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THE ESSENTIAL GUIDE TO ASTRONOMY

SKY & TELESCOPE

SEPTEMBER 2016

The Impending Flood of Big Data p. 14

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September 2016 VOL. 132, NO. 3

On the cover:
Weak gravitational lensing doesn't alter distant galaxies' images as much as is illustrated here, but the science gained could be just as dramatic.

SPACE ART: CASEY REED

FEATURES

SKY & TELESCOPE (ISSN 0037-6604) is published monthly by Sky & Telescope, a division of F+W Media, Inc., 90 Sherman St., Cambridge, MA 02140-3264, USA. Phone: 800-253-0245 (customer service/subscriptions), 888-253-0230 (product orders), 617-864-7360 (all other calls). Fax: 617-864-6117. Website: SkyandTelescope.com. ©2016 F+W Media, Inc. All rights reserved. Periodicals postage paid at Boston, Massachusetts, and at additional mailing offices. Canada Post Publications Mail sales agreement #40029823. Canadian return address: 2744 Edna St., Windsor, ON, Canada N8Y 1V2. Canadian GST Reg. #R128921855. POSTMASTER: Send address changes to Sky & Telescope, PO Box 420235, Palm Coast, FL 32142-0235. Printed in the USA.

OBSERVING SEPTEMBER

S&T TEST REPORT

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CINDY HUNT / MOUNT WILSON INSTITUTE

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TIPS FOR BEGINNERS
Here's everything you need to jump into the fun of astronomy.
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September 2016 Digital Extra

BONUS WEB CONTENT

- **Aid Juno at Jupiter**
  Amateur astro-imagers can help planetary scientists enhance Juno's data.
- **Watch Kuiper Belt Object 2007 OR10**
  See Kepler's observations of this icy rock in the farthest reaches of the solar system.
- **Shoot Time-Lapse Movies (Video)**
  Learn time-lapse astrophotography using the iPano mount from iOptron.

Photo Gallery

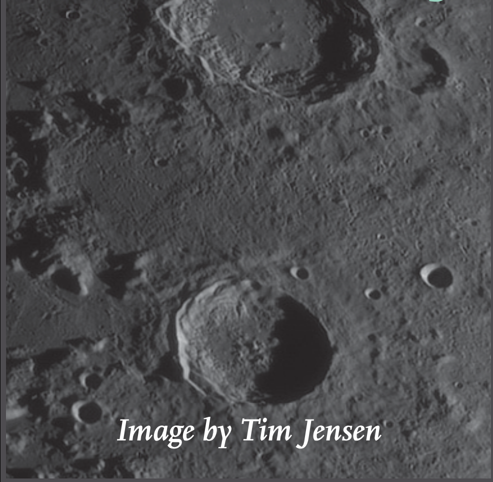

Image by Tim Jensen

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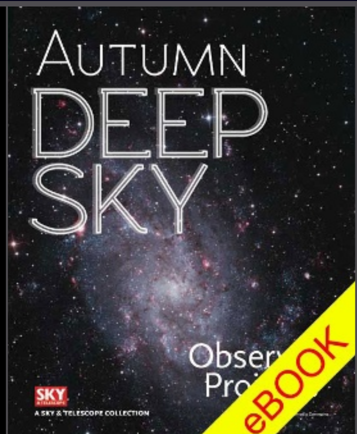

DIGITAL BACK ISSUES: June, July, and August

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ONLINE PHOTO GALLERY

José J. Chambó imaged Comet C/2013 X1 (Pan-STARRS) on June 12th, just 10 days before its closest approach to Earth.

Peter Tyson
Spectrum

Beating Down Uncertainties

IN THE CONTEXT OF SCIENCE, I have always liked the verb "to constrain." I have a visceral response to it, as if I can feel the word going about its business of squeezing a value to bring it within specified limits. (It comes from the Latin *constringere*, to constrict or bind tightly together.) Like a good piece of writing, which casts out the unnecessary and gets straight to the point, the word neatly describes the process astronomers and other scientists use to zero in on a hypothesis that fits the evidence.

Two of the meatiest cosmological enigmas in need of proper constraint are dark energy and dark matter. Current models of cosmology require the existence of these two glaring unknowns, which together make up roughly 95% of everything in the universe. Yet we have no clear idea what either one is. Until we do, we won't have a basic understanding of our cosmos, including the growth of large-scale structure or the cause of its accelerating expansion.

Dark matter (mapped in blue) in a Hubble galaxy-cluster image

In their attempts to rein in these two elephants in the room, astronomers employ various techniques or "probes." One such probe is weak gravitational lensing (see our cover story on page 34). Strong and cluster lensing serve as probes too. So do Type Ia supernovae, the cosmic background radiation, and baryon acoustic oscillations (*S&T:* Apr. 2016, p. 22). Our best hope of yielding the necessary precision to distinguish among models of dark energy and dark matter lies in using these and other such tools in combination, as well as in maximizing their potential.

