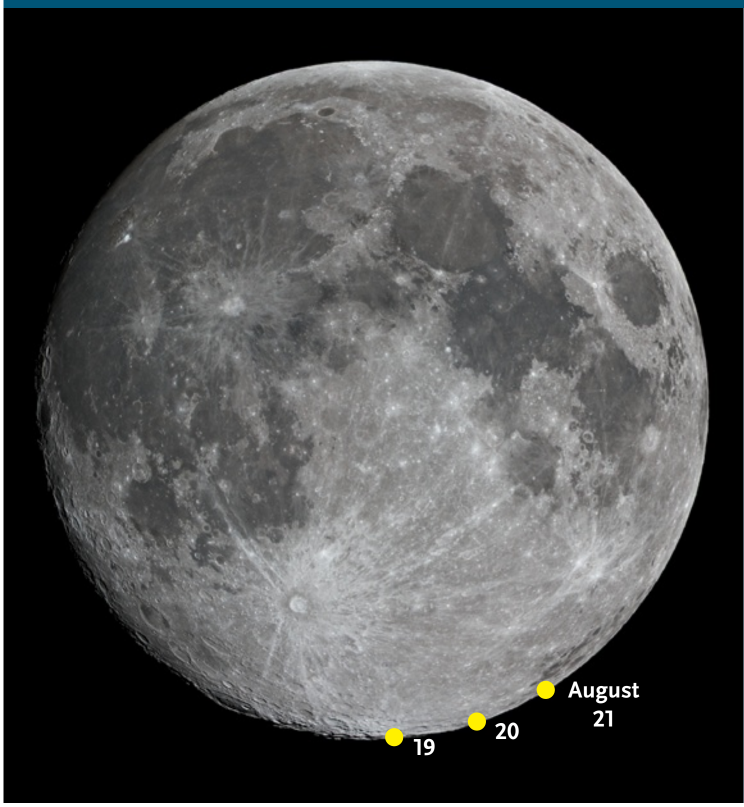
There could still be basin secondaries on the maria, but their primaries would be located on Earth. Some of the ejected rocks from the 2-billion-year-old Vredefort impact basin in South Africa may have hit the Moon. And ejecta must have also traveled the other direction. Ejecta rained down on Earth 3.8 billion years ago when the Imbrium Basin formed, but almost no rocks of our planet are left from that ancient time, so our Imbrium secondaries are long gone. ✦



THIERRY LEGAULT

Countless secondary carters litter the broad plains surrounding Copernicus. A particularly interesting line of secondary craters spanning 60 kilometers lies to the lunar northeast of Copernicus, forming an isosceles triangle with Pytheas.

The Moon • August 2013



S&T: DENNIS DI CICCO

Phases

August 6 **NEW MOON** **21:51 UT**	August 14 **FIRST-QTR MOON** **10:56 UT**
August 21 **FULL MOON** **1:45 UT**	August 28 **LAST QTR MOON** **9:35 UT**

Distances

Apogee	**August 3, 9^h UT**
252,172 miles	diam. 29′ 44″
Perigee	**August 19, 1^h UT**
225,102 miles	diam. 33′ 59″
Apogee	**August 31, 0^h UT**
251,581 miles	diam. 29′ 31″

Librations

Scott (crater)	**August 19**
Wexler (crater)	**August 20**
Lyot (crater)	**August 21**

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

Bird of the Mighty Wing

The celestial eagle harbors a wide variety of deep-sky objects.

The dome of heaven is thy house
Bird of the mighty wing,
The silver stars are as thy boughs
Around thee circling.
Thy perch is on the eaves of heaven
Thy white throne all the skies
Thou art like lightning driven
Flashing over paradise!
— George Edwin Curran, *The Eagle*, 1920

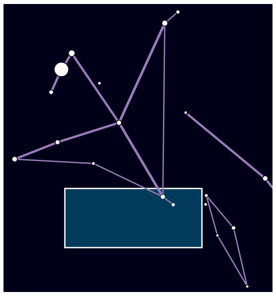
Aquila, the star-born eagle, now soars on mighty pinions in our evening sky, bringing with him a flock of celestial wonders to survey.

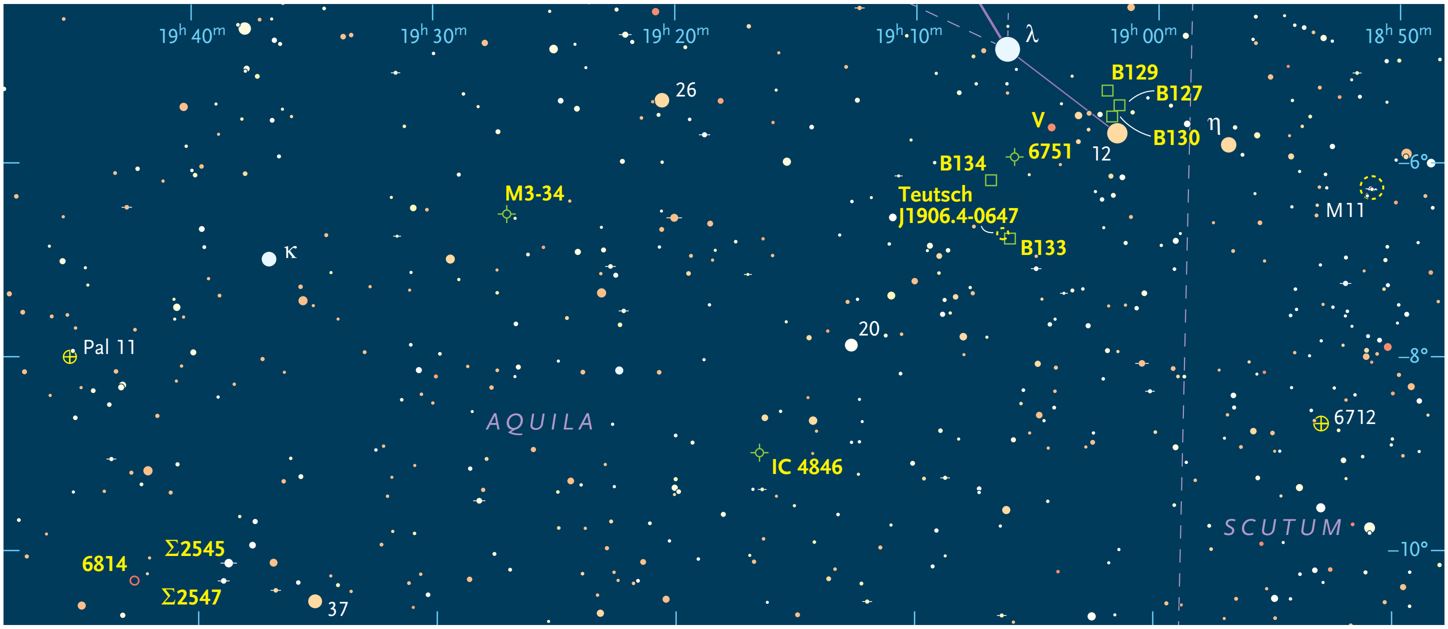
One of my favorite objects to visit in the realm of the Eagle is the carbon star **V Aquilae**, one of the reddest stars visible in a backyard telescope. A carbon star is a red giant whose atmosphere is rich in carbon-bearing molecules that absorb blue light, making the star look redder than an ordinary giant. According to the 19th-century astronomer Eduard Schönfeld, the brilliant mathematician and astronomer Friedrich Wilhelm Bessel was the first person to note this star's crimson glow. Bessel observed V Aquilae in 1823 while working on a catalog that would eventually include more than 75,000 stars.

Pointing 12×36 image-stabilized binoculars at the naked-eye stars Lambda (λ) and 12 Aquilae, I'm smitten by the lovely red-orange tint of V Aquilae. About one-quarter of the way from 12 Aql to Lambda, a little arc of three stars leads my eyes east-southeast to the ruddy star. Some observers aren't particularly sensitive to the color of reddish stars and might need a larger instrument to appreciate them. I find the hue strikingly vivid in my 130-mm (5.1-inch) refractor.

Most carbon stars are variable, but V Aquilae remains within the reach of binoculars throughout its cycle. The star changes from about magnitude 6.7 to 7.2 and back in a semiregular period of 1.1 years.

North of 12 Aquilae, an arc of three dark nebulae is an indistinct congregation of shadows from my moderately light-polluted yard. Last year I took advantage of darker skies at the Stellafane Convention in Vermont for a better view through my 105-mm refractor at 47×. **Barnard 130** rests 11′ north-northeast of 12 Aquilae and is the largest, but least





ERIC AFRICA / ADAM BLOCK / NOAO / AURA / NSF

Sue French *welcomes your comments at scfrench@nycap.rr.com.*

***Left*: North is to the upper left in this image of the spiral galaxy NGC 6814.**

***Below*: The dark nebulae near the carbon star V Aquilae show particularly well in this red plate from the first Palomar Observatory Sky Survey.**

star-free, of these dusky patches. **Barnard 127** hovers near B130's northwestern edge, and it's escorted on the southwest by a 3′ triangle of 8th- and 10th-magnitude stars. To the northeast, **Barnard 129** is inky, but it's not as well framed with stars as its companions and appears only semidetached from B127. The whole sooty arc spans a mere 22′.

The distances to most dark nebulae aren't well determined. A 2006 study by Gopinathan Maheswar and Harish Chandra Bhatt in the *Monthly Notices of the Royal Astronomical Society* places B127 at 590 ± 110 light-years and B129 at 650 ± 130 light-years. We could reasonably assume that B130 is at a comparable distance.

Sliding 29′ southeast from V Aquilae takes us to the planetary nebula **NGC 6751**. The nebula and star share a field of view through my 130-mm refractor at 63×, with NGC 6751 presenting a tiny disk. It becomes a sizable spot at 102×. At 234× the disk has a dimmer center that harbors an elusive central star, while the annulus seems a little brighter in the southeast. Two very faint stars bracket the nebula. The slightly brighter one is 23″ east and a bit north, the other is 38″ west and a bit north. The planetary's central star looks about as bright as the closer star.

NGC 6751 is a cute little robin's-egg-blue disk in my 15-inch scope at 49×, offering a lovely color contrast with V Aquilae. At 248× the nebula's annulus is a fat ring roughly 25″ across.

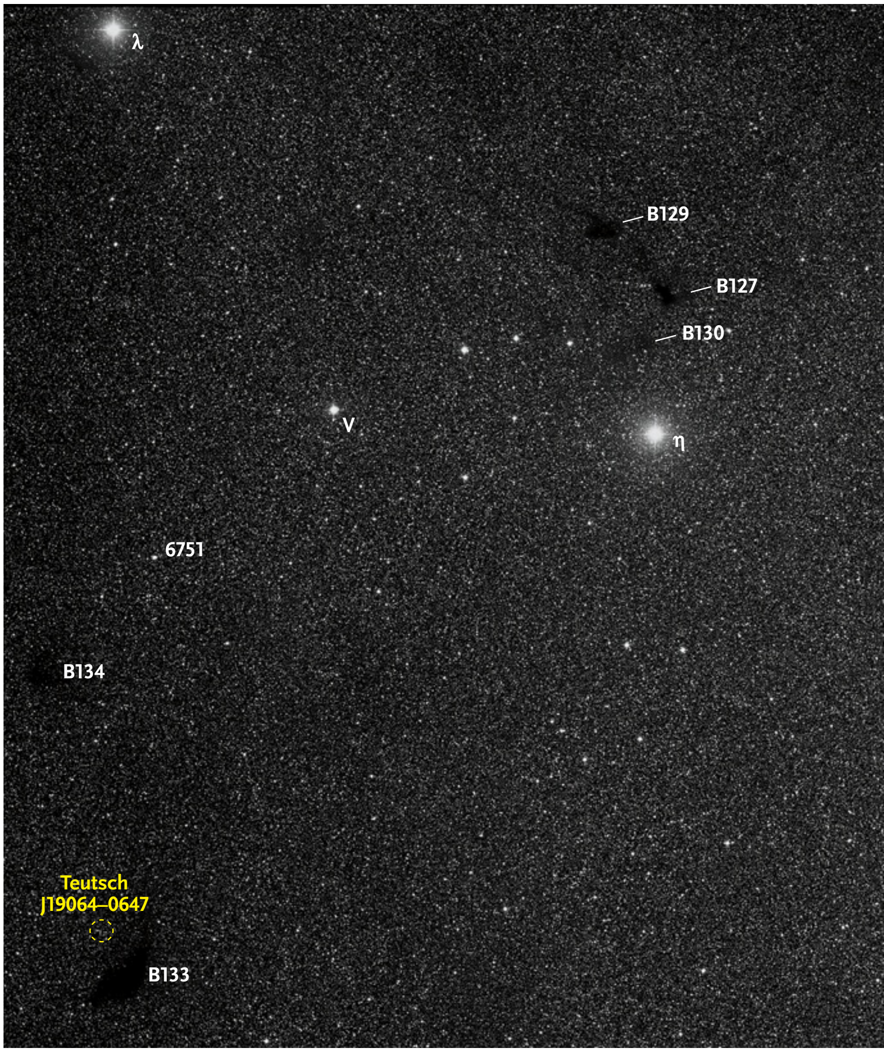
Under some conditions NGC 6751 displays a bright center that can be mistaken for a star. If so, try higher magnifications to pluck out the true central star, which is much fainter.

NGC 6751 is sometimes called the Dandelion Puff Ball, and it looks very much like the head of a dandelion gone to seed in the remarkable Hubble Heritage image shown on the following page.

The dark nebula **Barnard 134** sits 21′ southeast of NGC 6751. It covers about 4½′ through my 130-mm refractor at 63×, and the two disparate nebulae share the field of view. Maheswar and Bhatt put B134 at the same distance as B129.

Dropping 40′ south-southwest from B134, we come to **Barnard 133**. In my 130-mm refractor at 48×, it's a fairly obvious 8½′ × 3½′ oblong of darkness tipped northwest. Just beyond the nebula's edge, south of center, a 5′-tall asterism of nine faint stars reminds me of the blocky numeral 8 on a digital clock. Off the opposite side of the nebula is **Teutsch J1906.4–0647**, discovered by Philipp Teutsch, a participant in the Yahoo group known as the Deep Sky Hunters. Once deemed a possible open cluster, the group is now known to be an asterism. It's a challenging collection of stars to observe, and my 10-inch reflector at 299× shows its brightest members as a daisy chain of several faint to extremely faint stars draped along the shallow curve of an east-west garland about 2′ long.

Next we'll set sail for the tiny planetary nebula **IC 4846**. To locate it, head 1° southeast from the blue-white,



POSS-I / CALTECH / PALOMAR OBSERVATORY


NASA / HUBBLE HERITAGE TEAM / STSCI / AURA

The planetary nebula NGC 6571 resembles a dandelion gone to seed in this Hubble Space Telescope image.

5th-magnitude star 20 Aquilae to a 7th-magnitude, east-west pair of deep-yellow stars ½° apart. IC 4846 dangles 21′ south of the eastern member of the pair and floats in a 7′ pail of seven 11th-magnitude stars that opens northeast. At 48× through my 130-mm refractor, this drop in the bucket doesn't quite look like a star, and a magnification of 117× confirms a teensy blue-gray disk.

Minkowski 3-34 is a somewhat larger planetary nebula 2° southeast of yellow, 5th-magnitude 26 Aquilae. A 10′ triangle of 9th-magnitude stars just southeast of 26 Aql points toward the nebula. M3-34 makes a 17′-long straight line with three stars. From south-southwest to north-northeast, they are magnitude 10.7, 12.5 (the planetary), 11.9, and 10.5. A 9th-magnitude star rests 6.2′ west southwest of the nebula.

M3-34 is moderately faint and not as sharp as the stars in my 130-mm scope at 48×. It becomes a small disk at 102×, while at 164× it looks quite nice and is fainter around the periphery. The nebula dons a blue-green hue in my 10-inch scope at low power, and it gains a substantial contrast boost through an O III filter when using my 15-inch scope.

Now we'll move on to the triple stars **Struve 2545** and **Struve 2547**, which dwell 57′ east-northeast of deep-yellow, 5th-magnitude 37 Aquilae. Struve 2545 (Σ2545) is the brighter trio. My 130-mm refractor at 63× shows the white, 6.8-magnitude primary star barely separated from its 8.5-magnitude secondary to the northwest. The third star is considerably farther away, south-southeast of the primary, and much fainter. The close companion is more comfortably split from its primary at 102×.

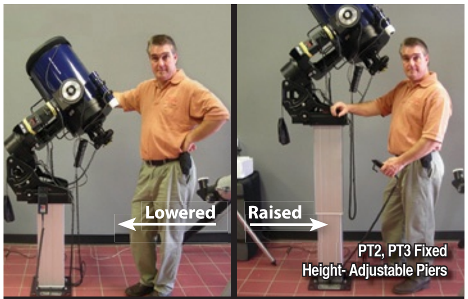
Only 11′ to the south-southeast, Σ2547 shares the field of view with Σ2545, but it doesn't require as much power to reveal its components. At just 37× the 8.7-magnitude primary displays a 9.5-magnitude attendant north-northwest, and a much fainter one more than twice as far away in the opposite direction.

The spiral galaxy **NGC 6814** also shares the same low-power field of view, 55′ east of Σ2547. It's a fairly small, very faint, round, misty spot. At 102× it spans about 1½′ and has uniform surface brightness. There's a very faint star close to the galaxy's northwestern edge and another more distant from its south-southeastern side. My 10-inch scope at 213× adds a small, brighter core. How large a telescope do you need to see the spiral arms of this nearly face-on galaxy? ✦

Several Stars, Many Nebulae, and One Fine Galaxy in Aquila

Object	Type	Magnitude	Size/Separation	RA	Dec.
V Aquilae	Carbon star	6.7 – 7.2	—	$19^h 04.4^m$	–05° 41′
Barnard 130	Dark nebula	—	7′	$19^h 01.9^m$	–05° 34′
Barnard 127	Dark nebula	—	4′	$19^h 01.6^m$	–05° 27′
Barnard 129	Dark nebula	—	5′	$19^h 02.1^m$	–05° 18′
NGC 6751	Planetary nebula	11.9	26″	$19^h 05.9^m$	–06° 00′
Barnard 134	Dark nebula	—	6′	$19^h 06.9^m$	–06° 14′
Barnard 133	Dark nebula	—	10′ × 4′	$19^h 06.2^m$	–06° 53′
Teutsch J1906.4–0647	Asterism	—	2′	$19^h 06.4^m$	–06° 47′
IC 4846	Planetary nebula	11.9	2″	$19^h 16.5^m$	–09° 03′
Minkowski 3-34	Planetary nebula	12.5	6″	$19^h 27.0^m$	–06° 35′
Struve 2545	Triple star	6.8, 8.5, 11.6	4″, 26″	$19^h 38.7^m$	–10° 09′
Struve 2547	Triple star	8.1, 9.5, 11.1	21″, 50″	$19^h 38.9^m$	–10° 20′
NGC 6814	Spiral galaxy	11.2	3.0′ × 2.8′	$19^h 42.7^m$	–10° 19′

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.



Lowered
Raised
PT2, PT3 Fixed Height- Adjustable Piers

TP2 Portable Height - Adjustable Piers
Raised
Lowered

20
SERIES FULLY MULTI-COATED
ROGEN-PURGED WATERPROOF

Explore Saturn
with Our Newest App
SKY
Saturn's Moons
Download on the App Store

NEAF 2013

This two-day gathering is one of the world's premier annual astronomical events.

During a pleasant weekend last April, several thousand astronomy enthusiasts made their annual pilgrimage to Rockland Community College in Suffern, New York, for the Northeast Astronomy Forum (NEAF). The debut of new astronomy gear is always a highlight of the gathering, and our photo coverage this year focuses on some of the equipment we found particularly interesting.

1. www.celestron.com • The fist-sized StarSense module is a retrofit that adds fully automated and foolproof initialization to most of Celestron's Go To scopes made during the past decade.

2. www.denkmeier.com • You'll never have to worry about a heavy eyepiece unexpectedly spinning sideways with this 2-inch star diagonal and Inter-Locking Visual Back (IVB) for Schmidt-Cassegrain telescopes. A toothed coupling allows quick and secure positioning of the diagonal in any viewing position.

3. www.pro.usa.canon.com • With their EOS EF mounts, Canon's Cinema lenses offer unprecedented optical and mechanical quality for discriminating night-sky photographers.

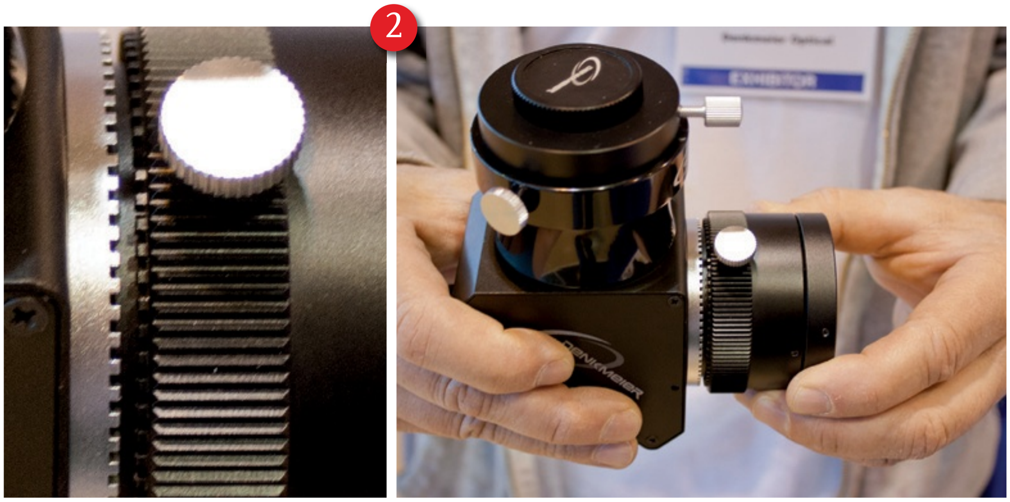
4. www.celestron.com • Celestron's new off-axis guider includes helical focusing on the guiding port along with features that make it highly compatible with today's digital cameras and autoguiders.

5. www.skycube.org • This flight-ready spare for a crowd-funded satellite slated for launch later this year garnered lots of attention. Watch our in-depth video interview with project leader Tim DeBenedictis at **skyandtelescope.com/NEAF2013**.

6. www.explora-dome.com • The folks at Explora Dome offer a variety of cost-effective solutions for backyard amateur observatories ranging from simple domes to complete buildings.

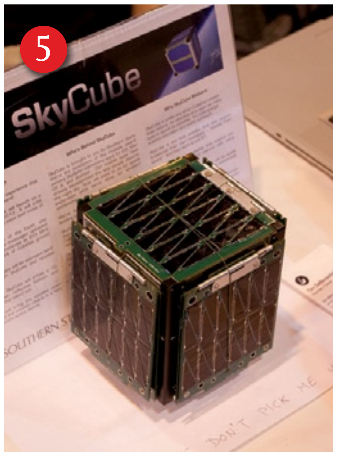
Photos and text by Sean Walker & Dennis di Cicco


1


2


3
Canon
85


4


5
SkyCube


6
EXPLORADOME

7. www.astronomerswithoutborders.org • Mike Simmons, President and CEO of Astronomers Without Borders (AWB), displayed the organization's soon-to-be-available Dobsonian reflector. Imported by Celestron exclusively for AWB, the 130-mm (5.1-inch) f/5 reflector has a collapsible tube and weighs only 14 pounds (6.4 kg), including the mount. But perhaps best of all, it costs just $199 with two eyepieces and free shipping in the U.S.

8. www.celestron.com • The just-announced Advanced VX German equatorial mount from Celestron has been specifically engineered for imaging with mid-size telescopes weighing up to 30 pounds (14 kg). It incorporates numerous features found in the company's high-end astrophotography mounts. When fitted with the SkyQ Link WiFi module, it can be controlled with the company's *SkyQ* app for Apple mobile devices.

9. www.qsimaging.com • Quantum Scientific Imaging's Kevin Nelson shows off one of the company's large-format 700 Series Cooled Scientific Digital Cameras planned for release later this year. Made for chips as large as the KAF-16803, the 700 Series has a unique mechanical adjustment for precision squaring of the CCD to a telescope's optical axis.

10. www.meade.com • Among the larger telescopes on display this year was Meade's new 16-inch LX600 Advanced Coma-Free catadioptric fitted with the StarLock system that automatically acquires a guide star and begins autoguiding the telescope each time it is aimed at a new target.