To do that, astronomers need more data — heaps more. Fortunately, we'll soon have enormously data-rich wide-field surveys like the Large Synoptic Survey Telescope, Euclid, and the Wide Field Infrared Survey Telescope. Astronomy is entering a new arena — that of "big data" (see article on page 14) — which will be challenging to manage but promises to open new windows on the universe's constituents and properties.

Who knows? Maybe we'll even succeed in constraining theories and models of dark energy and dark matter thoroughly enough not only to grasp what they are, but also to devise a fundamental theory of physics for our universe. Until now, both have been frustratingly elusive. Astronomers, constrain away. ✦

Peter
Editor in Chief

IMAGE: NASA / ESA, D. HARVEY (ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE, SWITZERLAND) / R. MASSEY (DURHAM UNIVERSITY, UK) / THE HUBBLE SM4 ERO TEAM / ST-ECF / ESO / D. COE (STSCI) / J. MERTEN (HEIDELBERG/BOLOGNA) / HST FRONTIER FIELDS / HARALD EBELING (UNIVERSITY OF HAWAI'I AT MANOA) / JEAN-PAUL KNEIB (LAM) AND JOHAN RICHARD (CALTECH, USA)

SKY & TELESCOPE

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

The Essential Guide to Astronomy

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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.

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My Town, Our Planetarium # 194

GOTO HYBRID PLANETARIUM CHIRON III

GOTO

Sapporo

Sapporo Science Center opened in 1981 to support a more creative young generation of Japanese students. Original exhibitions at the center include an artificial snow machine and low temperature exhibition room, as well as a hands-on workshop which enables visitors to get to know science with the help of older citizens of Sapporo. Its original planetarium projector in its 18-meter dome was a GOTO Model GN-AT, followed by a GOTO Model URANUS, and as of April 2016, a brand new GOTO CHIRON III HYBRID has been installed. This system synchronizes the beautiful CHIRON III projector with GOTO's VIRTUARIUM X fulldome digital system, to make the finest sky, and also a dynamic, colorful, animated experience.

The CHIRON III has features such as an independently dimmable Milky Way made up of 100,000,000 micro-stars. It is the first projector in the world to group 9,500 stars (down to magnitude 6.55) by color temperature, to show the diverse family of stars surrounding us. The CHIRON III sky is bright, colorful, fast-moving, and extremely accurate.

But the CHIRON III isn't the end of the story. GOTO's VIRTUARIUM X fulldome digital system supplies additional sky enhancements such as coordinate lines, constellation outlines, comets, eclipses, and many more images. At Sapporo, the VIRTUARIUM X is even loaded with panoramic images of the 202 local schools in Sapporo City. So students will feel like they are in familiar surroundings back at school for easy orientation to the night sky. Then, when they go back home, the night sky overhead will "fit" the mental image given to them at the planetarium.

VIRTUARIUM X is currently a product for domestic sales only, but GOTO INC works with other select fulldome providers to create HYBRID planetariums around the world. Ask GOTO about a HYBRID upgrade for your planetarium!

Panoramic image of local school

Before : Model Uranus

New : Model CHIRON III

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Free Telescope Draws a Crowd

Recently, I used Craigslist to give away my 6-inch Meade reflector and mount. It was a fine telescope when I bought it 30 years ago while in graduate school for $350, but it had become too heavy for me to haul around, especially to dark-sky areas. Besides, the primary mirror needed to be cleaned, and there was no clock drive.

I was astounded by the response. Within minutes of posting the ad, I received a flood of responses — 119 in all — from all sorts of people: young, old, men, women, husbands, daughters, uncles, a Boy Scout leader, and a young man wanting it for his grandfather. I'd say only 10% of them had any experience with telescopes; those who did valued this one because it had been made in the U.S., and they wanted to restore it.

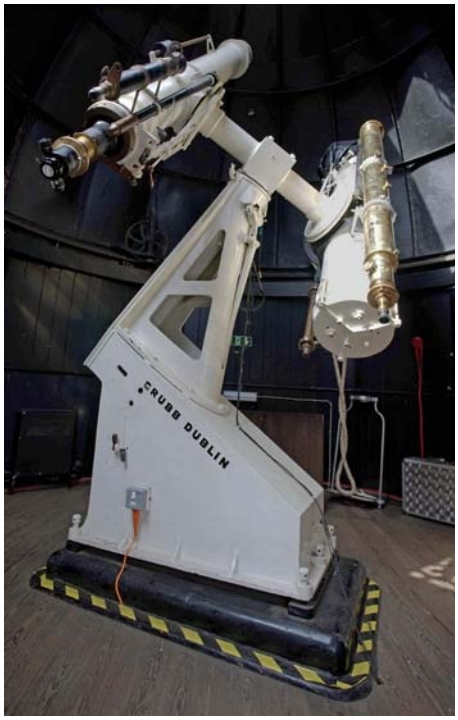
I ended up giving it to the first person who had sent me a request, and he immediately drove through Bay Area traffic to my house in Silicon Valley. He'd never used a telescope before — but he was ready to start.

Helen Gjerde
Saratoga, California

Grubb's "Twin Equatorials"

In Thomas Dobbins's article on anomalous appearances of the transits of Mercury (*S&T:* May 2016, p. 38), the photograph of William Huggins seated with a refracting telescope caught my eye. Huggins did indeed use a small Clark refractor for his early spectroscopic work, but the photograph actually shows him seated in front of a 15-inch Grubb refractor that was counterbalanced by an 18-inch reflector (not in view).

This refractor-reflector combination, the first of only four so-called "twin equatorials" manufactured by Howard Grubb between 1871 and 1902 to maximize the use of a small observatory, was made specifically for Huggins's visual and photographic spectroscopic investigations, respectively. Later "twins" included a 7-inch refractor and 20-inch photographic reflector made for British astronomer Isaac Roberts, and an 8- and 16-inch pairing put on display in Manchester, England, in 1887. This latter combo was dismantled after the exhibition, its telescopes sent separately to observatories in South America and India.



KEVIN KILBURN

These paired telescopes, one of only four "twin equatorials" produced by Howard Grubb more than a century ago, remain in use at Godlee Observatory in Manchester, England.

The fourth and final "twin," which combined an 8-inch refractor and 12-inch reflector, is the only one still in regular use. It's been housed since 1946 at the University of Manchester's Godlee Observatory and maintained by the Manchester Astronomical Society.

One final point: the refractor illustrated in Dobbins' article ended up at Cambridge Observatory early in the 1900s but eventually fell into disuse and was dismantled. In 2006, however, Mark Hurn, the librarian at the University of Cambridge's Institute of Astronomy, discovered its 15-inch objective lens in a little-used cupboard!

Kevin Kilburn
Manchester, England

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.

Shout-out for Sketching

I want to thank the editors of *Sky & Telescope* for publishing a section dedicated to sketches of astronomical objects (*S&T:* June 2016, p. 73). It was refreshing to see some space given to another form of recording observations, one using the age-old tradition of pencil and paper. As noted in the introduction there, sketching is a way to keep a record of observations while providing that personal connection with objects in the night sky. Sketching is not just for artists; it's a useful tool for all observers to enhance their ability to see deeper details. In a sense, sketches represent what is truly observed at the eyepiece.

I urge you to make this a more regular part of *S&T*'s content. Having a gallery for sketches or including them with astrophotography submissions would add to the magazine's appeal and educational value.

Cindy L. Krach
Maui, Hawai'i

Editor's note: *Krach coordinates the Astronomical League's recently instituted Sketching Award.*

Our Same-Faced Moon

Planetary scientist Paul Spudis favors the small offset between the Moon's centers of figure and mass to explain why its rotation has synchronized with its orbital period (*S&T:* Apr. 2016, p. 16). Yet any large moon that's close to its planet will become elongated by tidal interaction. Won't this elongation become frozen in as the body solidifies and then hasten tidal locking — even if its shape would have been perfectly symmetrical without tidal distortion?

Keith Brescia
Falls Church, Virginia

Researcher Mark Wieczorek replies: *It's true that the Moon would despin even if it were initially perfectly spherical. Nevertheless, it's almost inevitable that the Moon initially had an asymmetric shape as a result of large impact craters, with a portion of this global shape being of the "American football" variety. So, after despinning, the Moon* *would naturally end up occupying one of two equally stable states, with the long axis of the football oriented toward Earth. In fact, large impacts at a later date could have caused the Moon to unlock from synchronous motion and end up in the other stable state, flipped by 180° with respect to the current configuration. If this occurred, the current farside of the Moon could have once faced Earth!*

Fifty Shades of Green

As Alan MacRobert notes (*S&T:* May 2015, p. 50), many large lunar features can be challenging to observe with just the unaided eye. This led me on a quest to find a way to improve my chances of seeing them. After some research, I learned that the human eye can distinguish more shades of green than any other color. This suggests that observing the Moon through a green filter might offer an increase in contrast and make some of these lunar features more easily visible.

After some experimentation, I settled on using welding goggles fitted with a green-colored "lens" (glass plate). These lenses come in various shades, and for naked-eye observing of lunar features, I find that a shade value between 1.7 and 4.0 allows me to see the Moon clearly while providing a degree of brightness and glare reduction. The result is a modest increase in contrast for some (but not all) lunar features — a subtle change from "I think I see it" to "I'm pretty sure I see it."

I've only experimented with green-hued welding lenses, but other colors might also be effective for certain lunar features. So I invite further experimentation by other amateur observers.

One caution: those passing your observing chair might think you're crazy for observing through welding goggles. My wife did.