11. www.newmoontelescopes.com • A relative newcomer in the world of premium Dobsonian reflectors, New Moon Telescopes exhibited several of its finely crafted wooden scopes that feature a one-piece collapsible truss section, such as the one seen in this picture with company owner Ryan Goodson.

12. www.willbell.com • Familiar faces at amateur astronomy gatherings around the country, Perry and Patricia Remaklus were ready to answer questions about the books published by their company Willmann-Bell. It's impossible to overstate how much their specialized titles on telescopes, telescope making, optics, observing, and astrophotography have benefitted the hobby during the last 40 years. The *Uranometria 2000.0* star atlas has been a mainstay of observers since it was introduced in 1987.

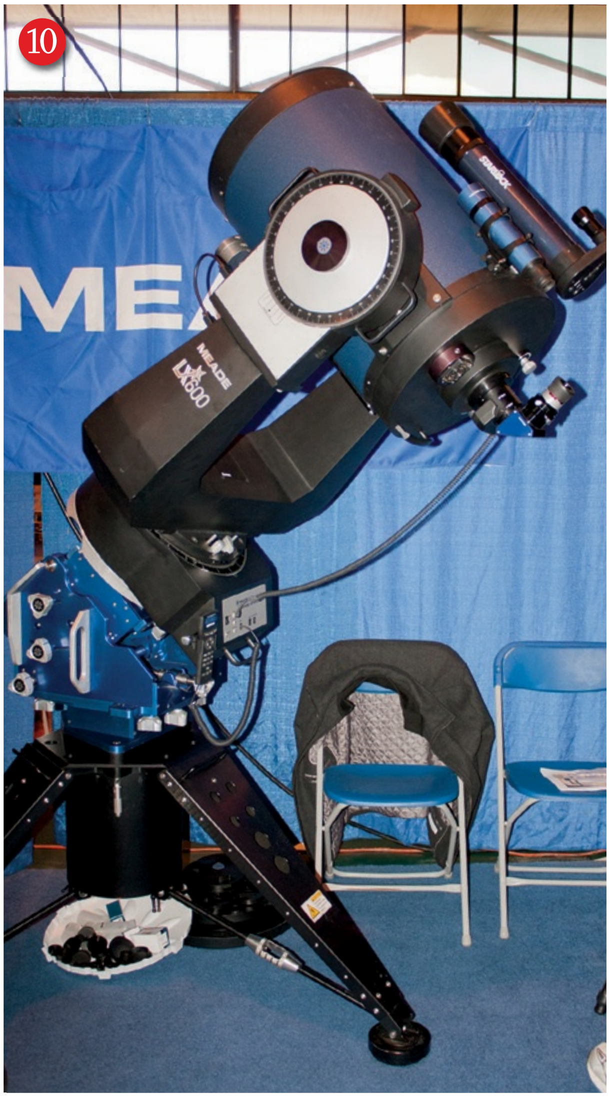
13. www.bucksnortobservatory.com • Although *Sky & Telescope* readers will likely associate John A. Davis with spectacular deep-sky photography that's appeared in the magazine recently, the Texas-based astrophotographer garnered much of his celebrity status at NEAF, especially with younger attendees, as the multi-talented creator of the *Jimmy Neutron: Boy Genius* cartoon series.

For video coverage of more equipment at this year's NEAF gathering, as well as at past events, go to skyandtelescope.com/Product Videos.

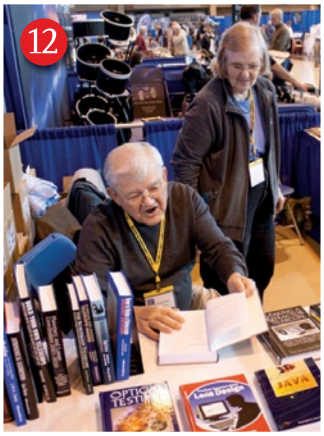
7

8


9
QSI
QUANTUM SCIENTIFIC IMAGING, INC.
Blazing Fast! Biting Cold!
QSI


10
MEA
MEADE
LX600


11
nmt


12
Lens Design
JAVA


13
ant
BULLY
JIMMY NEUTRON
BOY GENIUS

14. www.astrofactors.com • Although QHYCCD's digital cameras are better know outside of North America, that might change now that AstroFactors in Plano, Texas, has become a distributor.

15. www.televue.com • Among the prototype equipment on display this year was this integrated imaging setup that rigidly couples a Tele Vue TV-NP127 (5-inch f/5.3) apo refractor to a large-format FLI CCD camera and Atlas focuser.

16. www.rocklandastronomy.com/NEAF • Although we're focusing on the new equipment at this year's event, NEAF has much more to offer, including lectures, workshops, kids' events, and a program devoted to observing the Sun (pictured here).

17. www.focuser.com • MoonLite Telescope Accessories continues to add to its growing line of high-quality focusers for observers and imagers, including the model shown here that allows users to remotely control focus position and camera rotation.

18. www.skywatcherusa.com • Jeff Simon of Sky-Watcher USA displayed a wide range of telescopes at the show, including this prototype 18-inch transportable Dobsonian reflector that features an exceptionally lightweight primary mirror. A 20-inch version is also in the works.

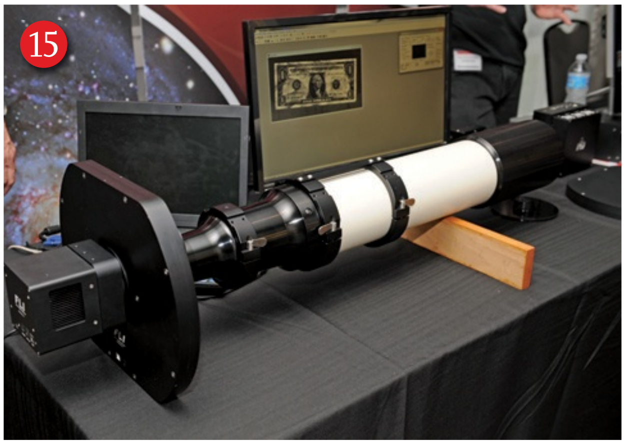
19. www.teeterstelescopes.com • Teeter's Telescopes had one of the largest displays of Dobsonian reflectors at this year's event. Among them was this new 10-inch f/5 Journey model made for "awesome portability." It's designed to disassemble and fit, along with your observing accessories, in one soft-padded travel case that rolls on wheels.

20. www.shelyak.com • One of the world's leading manufacturers of spectroscopy equipment for amateur astronomers, Shelyak Instruments debuted its new compact, modular spectrograph system called Alpy. The spectrograph assembly (less CCD camera) seen at right in the picture can be fitted to the separate guiding and calibrations modules at left, forming a complete system for acquiring detailed spectra of faint astronomical objects.

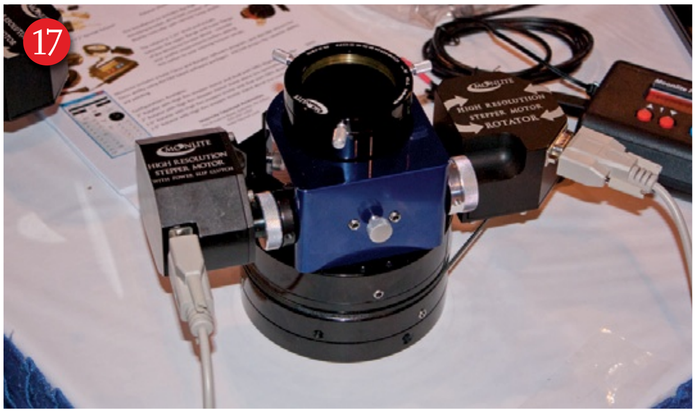
21. www.10micron.com • 10 Micron, the Italian manufacturer of high-end German equatorial mounts, exhibited the GM1000HPS, the smallest member of its new robotic mounts. It has a load capacity of 55 pounds (25 kg), and features direct Ethernet connectivity to a remote computer.

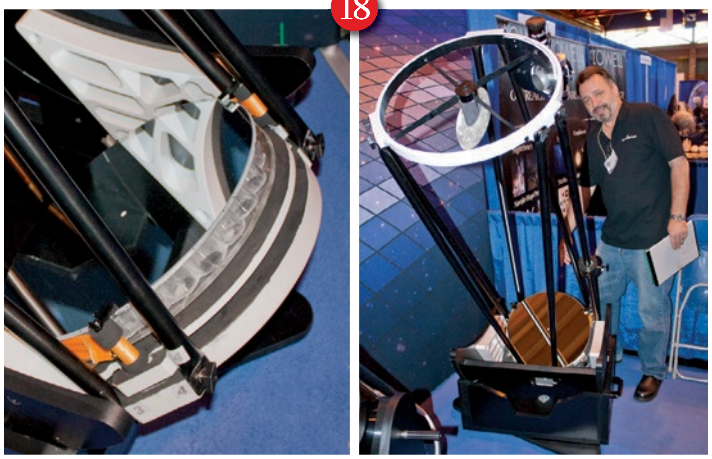
22. www.sbig.com • A new self-guiding filter wheel and prototype high-speed AO guider for its large-format cameras were among the wares on display by Santa Barbara Instrument Group. ✦

14


15


16


17
HIGH RESOLUTION STEPPER MOTOR
HIGH RESOLUTION STEPPER MOTOR ROTATOR


18


19


20
WWW.SHELYAK.COM
Alpy


21
CELESTRON
HPS


22
SBIG
SBIG

Jim's Traveling Telescope

This design yields a compact, portable instrument ideal for airline travel.

Lots of people enjoy cooking. Most of us are content to work from a recipe, but for a few adventurous cooks, that's just a starting point — the fun lies in creating something that's both tasty *and* new. Telescope makers can be a lot like that. Most ATMs build Newtonian reflectors, but there are a few who prefer to try something different when they have a specific observing need. ATM Jim Stilburn of Victoria, British Columbia, is one of them.

When Jim decided to build a travelscope for a recent trip to Costa Rica, he opted for something other than a simple Newtonian. "The main design goal was to make a high-quality, compact telescope that would qualify as airline carry-on luggage," Jim explains. A Cassegrain with a short tube was the only configuration that would permit him to have a 6-inch aperture instrument that wouldn't require a lot of assembly in the field.

As I have noted in previous columns, defining your telescope-making goals is half the battle. The other half is actually building the scope. But as baseball legend Yogi Berra might have said, that's the bigger half! The optical recipe for Jim's telescope is built upon preexisting ones. "I did a lot of experimentation with *Zemax* optical-design software, which makes it possible to let your imagination run wild," he recounts. "Most of the telescope ideas I investigated didn't produce good images, but after setting up and optimizing several corrected Dall-Kirkham configurations, I came up with a compact f/9 system that yields superb images."

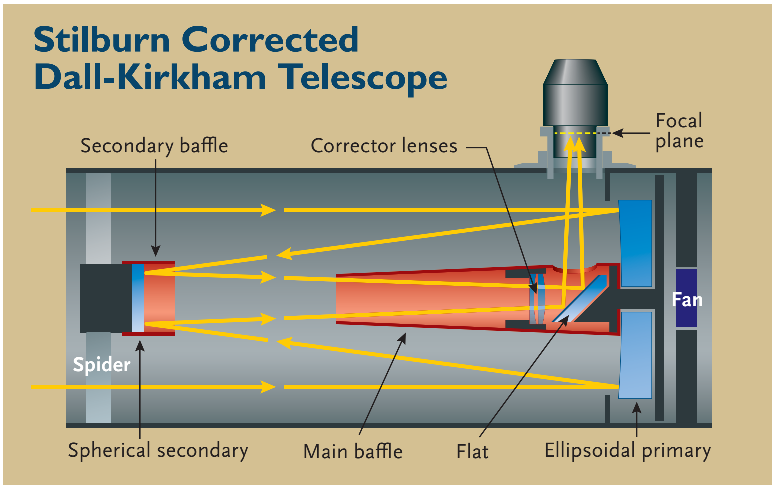
In some ways, the resulting telescope was decades in the making, beginning with the efforts of Jim's wife, Sylvia Alers. "When Sylvia was in high school she began grinding a mirror for a 6-inch f/9 Newtonian," Jim recalls. "She had finished the fine grinding, but the project was interrupted when she moved to Victoria and the mirror kit was put into a cardboard box, where it stayed for 40 years. She was quite happy to let me regrind the mirror for my telescope."