Frank Ridolfo
Bloomfield, Connecticut

Thomas Dobbins replies: *Glare reduction accounts for the lion's share of the effect, but green filters do provide an advantage. Research by Kaleigh Smith (Max Planck Institute for Informatics, Saarbrücken, Germany) and others reveals that the perception of a grayscale target really suffers when seen in red or blue light but is well preserved when viewed in monochromatic green. Visit* ***http://is.gd/grayscale_perception*** *to find more information.*

Hydrogen in the Trifid

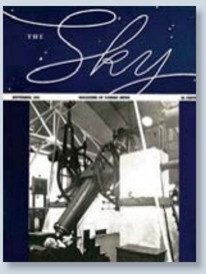
I greatly appreciate Howard Banich's in-depth exploration of the Trifid Nebula (*S&T:* June 2016, p. 57), which makes me want to observe and study it again at the earliest opportunity. But he describes H II regions as doubly ionized hydrogen, when in fact this is astronomical shorthand for *singly* ionized hydrogen atoms.

Roger Venable
Chester, Georgia

75, 50 & 25 Years Ago

Roger W. Sinnott

September 1941

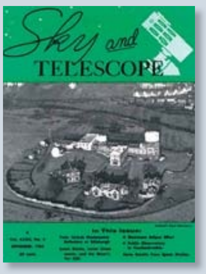


The Reflactor? "The Schmidt camera is not the first example of the combination of a mirror and a refracting component. Some time ago [in 1899] a German inventor, Ludwig Schupmann, obtained a United States patent for a telescope consisting of an objective lens and a curved mirror. . . . [T]he concave mirror is the corrector (of chromatic aberration) and the lens is the objective."

"As such instruments combine characteristics of the reflector and the refractor, the writer suggests the name 'reflactor.'"

Carl A. Hellmann's neologism did not stick. But the odd design still has ardent followers, notably James Daley, who authored The Schupmann Telescope *(Willmann-Bell, 2007). Each year at Vermont's Stellafane convention, visitors admire the 13-inch Schupmann of McGregor Observatory. In 1963, Harvard's James G. Baker (famed for the Baker-Nunn satellite tracker and Super-Schmidt meteor camera) wrote, "The Schupmann does happen to be the most nearly perfect telescope mathematically."*

September 1966



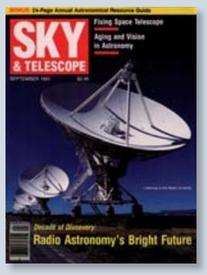
Alternative Life? "In late May, aerospace engineers met with biologists, geophysicists, and astronomers in a three-day symposium at Anaheim, California, to discuss many problems of extraterrestrial life. Most fundamental of these questions was how life may have originated. . . .

"Because DNA molecules can reproduce themselves and sometimes undergo mutations that are maintained in further reproduction, the evolution of terrestrial life forms is possible. The 'code' used in this process is the same for all earthly organisms. . . .

[Biochemists] now believe that the only possible living forms are based on carbon compounds (as on earth), and that speculations about silicon-based extraterrestrial life are unfruitful."

Not so fast. In 1973 Carl Sagan warned biochemists of "carbon chauvinism." Today they no longer rule out other elements, including sulfur, chlorine, nitrogen, phosphorous, and arsenic, as a basis for the complex molecules of life.

September 1991



Lost and Found "The book can now close on an asteroid mystery of 75 years' standing. Gareth V. Williams [Minor Planet Center] has identified an April 10th observation as belonging to the long-lost asteroid 878 Mildred. . . .

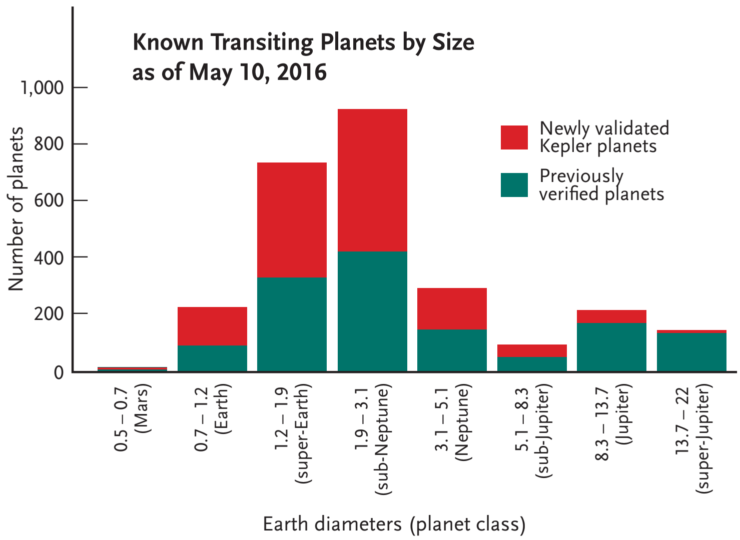
This main-belt asteroid was initially discovered in September, 1916, by Seth B. Nicholson and Harlow Shapley [and] Shapley named it for his infant daughter. But the faint object could only be followed for six weeks — not enough to establish a reliable orbit. . . .