Jim Stilburn designed and built his 6-inch f/9 corrected Dall-Kirkham for a stargazing trip to Costa Rica. The scope provides diffraction-limited performance across a 1.2° field. *Right:* Weighing only 14 pounds (6.4 kg) in its padded case, the scope easily qualifies as carry-on airline luggage. Its alt-azimuth base and tripod travel with the rest of Jim's checked luggage.

ALL PHOTOGRAPHS BY THE AUTHOR

Jim's scope has an ellipsoidal primary mirror and a spheroidal secondary. In this case, the primary has a functioning diameter of 5¾ inches and focal ratio of f/3.75, with a conic constant of 0.75, which means it's under-corrected compared to a Newtonian's paraboloidal mirror. The 2-inch-diameter secondary is a convex spheroid with a radius of curvature of 24.78 inches.

The Achilles heel of the



S&T: GREGG DINDERMAN

Key to any Cassegrain-type telescope is effective baffling. Jim's design has a baffle for the secondary mirror as well as a main baffle tube, which also houses the scope's corrective lenses.

standard Dall-Kirkham design is strong coma — especially when the scope is faster than f/15. This generally limits its utility for wide-field observing. To solve the coma problem, Jim designed his optical train around a pair of carefully selected corrective lenses. This 2-element corrector is housed in the scope's carbon-fiber baffle tube, just ahead of the tertiary mirror that feeds the converging light cone to the helical focuser and eyepiece on the top of the optical tube assembly. The best part of Jim's recipe is that the mirrors are relatively easy to make, and the corrector lenses are available as off-the-shelf items from Ross Optical (**www.rossoptical.com**) for $38 each (part numbers L-PCC090 and L-PCX250).

Assembling the scope takes more care than a typical Newtonian, but is in line with many other compound designs. The tolerance for all of the element spacings is quite tight (about 0.05 inch), but this isn't difficult to achieve with a caliper. Precise collimation is also very important, especially between the primary and secondary mirrors.

So how does Jim's scope perform? Having viewed with it in Costa Rica, I can say that it's a splendid instrument. Although Cassegrain telescopes are generally thought of as planetary scopes, the f/9 focal ratio of Jim's design also makes it a good deep-sky hunter capable of delivering a true field of more than 1° across. Using the scope in Costa Rica, Jim noted that his views of the Orion and Eta Carina nebulae were memorable indeed, while old friends such as M51 and NGC 4565 demonstrated how much a 6-inch can show under a dark sky.

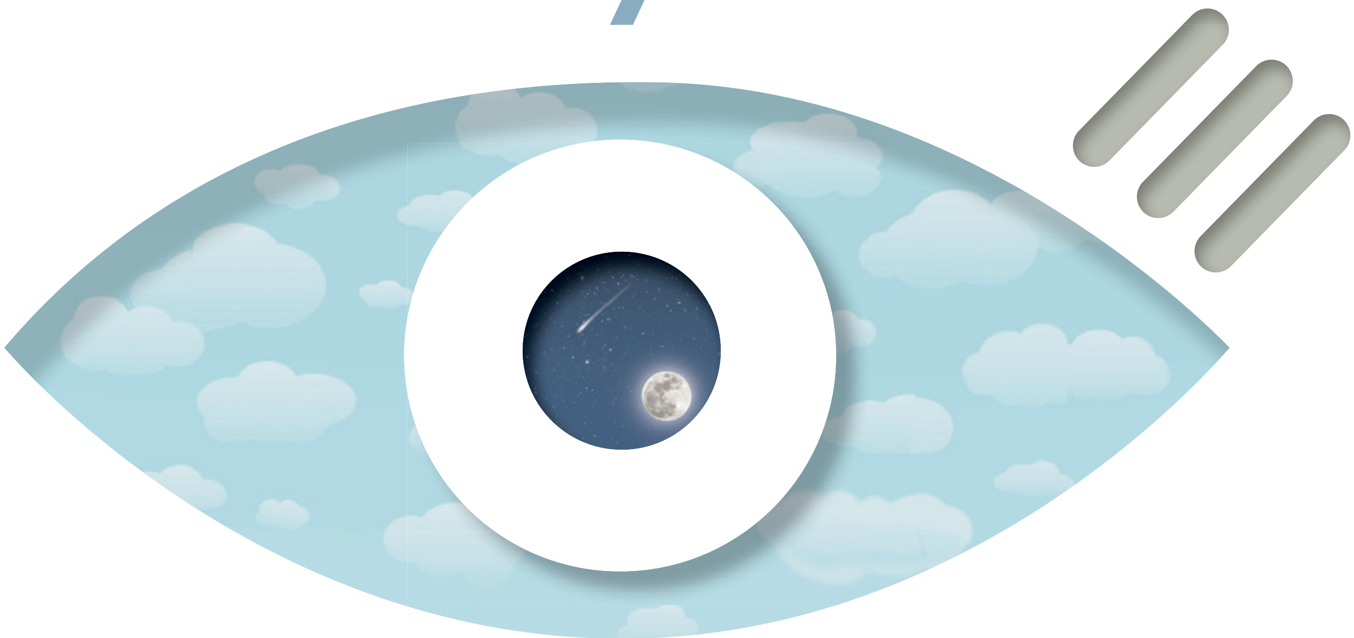
I couldn't help but ask what Jim might do for an encore now that he's designed and built such a satisfying travel-scope. "There is very little that can be done to optimize my scope further," Jim replied. "The secondary obstruction could be reduced from the current 39% to perhaps 33%, but that would require a longer focal length. However, the design scales linearly, so increasing the aperture to 8- or 10 inches would be easy." I'd like to see that.

Readers wishing to learn more about Jim's design can contact him via e-mail at watoto1@gmail.com. ✦

Contributing editor Gary Seronik is an experienced telescope maker. Some of his creations (including a distinctly non-compact 6-inch f/9 Newtonian) are featured on his website, ***www.garyseronik.com***.

While attending the 10th annual Costa Rica Southern Sky Party last February, Jim and his wife Sylvia observed many of the sky's showpieces with the scope.

The Sky Within



Eye aberrations can have a big effect on visual observing. Here are some tips for seeing the universe more clearly by working with your eyes' imperfections.

When you look naked-eye at the brightest stars in the night sky, do they really look like small pinpoints of light? If your answer is yes, congratulations: you may be among the few people whose eye optics are nearly perfect. But most of us will probably see "hairy" star images if we look carefully. This is nothing unexpected. It's just the most conspicuous effect of eye aberrations.

From an instrument maker's viewpoint, the eye's optics are indeed far from perfect. As the renowned German anatomist and physicist Hermann von Helmholtz (1821–1894) once wrote:

> Now it is not too much to say that if an optician wanted to sell me an instrument which had all these defects, I should think myself quite justified in blaming his carelessness in the strongest terms, and giving him back his instrument.

In an optically perfect eye, all rays coming from a distant point source should be focused to a single point on the retina (see page 70). The human eye is, however, a highly complex living structure, composed of several refracting surfaces and an aperture stop, all kept in place by a combination of tissue rigidity, muscular stress, and intraocular pressure. It's also subject to continuous short-term changes (such as variations in pupil size) and long-term growing processes, such as changes in the size, shape, and internal structure of the eye lens, which cause our vision to alter as we age. The eye's components are somewhat off center and tilted with respect to one another, and their surfaces are deformed in various ways. It would be rather surprising if such a rich biological structure created an absolutely stable and perfect optical system.

In most healthy eyes, light leaving the lens's backside deviates from the shape of an ideal wavefront that is perfectly spherical and focused at the retina. This deviation is called the eye's *wave aberration*. The simplest eye aberrations are nearsightedness (myopia), farsightedness (hyperopia), and astigmatism. These are the smoothest deformations an ideal wavefront can suffer and they change where light focuses in the eye: moving the focal point in front of (myopia) or behind (hyperopia) the retina, or refracting incoming light differently depending on which eye meridian the light passes through (astigma-

S&T ILLUSTRATION: PATRICIA GILLIS-COPPOLA

Your Eyes

Salvador Bará

tism). Since these deformations can be described mathematically by expressions called second-order polynomials, they are technically termed *second-order aberrations*.

Normal eyes also show more complex wavefront distortions, collectively known as *higher-order aberrations* (HOAs). The existence of these higher-order refractive defects has been known for years, but only in recent times have we developed practical devices to measure them and, in some cases, to correct them. This is a story closely tied to the development of advanced astronomical instrumentation. In the lab, eye aberrations are now measured — and even compensated for — using essentially the same kind of wavefront sensors, deformable mirrors, and laser guide stars that are used in today's high-resolution adaptive-optics systems.

So are we fighting a losing battle against our eyes? Not at all. A better understanding of your own eyes' strengths and weaknesses can actually improve your observing.

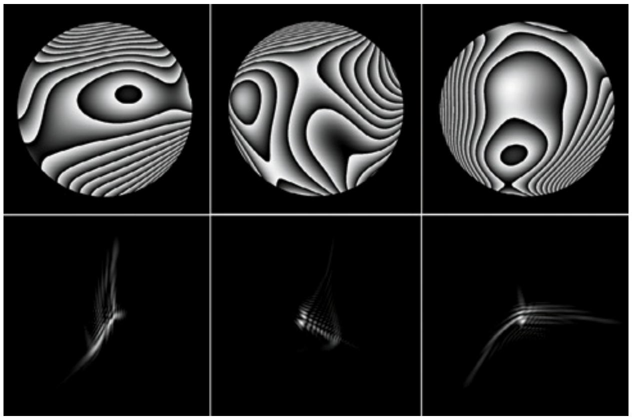
Play With Pupil Sizes

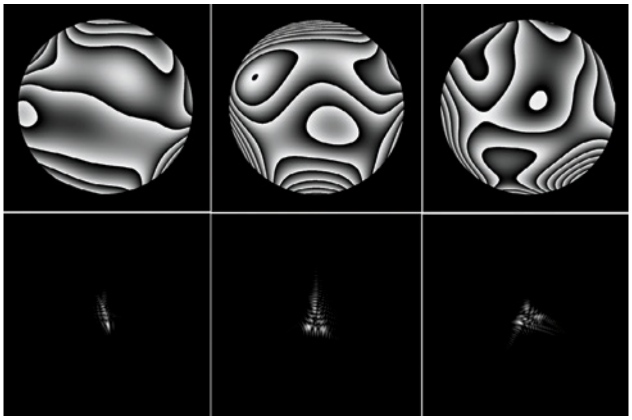
Each human eye has its own aberration pattern. This pattern creates unique "star images" on the retina. Under normal nighttime viewing conditions and with fully dilated pupils, the retinal image of a bright point source may span several tens of arcminutes and can be even greater than the angular size of the full Moon. This irregularly shaped light distribution is commonly called the eye's *point-spread function* (PSF). The aberrations might be similar in a person's left and right eye, but patterns vary widely between people. Aberrations are in some sense the eye's fingerprints.

The magnitude of aberrations increases with pupil diameter and with age. Once spectacles or other equipment corrects for the classical forms such as myopia, the HOAs of healthy eyes for people in their 30s are still typically far more severe than you would accept in your telescope optics.

When observing extended objects such as the Moon or planetary nebulae, your eye aberrations will blur the target's small-scale structures. The magnitude of this blurring is highly variable between people, but it averages what would be produced by the lowest increment in a prescription for myopia, 0.25 diopter. That's not too much for everyday life, but it will be noticeable for any careful visual astronomer.

***Left panels*: Eye-aberration maps of the right eyes of three observers (*top row*) and how a point source looks to their retinas (*bottom row*). The pupil diameter is 6.5 mm, and the size of each retinal image box is 36.5 arcminutes, slightly bigger than the full Moon. The maps are like topographic plots: the grayscale between consecutive curves spans 0.5 micrometer in height, like terrain elevations — except here the "terrain" is the difference between the ideal and actual wavefronts. If no aberrations existed, the maps would be completely flat. *Right panels*: Eye-aberration maps and retinal images of a point source for the same observers in the left panel, but with fully corrected second-order aberrations (that is, showing only the higher-order effects).**



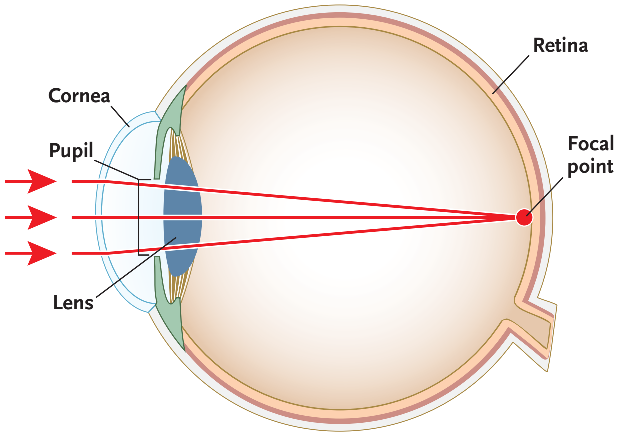


SALVADOR BARÁ, SOURCE: RAFAEL NAVARRO / ICMA-CSIC ZARAGOZA (6)

The eye's resolution improves at first with decreasing pupil diameter, because shrinking the pupil size also shrinks the halo created around a point source by the eye's aberrations. But for very small pupil diameters of about 1 mm or less, diffraction limits the resolution. (A 1-mm aperture, for example, has a fundamental resolution limit of about 2 arcminutes.) As a result, eyes tend to perform best with pupil diameters in the 2–3 mm range (a typical daytime pupil size).

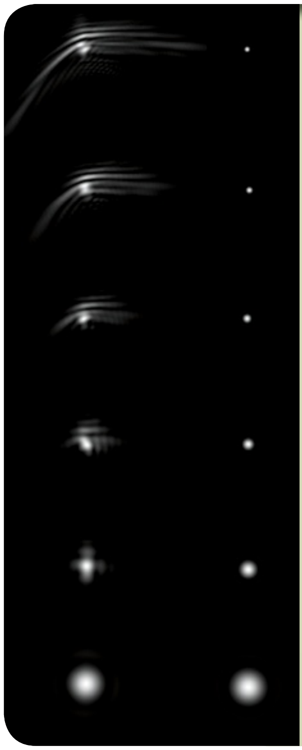
For visual observing through a telescope, the effective pupil size will be determined by your instrument's "exit pupil" or by the entrance pupil of your eye, whichever is smaller. Using eyepieces with small exit pupils is a good strategy to stop down the aperture and counteract the effects of your eye aberrations. Small exit pupils may also be helpful if your eyes have a moderate to high astigmatism and you prefer to not wear spectacles when observing: unlike near- and farsightedness, you cannot fully compensate for astigmatisms (or HOAs) by simply refocusing the telescope.

The size of your telescope's exit pupil is given by the diameter of the telescope's objective divided by the magnification. You may find that for your particular telescope (and eyes) there is a range of magnifications that give you the most detailed images. For example, if your optimum pupil diameter is about 2 mm and the aperture of your telescope is 200 mm, then magnifications close to 100× will probably do the best job. When observing objects at lower magnifications (and hence using eyepieces that create larger exit pupils), you may want to stop down the exit pupil by putting an appropriately sized hole in a spare eyepiece cap and putting the cap on the eyepiece. The aperture stop should ideally sit at the plane of the exit pupil, the precise position of which will depend on your eyepiece's eye relief. You can also stop down the telescope objective itself by using a set of masks with diameters appropriate for your most frequently used magnifications.



In an ideal eye, light (red rays) passing through the eye's lens should focus on the retina at the back of the eye. However, few of us have eyes that meet this standard. *S&T* ILLUSTRATION: CASEY REED

Of course, retinal image resolution is not the only issue when selecting an eyepiece. When it comes to observing the delicate structure of dim, extended objects, the target's average brightness and size also come into play. It's easier to detect small contrasts in images that are



SALVADOR BARÁ

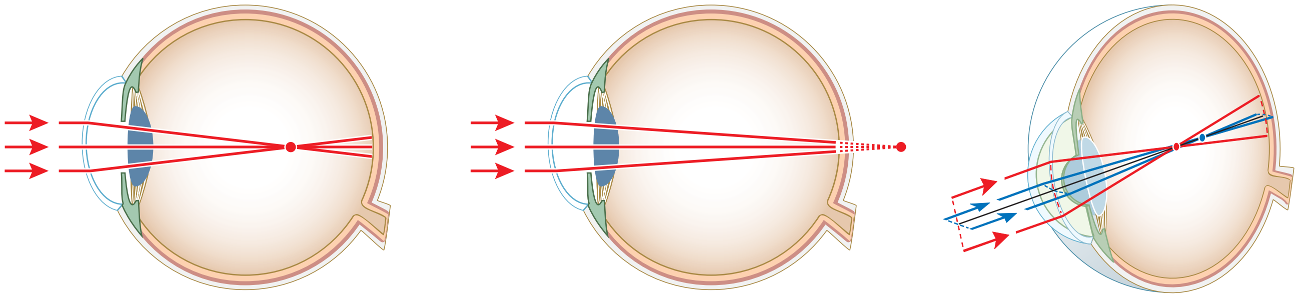
Looking at Your Eyes' Aberrations

If you wish to observe how irregularly your eye distributes light, look at a bright pointlike source surrounded by a dark background while wearing your usual prescription glasses or contact lenses. Since the central core of the eye's light distribution, or *point-spread function* (PSF), is generally much brighter than the wings, you need a dark background in order to observe the subtle structure of these peripheral regions. Keep the ambient light level low to encourage your pupils to dilate. With dilated pupils, ocular aberration effects will become more noticeable. Suitable pointlike sources are bright celestial objects, such as Sirius or Jupiter; unshielded streetlamps a few hundred meters away; or even tiny LEDs at the other end of a darkened room.

Look at the light sources with each eye separately, covering the unused eye with your hand or a card (closing your eye can affect the result), and let your brain perceive the retinal images. You may find that the PSFs of your right and left eyes look a bit symmetric. Then look with both eyes — you will probably perceive a pattern composed of your eyes' individual results.

You can also look through tiny holes of different sizes in a piece of cardboard in order to determine the best diameter for your vision. Also shift the hole side-to-side to find the position that gives the best image: the optical quality of the eye stopped by an artificial aperture is *not* homogeneous across the pupil, and some pupil regions provide better overall optical quality than others.

Left column: The spread of an eye's light distribution for different pupil diameters, from 6 mm (top) to 1 mm (bottom), decreasing in steps of 1 mm. ***Right column***: the light distribution for an ideal eye with no aberrations, for the same pupil sizes.



bright and big, but bright images call for low magnifications, whereas big images require high ones. You'll need to compromise in order to simultaneously achieve enough brightness and magnification while keeping aberration blur at bay. In these cases, the optimum pupil size might be somewhat different from that suggested by eye aberrations alone.

Second-order aberrations move the eye's focal point forward (nearsightedness, *left*), backward (farsightedness, *center*), or create two perpendicular foci, depending on the plane in which light rays travel (astigmatism, *right*). The eye can also have more complex distortions, which further affect focusing. *S&T* ILLUSTRATIONS: CASEY REED (3)

Aberrations Made Normal

Our visual system has its own ways of compensating for its limitations. One phenomenon, known as the Stiles-Crawford effect, reduces the perceived brightness of light rays entering pupils' outer edges in comparison with the rays entering the pupil center. Peripheral rays are generally the most affected by aberrations, but most photoreceptor cells point toward the pupil's center, naturally minimizing the problem. Another correction, suggested by a recent experiment carried out by the teams of Pablo Artal (University of Murcia, Spain) and David Williams (Center for Visual Science, University of Rochester), happens when the brain simply adapts to its particular eye-aberration pattern, removing part of the aberration-induced blur.

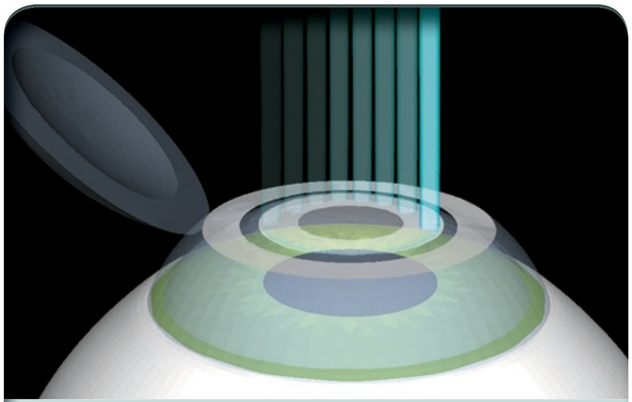
Several technologies can optically compensate for the eye's aberrations, mostly at the research laboratory level. But researchers are also studying whether normal eye aberrations are actually helpful for vision: recent studies show that they may well be the eye's defense against chromatic blur. If so, they would not be mere defects.

Nevertheless, besides bad atmospheric conditions, your eye aberrations can be one of the main sources of poor resolution in visual observing, especially when you're using relatively large-aperture instruments at low magnifications, with their resulting large exit pupils. Should we then give back our eyes? Probably not. Helmholtz himself added a wise (and seldom-quoted) qualification to his dismay:

> Of course, I shall not do this with my eyes, and shall be only too glad to keep them as long as I can — defects and all.

Surely most of us would agree with him.

***Salvador Bará** is an optics researcher at the Universidade de Santiago de Compostela in Galicia, Spain. His research interests include adaptive-optics systems and their applications to high-resolution imaging in astronomy and vision.*



S&T ILLUSTRATION: CASEY REED

Will LASIK help?

LASIK refractive surgery is an efficient technique to correct the classic aberrations called *ametropies* — nearsightedness, farsightedness, and astigmatism — by laser removal of corneal tissue (*S&T*: September 2005, page 36). Advanced surgical systems have wavefront sensors that allow surgeons to attempt to correct not only these ametropies but also several higher-order aberrations (HOAs). However, the practical results of LASIK concerning HOAs still fall somewhat short of expectations. Although the ametropy correction is highly successful and patients are usually very happy with the overall outcome, their post-surgical HOAs tend to increase by a factor of about two. Surgical systems and procedures are getting more precise as time goes by, and it is foreseeable that in the near future these outcomes will improve. Meanwhile, if you are planning to undergo refractive surgery and eye aberrations are an issue for you, talk about them openly with your surgeon so you can make an informed decision.

Imaging the Disk of Beta Pictoris

A motivated amateur captures the beginnings of a nearby planetary system.

Rolf Wahl Olsen

The last decade has seen the exponential growth of amateur astrophotography. The amazing developments in CCD detectors and Go To telescope technology allow amateurs to consider projects and goals once better suited for professional observatories with massive telescopes in the final years of the 20th century. Now amateurs are imaging the light produced by quasars more than 8 billion years ago, or resolving tiny features on the Galilean moons of Jupiter. By thinking outside of our comfort zone, we can accomplish feats previously thought impossible.

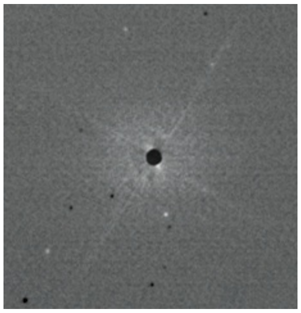
With these rapid advances in imaging technology, what is out there to shoot that can truly test an amateur's capabilities? Although another great photo of M42 or the Magellanic Clouds is nice, my imaging goals focus on taking pictures that are unusual in some way, either being of a rarely imaged object or a familiar object presented in a new way. For the last couple of years I've been wondering if it's possible for amateurs to resolve the circumstellar disk of debris and dust around the 4th-magnitude star Beta Pictoris, first detected by the Infrared Astronomical Satellite (IRAS) in 1983.

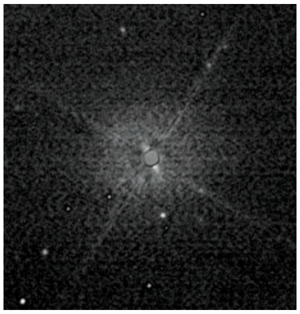
Above: New Zealander Rolf Wahl Olsen poses with his 10-inch (25-cm) Serrurier Truss Newtonian on a Losmandy G-11 mount.

All images courtesy of the author unless otherwise credited

Beta Pic is a young star about 63 light-years away in the southern constellation of Pictor. Roughly 12 million years old, Beta Pic is thought to be similar to how our own solar system must have appeared some 4.5 billion years ago. Its circumstellar disk is seen edge-on from our perspective and appears in professional images as thin wedges or lines protruding radially from the central star in opposite directions.