"Through May of this year, 4,848 minor planets have been numbered by the International Astronomical Union."

No one was more delighted with this news than Mildred Shapley Matthews, an astronomer in her own right, who worked many years at the Lunar and Planetary Laboratory as scientific editor and author for the University of Arizona's Space Science Series on the solar system. Until the asteroid's recovery, Mildred was often ribbed about being a "lost woman." She died earlier this year, just shy of her 101st birthday.

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

EXOPLANETS | 1,284 Added to Kepler's Confirmed Tally



Green bars represent all previously verified exoplanets, including those detected by other methods and telescopes. Red bars represent Kepler's 1,284 newly validated planets. Surprisingly, the spike in super-Earths and sub-Neptunes is real — it's not an observational bias.

S&T: LEAH TISCIONE, SOURCE: NASA AMES / W. STENZEL

A new analysis by the Kepler team has doubled the total number of confirmed exoplanets.

Over four years, the Kepler spacecraft stared at a patch of sky straddling the Cygnus-Lyra border and tallied up 4,696 exoplanet candidates. But to confirm that any one planet is real requires difficult, time-consuming follow-up observations, often impossible for the smaller candidates.

Timothy Morton (Princeton University) and colleagues took a different tack. Instead of looking for additional evidence supporting a given candidate's existence, they searched for signs that it *wasn't* there. Their fully automated code first examined the transit light curve itself — a real planet will block the star's light in a certain way that can sometimes be distinguished from imposters, such as an eclipsing binary. Then the code factored in how common imposters might be. For example, how common are binary stars, and how many lie in the direction Kepler was looking?

The algorithm studied each planet candidate for several minutes, then spit out a probability that the signal is a fake. Any candidate with less than a 1% chance of being a false positive is now considered real.

The new study, reported in the May 10th *Astrophysical Journal*, doubles the list of confirmed exoplanets from 1,041 to 2,325. That tally includes worlds found with all methods and telescopes, not just Kepler's transit detections (see graph). The algorithm also "passed" 651 earlier Kepler detections that had already been confirmed by some other method. And 428 candidates (generally those with large radii, whose signals are more easily mimicked by other astrophysical sources; *S&T:* Apr. 2016, p. 13) were flagged as imposters.

Of the newly confirmed planets, nine orbit in their stars' putative habitable zones, regions in which a planet with an Earth-like atmosphere could sustain liquid water on its surface. That raises to 21 the number of planets with diameters less than twice Earth's that are orbiting in their stars' habitable zones.

Expect one last Kepler catalog next year, says mission scientist Natalie Batalha (NASA Ames). The secondary K2 mission is still going strong and will likely end in mid-2018, when the spacecraft runs out of fuel for its attitude-control thrusters.

■ **MONICA YOUNG**

SUPERNOVAE | Brightest Explosion Resurges

Last year, ASASSN-15lh gained fame as the most luminous supernova ever discovered (*S&T:* Nov. 2015, p. 12). Now almost a year later and against all odds, the supernova has rebrightened.

Subo Dong (Peking University, China) and colleagues discovered ASASSN-15lh on June 14, 2015, using the All-Sky Automated Survey for Supernovae (ASASSN). Its peak power was more than twice that of any previously known stellar explosion. Usually, much of a supernova's initial glow actually comes from the decay of radioactive nickel, created in abundance near the core. What's weird about ASASSN-15lh and a few others like it is that they're so bright, they'd need an awful lot of nickel to explain their glow.

Then, three months after it began fading, the supernova changed its mind. Over some 40 days, its ultraviolet radiation increased fivefold before plateauing for another couple of months and finally dropping away again. Meanwhile, radiation at visible wavelengths ignored this transformation and continued to fade unabated.

A born-again supernova isn't unheard of. But typically when that happens, the blast has run into nearby gas ejected by the star before it exploded. ASASSN-15lh doesn't display any of the emission lines you'd expect in its spectra if this were the case, explains Diego Godoy-Rivera (Ohio State University) and others in a preprint posted to the open-access site arXiv.org on May 2nd.

The creation of a *magnetar* — until now the most successful explanation for the supernova's oddities — also struggles to explain ASASSN-15lh's behavior.

■ **MONICA YOUNG**

PRO-AM | Astro-imagers Get Ready for Juno

On May 12–13, amateurs and professionals interested in supporting NASA's Juno mission met in Nice, France, for a workshop dedicated to projects and techniques related to observing Jupiter.

The spacecraft arrived at the giant planet on July 4th (*S&T:* July 2016, p. 18). Although Juno will image Jupiter at very high resolution, especially in the polar regions, it lacks the ability to create global portraits. So it falls to Earth-based observers to watch regions out of view from the probe and to acquire the large-scale views that provide context for the spacecraft's small-scale scrutiny.