The first optical image of the disk was taken in 1984 by Bradford A. Smith (University of Arizona) and Richard J. Terrile (Jet Propulsion Laboratory) using a 2.5-meter telescope and CCD camera at the Las Campanas Observatory in Chile. The difficulty in imaging the disk is the overwhelming glare from Beta Pic itself, which completely drowns out any features very close to the star. Images of the disk taken by the Hubble Space Telescope and other





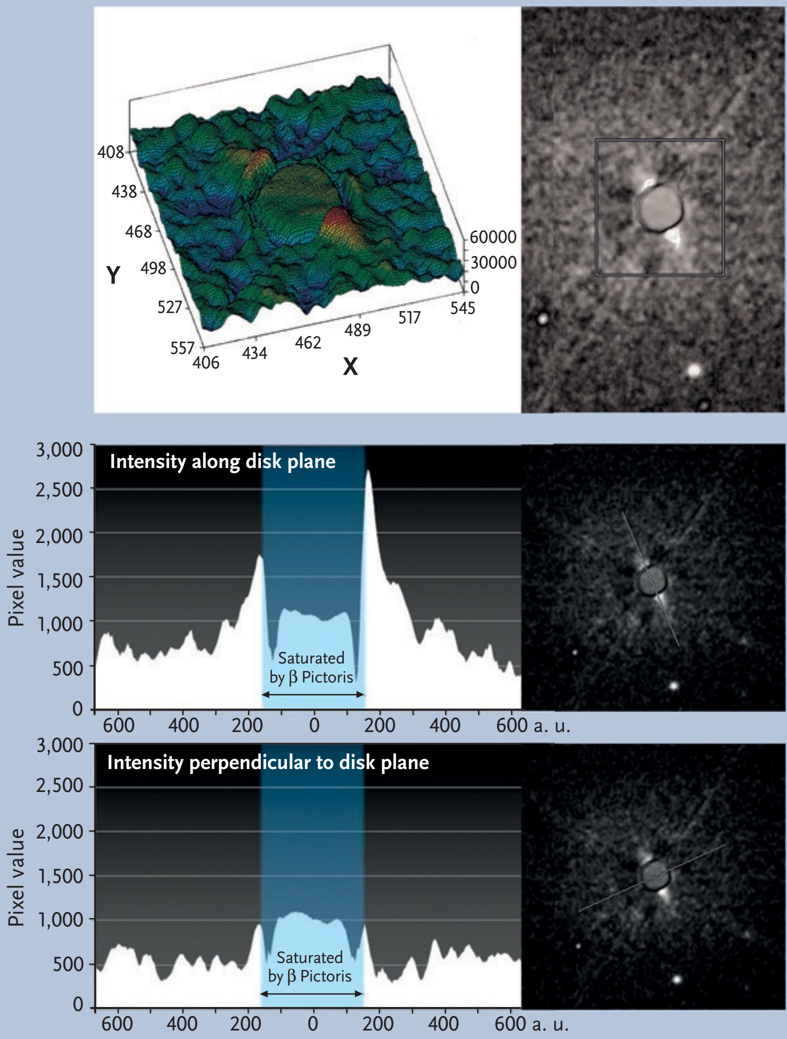
Above: The author's November 2011 image shows Beta Pictoris's debris disk as glowing lines poking in the 5 and 11 o'clock directions from the young star (blacked out). Professionals discovered the disk in a 1983 satellite image, but Olsen became the first amateur to image such a structure.

Using *PixInsight LE*, the author subtracted an image of Alpha Pictoris from an image of Beta Pictoris (*far left*), easily revealing the disk. An absolute difference image produced a noisier but higher-contrast result (*near left*). The author blended the two images to produce his final result above.

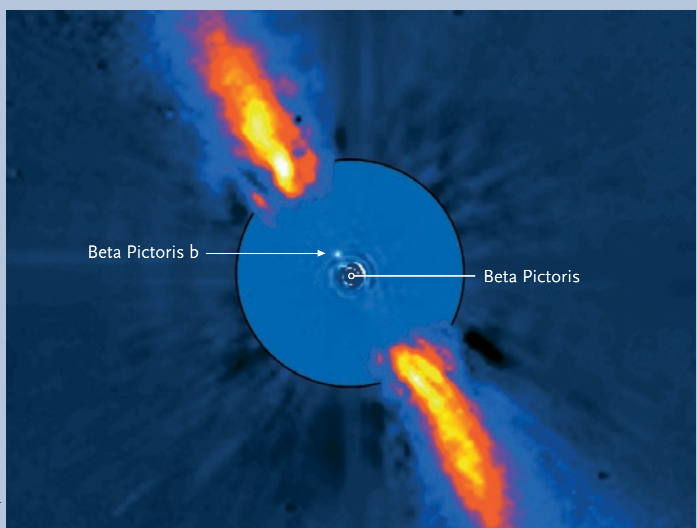
ground-based professional observatories are usually made by physically blocking out the glare of Beta Pic itself using an occulting disk within the optical path.

In pondering this challenge, I came across the paper "Observation of the central part of the Beta Pictoris disk with an anti-blooming CCD," by Alain Lecavelier des Etangs (Astrophysics Institute of Paris) et al., published in *Astronomy & Astrophysics* in 1993. Their idea consisted of imaging Beta Pic and then taking another image of a similar reference star under the same conditions. The reference-star image is subtracted from the Beta Pic image to eliminate the stellar glare, and the dust disk should then reveal itself. I realized that with this technique it might be possible to also record the debris disk with relatively modest equipment. As in the *Astronomy & Astrophysics* paper, I chose Alpha Pictoris as the reference star because it's near Beta Pic in the sky and also of similar spectral type and brightness. However, since the two stars have slightly different magnitudes, I needed to calculate how long to expose Alpha Pic in order to get a proper reference image that I could then subtract from the Beta Pic image.

The magnitudes of the stars are 3.86 for Beta Pic and



Above: **Using the software *MaxImDL*, the author created these plots of the light intensity around Beta Pictoris, showing the debris disk.**



Scientists studying Beta Pictoris using the European Southern Observatory's Very Large Telescope imaged a young planet within the debris disk by carefully subtracting the bright stellar halo close to the star.

3.30 for Alpha Pic. The magnitude difference between the stars then becomes 3.86 – 3.30 = 0.56.

Due to the logarithmic nature of the magnitude scale, a difference of 1 magnitude equals a brightness ratio of 2.512. Therefore 2.512 to the power of the numerical magnitude difference gives the difference in brightness: $2.512^{0.56} = 1.67$. This means Alpha Pic is 1.67 times brighter than Beta Pic. In order to obtain a reference image of Alpha Pic with equal brightness to the Beta Pic image, the exposure times for Alpha Pic should be 1/1.67th, or 0.597 times, that of Beta Pic.

By subtracting the Alpha Pic image from that of Beta Pic, I captured the first amateur picture of the debris disk on November 16, 2011. This image received a lot of attention from amateur and professional astronomers and was subsequently reported in the media all over the world. I was also interviewed live on Radio New Zealand and came home to a television crew and journalists in my driveway wanting to interview me for TV3 here in New Zealand.

Second Pass

After the initial success of capturing the disk, I was also contacted by several people in the amateur astronomy community, including Grant Christie of Auckland's Stardome Observatory. We discussed various techniques and possible improvements that could be made, and following his suggestion, I tried imaging it again using shorter exposures. I did this to minimize the area saturated by Beta Pic itself, which could potentially reveal more of the debris disk closer to the star.

The Sony ICX098BQ chip in my Philips ToUCam is an 8-bit detector that saturates fairly quickly when imaging bright stars, even when using very short exposures. Long exposures with the camera can only be controlled in ½-second increments, so I decided to use 7- and 4-second exposures for Beta Pic and Alpha Pic respectively, which translates to a factor of 0.571. This was very close to the calculated brightness factor of 0.597 and still significantly shorter than the 55 thirty-second exposures I used for the first image on November 16th.

For this second image, I recorded 344 images of Beta Pic at 7 seconds each, and 299 four-second exposures of Alpha Pic. I next calibrated both sets of images using darks and then stacked them separately in *RegiStax* (**www.astronomie.be/registax**). I then subtracted the Alpha Pic image from the Beta Pic image using *PixInsight* (**http://pixinsight.com**), and also created an "absolute difference" image between the two.

I found this absolute difference image easier to work with, but the subtraction image was important as a reference to examine which of the two images had contributed the various parts of the difference.

I created the "natural" appearance of the final image by taking the original stacked Beta Pic image and then blending in the central parts from a stretched version of the absolute difference image that showed the dust disk. I decided to also keep the black-spot result out of the difference image because the contrast with the protruding disk was more visually appealing — there was no occulting disk involved when recording the images. My new image was much better than my first attempt. The higher number of subframes (344 versus 55), coupled with the shorter exposure times, contributed greatly to its improvement.

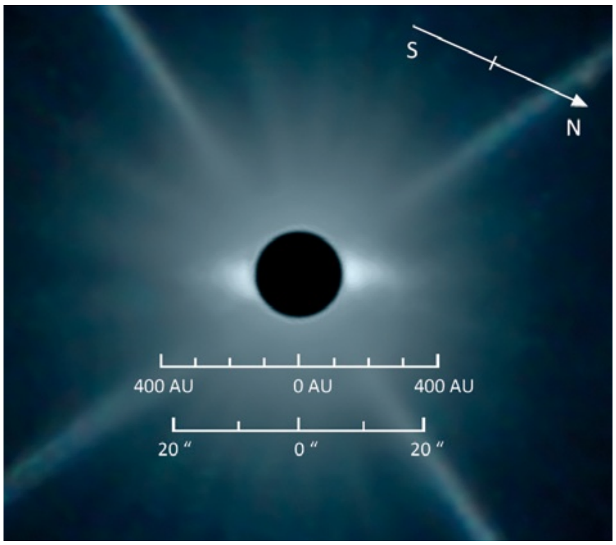
Astrophotographers should consider targeting nearby stars with known debris disks. Small targets such as these have a fascinating story to tell.

Image Analysis

Once I calibrated and combined all my data, I used the popular CCD imaging program *MaxImDL* (**www.cyanogen.com**) to analyze the final results. I first plotted the area intensity immediately around Beta Pic, shown at the top of the previous page. The circular plateau in the center corresponds to the saturated area caused by Beta Pic itself; the narrow trough immediately surrounding it is an artifact of the image processing. The debris disk is visible as the elevated red areas on each side of the star.

I then analyzed the image in *MaxIm DL* using the program's line profile tool. This feature works by displaying the intensity value of pixels between any two points. The two graphs on the facing page show the pixel intensity measured both through the debris disk plane (upper-middle panel) and perpendicular to it (lower middle). Because we know Beta Pic's distance, we can convert the angular scale on the sky into astronomical units (a.u.), which is plotted on the horizontal scale. The area saturated by Beta Pic itself is highlighted on the plots. Analyzing the second plot, the debris disk appears to extend roughly 250 to 300 a.u. before it becomes lost in the background signal.

Measuring the sky quality at my observatory, I have determined that the limiting magnitude with my ToUCam is about +20. So how far out should the debris disk theoretically be visible in my image? Based on the measurements of the signal intensity in the 1984 paper by Smith and Terrile and the limiting magnitude of approximately +20, the debris disk should be visible out to somewhere around 250 to 300 a.u. This corresponds well with my measured result shown below.



This annotated close-up of the author's second image shows the extent of the debris disk on both sides of Beta Pictoris.

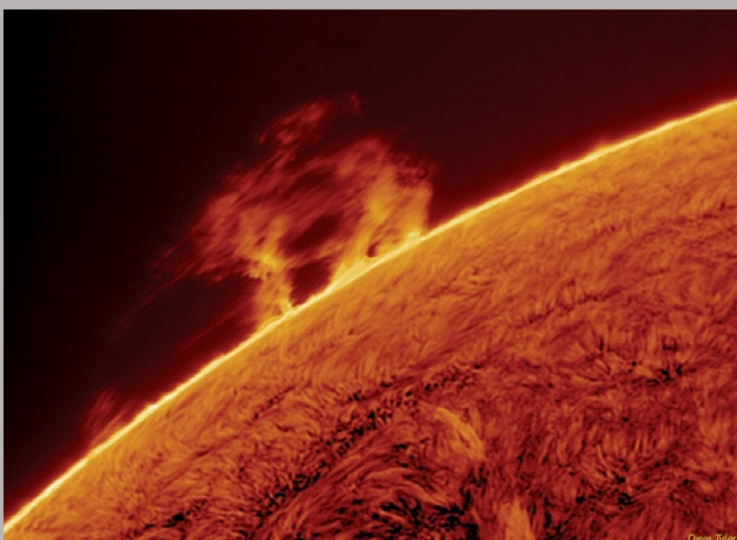
Infrared Sensitivity

The disk surrounding Beta Pic is most prominent in near-infrared and longer wavelengths. The Sony CCD chip in my camera is very sensitive at near-infrared wavelengths, perhaps on par with CCD detectors available today. And while the detector uses a Bayer matrix of color filters over each pixel to record accurate color images, the process of modifying the camera for astronomical use removes the camera's built-in infrared blocking filter, requiring an additional one to be placed elsewhere in the optical path to take accurate color photos. Since my main goal was to image the disk rather than producing an accurate color image, I chose to forgo use of an infrared-blocking filter so that every pixel would still include a strong signal from near-infrared wavelengths.