Highest on the "to-do" list for the months ahead is to sustain the ongoing ground-based survey of Jupiter, so lots of discussion focused on the necessary equipment, imaging, and processing tools and techniques needed for that task. For example, more and more planetary imagers are utilizing infrared and methane-band filters, as well as atmospheric-dispersion correctors.

In addition, John Rogers (British Astronomical Association) urged observers to watch for a possible revival of the planet's North Temperate Belt. This would start with a very bright spot in that region. After Earth-based observers identify a change, the spacecraft could follow up to record more details.

Cooperation between amateurs and professionals will be supported by maintaining or improving some specific projects and websites, including the JunoCam homepage, where amateurs can submit raw images for mission scientists to use. Through this website the public can also vote for features they would like Juno to take images of. Mission scientists will program the camera according to which features ranked the highest.

Also in the works in the coming months is a new version of the Planetary Virtual Observatory and Laboratory (PVOL) website, to facilitate image analysis. Find out more about the workshop and how to get involved at **https://is.gd/proamjuno**.

■ **CHRISTOPHE PELLIER**

EXOPLANETS | 5th Planet

Astronomers have made the first high-resolution image of a cometary belt around the young star HR 8799. The disk, a region comparable to our solar system's Kuiper Belt, lies outside the orbits of the star's four known planets. But in imaging the belt, Mark Booth (Pontifical Catholic University of Chile) and colleagues discovered signs of a *fifth* planet.

Previous observations found that the disk extended from roughly 100 to 310 astronomical units. Astronomers had also found evidence of a halo of small dust grains. But it was hard to tell the difference between the belt and the grains.

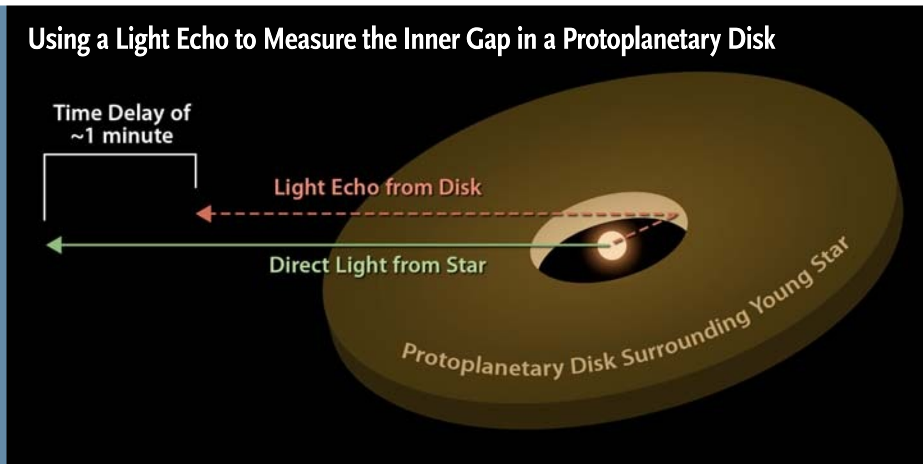
Using ALMA to pick up emission from the disk's dust, Booth's team found that the inner edge lies between 133 and 166 a.u. That's too far out to have been carved by the outermost known planet. Instead, the edge's location suggests that a smaller, not-yet-detected planet is setting the boundary, the team reports in the July 21st issue of *Monthly Notices Letters of the Royal Astronomical Society.*

■ **ANA V. ACEVES**

IN BRIEF

ExoMars Rover Delayed Until 2020. European and Russian officials have postponed the launch of the European Space Agency's first Martian rover for two years. The first ExoMars mission, comprising the Trace Gas Orbiter and the Schiaparelli lander, left Earth as planned this past March (*S&T:* July 2016, p. 10). The second phase, a rover, was scheduled to follow in 2018. But because the same team was working on both phases, holding to the 2018 launch date would have forced the team to build the final spacebound rover before completing the prototype and finishing engineering tests — clearly unacceptable.

■ **DAVID DICKINSON**

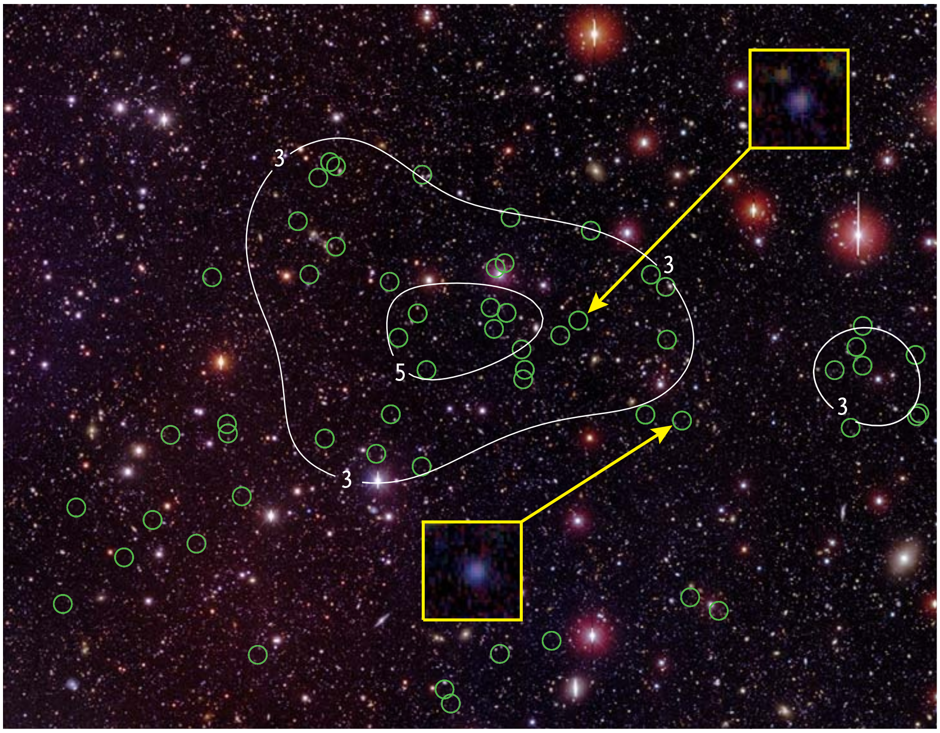


NASA / JPL-CALTECH

Light Echoes Map Planet-forming Disk. Astronomers have used light's finite speed to pinpoint the location of the "inner wall" of the disk of dust and gas that's feeding a growing baby star. Protostars naturally flicker in brightness, and the photons from these surges reach us two ways: by flying directly at us from the star, or after first bouncing off the disk surrounding it (see above). The latter are called *light echoes.* The delay between the two flashes reveals how far the gas is from the central object. Observers have long used light echoes to measure the mass of supermassive black holes, but now for the first time Huan Meng (Caltech) and colleagues have used them to study a protostar, YLW 16B. By watching the star's infrared brightness change, the team caught an echo 75 seconds after its initial flicker. This echo, the authors argue in the May 20th *Astrophysical Journal*, comes from an inner, dusty edge in the disk. The time delay corresponds to a traveled distance of about 0.08 astronomical unit, exactly what's expected for a dusty disk.

■ **MONICA YOUNG**

COSMIC STRUCTURE | Protocluster Spotted



RUI XUE / PURDUE UNIVERSITY

The galaxies circled in this image are members of a newly discovered protocluster. White lines encompass regions where the concentration of member galaxies is three and five times higher than elsewhere in the field. The inset images (in yellow boxes) highlight two galaxies in the group.

Astronomers have discovered a collection of 65 young galaxies whose light has taken 12 billion years to reach Earth. This protocluster, a precursor to a giant assemblage like the Coma Cluster, exists in a universe only 1.8 billion years old and is one of the most massive structures known in that early epoch of the universe.

The protocluster is the first to have its distance confirmed using extensive spectroscopy, as opposed to estimates based on the galaxies' brightness at various wavelengths. Arjun Dey (NOAO) and colleagues used the Mayall telescope on Kitt Peak and the Keck II telescope on Mauna Kea to measure the faint galaxies' distances. They report a redshift of 3.786 in the May 20th issue of the *Astrophysical Journal*.

The team is now searching larger areas of the sky to uncover more young, massive protoclusters. "It is important to find a large sample," says Naveen Reddy (University of California, Riverside), "so we can understand the possibly varied formation history of the population as a whole." Plus, their prevalence could help constrain the size and expansion history of the universe.

■ **ANA V. ACEVES**

MILKY WAY | Halo Weight

Astronomers have found a bizarre pair of *hypervelocity stars* in our galaxy's halo, racing along at twice the Sun's speed.

The stars, SDSS J121150.27+143716.2 and its dimmer mate, aren't the first hypervelocity binary discovered. But they're the first that's proven so difficult to explain. The Milky Way's central black hole can't have slingshotted them out — even if the trajectory matched that scenario, the encounter would have disrupted the binary. Nor could the explosive death of a third stellar companion have done it, explain Péter Németh (Friedrich-Alexander University Erlangen-Nuremberg, Germany) and colleagues in the April 10th *Astrophysical Journal Letters*.

If the stars are bound to the galaxy, then the dark matter halo within their orbit must contain at least 3 trillion Suns' worth of mass — an estimate that's a bit larger than previous measurements.

■ **MONICA YOUNG**

KUIPER BELT | Dwarf Planet 2007 OR_{10}: Big & Dark

A Kuiper Belt object discovered nearly a decade ago turns out to be much darker — and thus larger — than thought. It's also an especially slow spinner.