After publishing this image, I was contacted by several of the scientists involved in studies of the Beta Pic disk and circumstellar disks in general, including congratulations from Alain Lecavelier des Etangs, one of the scientists behind the 1993 paper that inspired me to attempt this image. It has been very rewarding to see how professionals acknowledge and celebrate the achievements of amateurs who push the limit. I am very grateful for and impressed with all the comments and interest I have received from amateurs and professionals from all around the world.

I hope my success encourages other amateurs to go off the beaten path and try to photograph some of the more unusual things thought to be beyond our reach. Although Beta Pic is only visible from the Southern Hemisphere, many other exotic objects, such as gravitational lenses, distant quasars, and relativistic jets emanating from the centers of massive galaxies could be within reach of motivated astrophotographers. These obscure targets often have very interesting stories to tell. ✦

For more images of exotic deep-sky objects such as galaxy clusters, gravitational lenses, and quasars, visit ***Rolf Wahl Olsen's*** *website at* ***www.rolfolsenastrophotography.com****.*



▲ THE OTHER BRIGHT COMET

Alex Cherney

While Comet PanSTARRS took the spotlight in March, fainter Comet C/2012 F6 Lemmon displayed a complex dust tail and greenish coma for astroimagers in the Southern Hemisphere.

Details: *Stellarvue SV80 refractor with a Sony NEX-5N compact digital camera. Total exposure was 150 seconds at ISO 3200, recorded on March 11th.*

◀ A GRAND SPIRAL

Terry Hancock

The bright spiral galaxy M101 in Ursa Major presents observers with numerous knots of star-forming regions, each bright enough to receive their own designation in *The New General Catalogue*.

Details: *Astro-Tech 10-inch f/8 Ritchey-Chrétien Astrograph with QHY9M CCD camera. Total exposure was 9 hours through color filters.*

◀ LIMB DANCE

Dave Tyler

A complex prominence dances along the edge of the chromosphere in the early hours of May 2nd.

Details: *Astro-Physics StarFire 130 EDT with Coronado 90-mm solar filter and Point Grey Research Flea3 video camera. Stack of multiple frames.*

▶ FROM ABOVE AND BELOW

Phil Hart

Bioluminescent algae add an ethereal glow to the water's edge in the Gippsland Lakes of Victoria, Australia. The glow is like a shouted reply to the wheeling stars above.

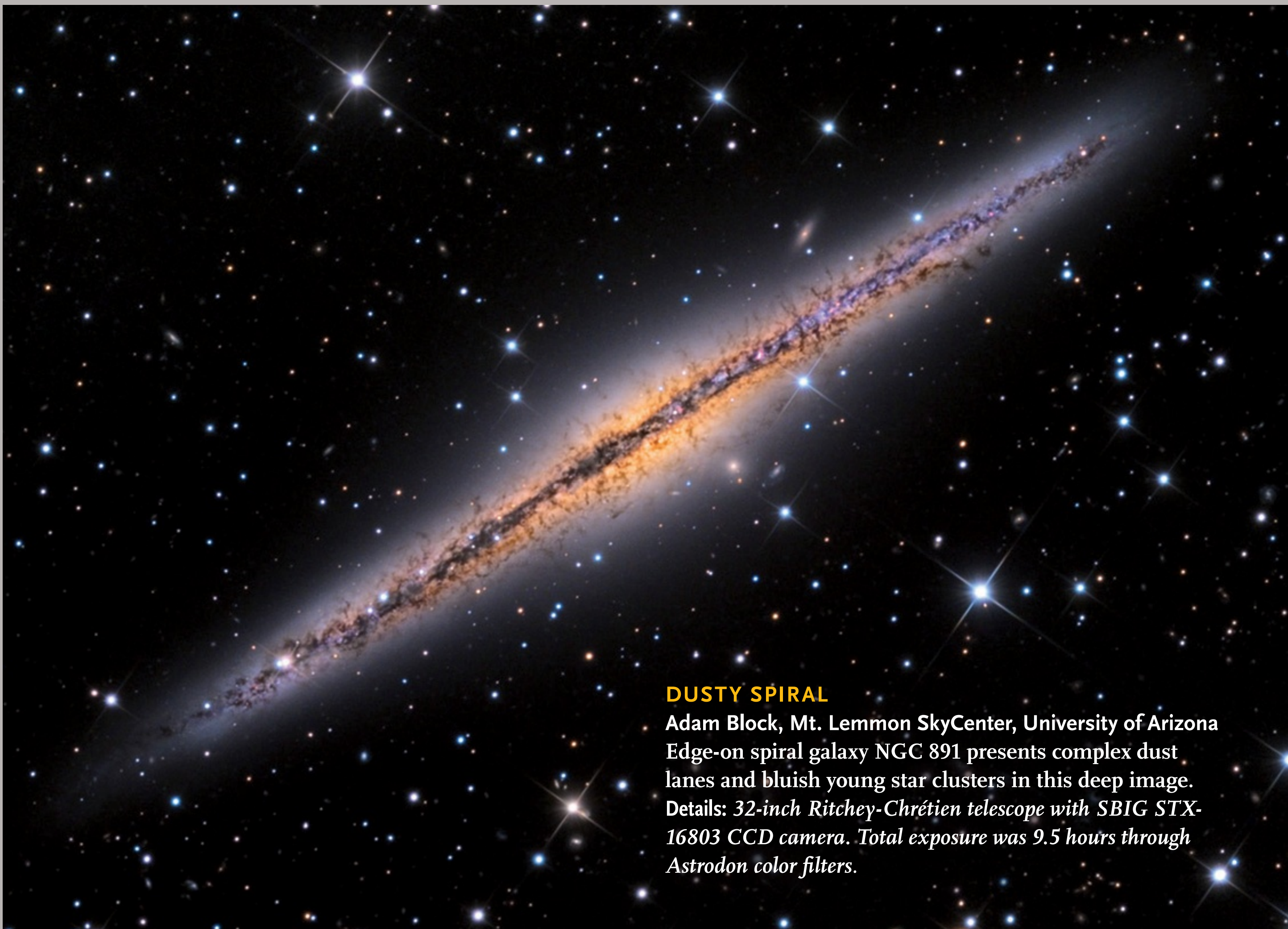
Details: *Canon EOS 5D Mark II DSLR camera with 24-mm lens at f/2. Total exposure was 53 minutes.*

◀ **SHIMMERING CURTAIN**

Richard Sewards

A colorful auroral display erupts over a lake on the Bruce Peninsula in Ontario, Canada. Comet C/2011 L4 PanSTARRS can just be seen below the green aurora band at left. **Details:** *Nikon D7000 DSLR camera with 16- to 85-mm zoom lens at f/4. Total exposure was 30 seconds at ISO 3200 on the evening of March 29th.*

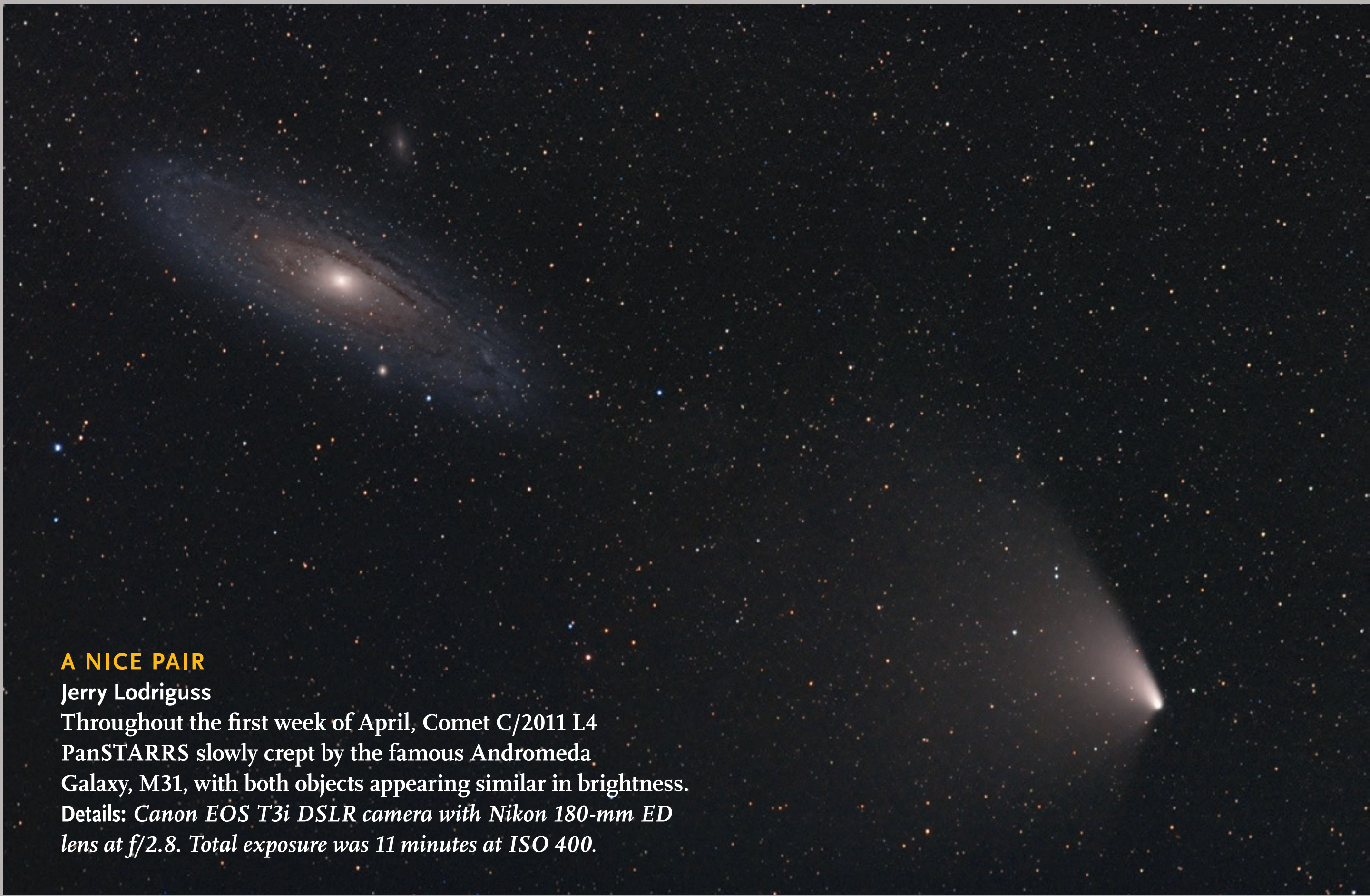
Gallery showcases the finest astronomical images submitted to us by our readers. Send your very best shots to gallery@SkyandTelescope.com. We pay $50 for each published photo. See SkyandTelescope.com/aboutsky/guidelines.



DUSTY SPIRAL

Adam Block, Mt. Lemmon SkyCenter, University of Arizona

Edge-on spiral galaxy NGC 891 presents complex dust lanes and bluish young star clusters in this deep image. **Details:** *32-inch Ritchey-Chrétien telescope with SBIG STX-16803 CCD camera. Total exposure was 9.5 hours through Astrodon color filters.*



A NICE PAIR
Jerry Lodriguss
Throughout the first week of April, Comet C/2011 L4 PanSTARRS slowly crept by the famous Andromeda Galaxy, M31, with both objects appearing similar in brightness. **Details:** *Canon EOS T3i DSLR camera with Nikon 180-mm ED lens at f/2.8. Total exposure was 11 minutes at ISO 400.*

◀ **EVENING EVENT**
Steve Rigel
Comet PanSTARRS was bright enough to be seen above the city lights as it greeted the young crescent Moon over Albuquerque, New Mexico, on t
he evening of March 12th. **Details:** *Canon EOS XSi DSLR camera with 180-mm lens at f/5. Total exposure was 2½ seconds ISO 800.* ✦

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

SKY & TELESCOPE

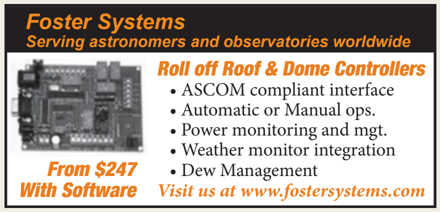
Market Place

Your essential source for astronomical products

ACCESSORIES

ACCESSORIES

ACCESSORIES



ACCESSORIES

ACCESSORIES

BOOKS

CCD EQUIPMENT

OBSERVATORIES / DOMES

OPTICS

ORGANIZATIONS

FOR SALE: 3BR/2.5BA custom-designed home with remotely controlled observatory in central Massachusetts. CN212 telescope on permanent Paramount ME w/ SBIG 10XME camera w/focuser and filter wheel in 2.3M dome (dark skies, 800' elevation). In-ground pool, two fireplaces, cathedral ceilings, hard-wired generator, professionally landscaped, 2-car garage, many upgrades. Also available: library of astronomy books and software. $550k. Contact df121819@aol.com or 508-248-1028.

WEST TEXAS DARK-SKY site 40 miles from McDonald Observatory. A mile high on 4 acres in the Davis Mountains, 12x12 roll-off observatory with electric, phone, pier and C-8. 2,023 sq-ft 3br turnkey house built 1990. Agent website: http://jwcarpenter.com/Z170.htm, phone: 432-837-3325. Owner phone: 314-209-1515.

NEW MEXICO OBSERVATORY with 3700 sq.-ft. modern 6-bedroom 3-bath home attached on 3.26 acres. Magnitude 6.5+ dark skies at 8300-ft. elevation. Located on WSW slope for excellent seeing. Best transparency in the west. Best view in Jemez Mountains. Near Valles Caldera National Monument and national forest. Asking $388k OBO. See www.jm-astro.com for sample astrophotos. Contact james: 505-500-0470 or jlmaxwell@jm-astro.com.

FOR SALE: Beautiful 2,000 sq-ft single-story Pueblo-style home, between Las Vegas and Kingman AZ, 12' automated clamshell dome, 4BR, 3BA, 5 car garage, very dark clear skies, $195,000, for pictures and details email: easton6@cox.net

SOUTHERN UTAH CANYON COUNTRY. Land, remote and beautiful, for sale near Capitol Reef National Park. Wonderful homes away from the lights of the small communities are on the market. The elevation ranges from 4000 to 7000 feet. Cathy Bagley, Boulder Mountain Realty, Inc. Torrey, Utah. 435-425-3200. www. bouldermountainrealty.com.

FOR SALE: Items from the estate of the late William Shawcross, past President of Sky Publishing Corp. Items include Lunt Calcium LS60T CaK scope, 8-inch Cassegrain from TAL, 4-inch f/10 TAL refractor, plus various eyepieces and accessories. For complete descriptive list send email to ads@skyandtelescope.com.

FOR RENT: 3 BR/2BA fully furnished adobe home in ARIZONA SKY VILLAGE in Portal, AZ. Observe and photograph under the darkest, clearest and most transparent skies with astronomers from all over the world. Contact irkitzman@gmail.com 520-203-8500 www.arizona-dreaming.com.

AUTHORS/SOFTWARE DEVELOPERS: is your passion astronomy and would you like to see your work published by Willmann-Bell? If so, let's explore the possibilities. Call 1-800-825-7827 or write PO Box 35025, Richmond, VA 23235.

EASTERN ARIZONA mountain-top observatory with 12' x12' retractable roof, charming 3br, 2ba cottage and large detached art studio on 1/2 acre. Contact blogan0821@gmail.com.

FOR SALE: Classic A-frame, 2x10 construction, 33 mountaintop acres at 6,200' altitude, dark-sky laws in effect. Fort Davis, TX. 250K; matthewoller@yahoo.com.

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 15th of third month before publication date.

SKY & TELESCOPE Inside This Issue

Product Locator

BINOCULARS
Meade (Page 88)
Meade.com
800-919-4047 | 949-451-1450

CAMERAS
Apogee (Page 7)
CCD.com
916-218-7450

FLI (Page 87)
FLIcamera.com
585-624-3760

Meade (Page 88)
Meade.com
800-919-4047 | 949-451-1450

Santa Barbara Instrument Group (Page 3)
SBIG.com
805-571-7244

EYEPIECES
Explore Scientific - Bresser (Page 59)
ExploreScientific.com
888-599-7597

Meade (Page 88)
Meade.com
800-919-4047 | 949-451-1450

Tele Vue (Page 2)
TeleVue.com
845-469-4551

FILTERS
Astrodon (Page 80)
Astrodon.com

FLI (Page 87)
FLIcamera.com
585-624-3760

Meade (Page 88)
Meade.com
800-919-4047 | 949-451-1450

Tele Vue (Page 2)
TeleVue.com
845-469-4551

FOCUSERS
FLI (Page 87)
FLIcamera.com
585-624-3760

MOUNTS
iOptron (Page 13)
iOptron.com
866-399-4587

Meade (Page 88)
Meade.com
800-919-4047 | 949-451-1450

Paramount (Page 27)
Bisque.com
303-278-4478

PlaneWave Instruments (Page 82)
PlaneWave.com
310-787-9411

Tele Vue (Page 2)
TeleVue.com
845-469-4551

OBSERVATORIES
Observa-Dome Laboratories (Page 42)
Observa-dome.com
800-647-5364

SOFTWARE
Fisch Image Lab (Page 59)
ExploreScientific.com
888-599-7597

Software Bisque (Page 27)
Bisque.com
303-278-4478

TELESCOPES
Explore Scientific - Bresser (Page 59)
ExploreScientific.com
888-599-7597

iOptron (Page 13)
iOptron.com
866-399-4587

Meade (Page 88)
Meade.com
800-919-4047 | 949-451-1450

PlaneWave Instruments (Page 82)
PlaneWave.com
310-787-9411

Tele Vue (Page 2)
TeleVue.com
845-469-4551

Dealer Locator

CALIFORNIA
Oceanside Photo & Telescope (Pages 27, 53)
Optcorp.com
800-483-6287

CALIFORNIA
Woodland Hills (Page 9)
Telescopes.net
818-347-2270

NEW YORK
Adorama (Page 35)
Adorama.com
888-223-2500

To advertise on this page, please contact Lester Stockman at 617-758-0253, or Ads@SkyandTelescope.com

Index to Advertisers

BOTTOM: TIM JENSEN; TOP: NASA / JPL / UNIVERSITY OF ARIZONA

IN THE NEXT ISSUE

Water on Mars

NASA has claimed to have discovered water on Mars umpteen times. Has it? We’ll set the record straight.

Quasars at 50

In 1963 a Dutch astronomer discovered that some star-like objects weren’t stars at all. They hailed from earlier times and had more power than anything seen before.

Stitching the Sun & Moon

It’s easy to assemble beautiful solar and lunar mosaics using *Photoshop*.

Windows on the Universe

An experienced observer explains how to make the right choices when selecting eyepieces.

On newsstands July 30th!

Creating Craters at Home

The author inadvertently re-created a miniature lunar landscape.

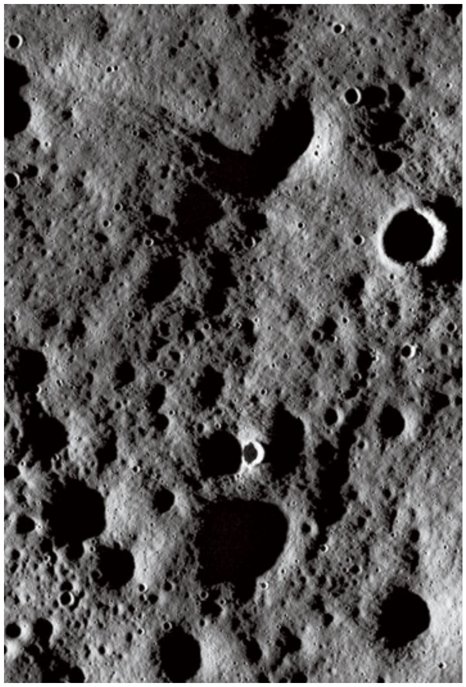
As a do-it-yourselfer and an inhabitant of an old house, I occasionally have to install gypsum-board drywalling. When the time comes to apply the mud-like compound to fill the joints, my technique is not pretty. To achieve a smooth joint, I have to apply multiple layers of mud and then follow up with sanding. I seal the room with plastic sheets, don protective gear, and then go at it. The room fills with an awful fog, and dust falls like snow into what I call my disaster area.

Once, when working near the bottom of a vertical joint, I took a break. As the fog began to clear I wiped dust off my goggles and saw something familiar. There in the dust pile was a miniature lunar landscape, just as I recalled seeing it through a telescope. It was covered and pitted with craters, reminiscent of the Moon's southern highlands.

This started me thinking of similarities between what I was producing on a small scale and what may have happened on the Moon a few billion years ago. The Moon endured a period of heavy bombardment as it did its share of clearing the solar system of primordial stuff. Some of this material was in the form of loose agglomerations of rock held together by their own feeble gravity. As some of these rubble piles approached the Moon, tidal forces tore them apart and pieces struck the Moon not as lumps but as dense streams, much like the dust falling from my wall. On both scales we see the results of streams of small fragments impinging on a bed of essentially the same substance.

Of particular interest was the presence of a central peak in some craters. A common explanation for such peaks in lunar craters is the rebound of the surface following impact, but in my accidental model, the spring back from the dust bed would be virtually nonexistent. More probable is that the dynamics of the flow produced a stagnation zone in the center of the impact site where material was deposited and compacted.

BILL MELLORS



NASA / GSFC / ARIZONA STATE UNIVERSITY

The author accidentally created this landscape (*left*) while installing drywall in his house. It bears a resemblance to this view of the Moon's surface from NASA's Lunar Reconnaissance Orbiter (*right*).

How might this model relate to events that actually took place on the Moon? It would not apply at all to the hypervelocity impacts of rocky asteroids and comets, but maybe there's some similarity to the impacts of loose rubble piles or to debris clouds that had not had time to form into rubble piles. Given the enormous differences in scale and energy levels, this idea might be straining credibility somewhat, but the fractal relationship of the two phenomena remains intriguing.

After this excursion into scientific speculation, my mind returned to Earth to continue sanding. I was left with a lingering facetious thought, which I realize is not the theory currently accepted by most astronomers. Could this Moon that generations of scientists have found so intriguing, and that artists and lovers have found so inspiring, be nothing but an orbiting pile of debris left over from the creation of Earth? ✦

***Bill Mellors** is a retired engineer with a broad interest in astronomy. He observes and takes photographs from his home in a semirural location in Ontario's Ottawa Valley, and writes articles on astronomical events for a local newspaper.*

THE BEST OF BOTH WORLDS

The LX600 and LX850 f/8 ACF with StarLock™

Meade offers you a choice between two precision, ultra stable mounts; both available with fast f/8 ACF® optics and with StarLock™ built in full time autoguiding.

LX850 – The Ideal Astro-Imaging System

The LX850 delivers the ultimate in a portable precision German equatorial mount, able to carry apertures up to 14″ in diameter. Choose from one of Meade's legendary optical system – or use your own.

LX600 – Advanced Technology, Easy to Use, Easy to Move

The LX600 offers you choice of alt-azimuth or polar mode with the X-Wedge™. Alt-azimuth for serious visual observation. Polar mode for digital imaging. Either way, assembly is made easy with the standard Split Fork Arm™ which reduces the heaviest component of the telescope assembly by up to 54 lbs.

Which one will it be? For more information visit Meade.com or contact an authorized dealer.

LX600™ ACF (f/8)

Advanced Coma-Free Telescopes with StarLock™

Prices start at $4,449.00

LX850™

ACF f/8 & 130mm APO f/7 Telescopes With StarLock™

Prices start at $5,999.00

Optics Planet 800.504.5897	OPT Telescopes 800.483.6287	B & H Photo 800.482.8143
Telescopes.com 800.303.5873	Woodland Hills 888.427.8766	Astronomics 800.422.7876
	Canada • Khan Scopes 800.580.7160	

MEADE® INSTRUMENTS

Innovative products for curious minds | *since 1972*