Planetary scientists typically guesstimate the diameter of any newly discovered solar-system object using its magnitude. But that requires assumptions about its surface reflectivity, or *albedo*.

To learn more about the Kuiper Belt object 2007 OR_{10}, András Pál (Konkoly Observatory, Hungary) and others used data from NASA's repurposed Kepler space telescope along with archival observations from ESA's Herschel Space Observatory. By combining the object's radiated heat with its visible brightness and its rotational period, Pál explains, "one can unambiguously obtain the size of the object and the surface albedo as well."

Watch a video of Kepler's observations at http://is.gd/2007or10darkslow.

As the team explains in the May *Astronomical Journal*, the object is bigger and darker than anyone thought. Its spin period is a little bit less than 45 hours, longer than most objects orbiting beyond Neptune, and its albedo is just 9% — half that found in a previous study. Together, these imply a diameter of 1,535 km (955 miles), up from the previous estimate of roughly 1,280 km (795 miles). The revision makes 2007 OR_{10} the largest as-yet-unnamed world in our solar system and the third largest of the known dwarf planets, after Pluto and Eris.

This larger size means 2007 OR_{10} probably has the gravity to retain icy coatings of volatile chemical compounds such as methane (CH_4), carbon monoxide (CO), and molecular nitrogen (N_2). Herschel's infrared spectra also reveal a reddish surface consistent with a covering of methane frost. ✦

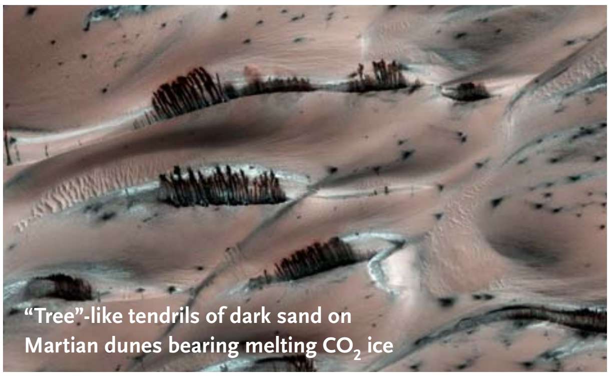
■ **ALLEN ZEYHER**

Cosmic Relief
David Grinspoon

Ten Years Over Mars

It's easy, but wrong, to take for granted a mission that's still going strong after a decade.

ON MARCH 10TH NASA's Mars Reconnaissance Orbiter (MRO) completed 10 years in orbit around Mars. That's not bad for a spacecraft that had a primary mission lifetime of 2 years. Among its six main scientific instruments, all of which are still working, the standout has been HiRISE, the High Resolution Imaging Science Experiment. This amazing telescopic camera can spot features as small as a picnic table.



"Tree"-like tendrils of dark sand on Martian dunes bearing melting CO_2 ice

HIRISE / MRO / LPL (U. OF ARIZONA) / NASA

Combined with imaging spectroscopy, which determines the make-up of surface materials, HiRISE has illustrated the stories of countless, highly varied Martian landscapes. And, crucially, its great longevity has allowed us to see many subtle — and a few dramatic — ways in which those landscapes change over time. Whole new aspects of Mars are revealed when we see the planet with this clarity and detail, and with the luxury of being able to pick the right targets on a planet that has become increasingly known to us.

We've seen incredible views of eroded canyons and meandering riverbeds, vast fields of curvaceous dunes, interlaced patterns of ice and rock looking almost biological in their filigreed complexity, and an endless menagerie of impact crater shapes and styles. From a sheer aesthetic perspective, these images continue to astound. They show us that whatever it is in nature that rouses us to wonder, triggers awe and appreciation of beauty, it is not limited to our home planet.

In the early 20th century, charismatic American astronomer Percival Lowell had the world briefly enthralled with his "observations" of canals carrying irrigation water for a thirsty civilization, until better images revealed them to be mirages. Ever since we've been following that water, chasing it underground and into the distant past. At the beginning of the Space Age, belief was widespread that vegetation caused the planet's seasonal changes in color. But our first missions in the 1960s showed a lunar-like world: cratered, dead, and quiescent.

Those fly-bys provided only partial and misleading glimpses. In 1971 Mariner 9, our first orbiter, arrived to discover that, contrary to first impressions, Mars had seen lots of action. But it was a geologically dead world that had only long ago raged with rivers, quaked with active faults, and sizzled with towering volcanoes. Its glory — geological, meteorological, and maybe even biological — resides mostly in the distant past.

MRO has, again, changed the way we think about our anti-sunward neighbor. It has revealed that, even today, Mars is constantly changing. We've seen the dark, spiny splats of fresh impact craters that were not there a decade ago, and the sinuous shadows of giant dust devils caught writhing across the surface, leaving dark, convoluted doodles in the bright sand.

Some of the most striking images are of the strange polar terrains where seasonal cycles of freezing, thawing, condensation, and sublimation produce shifting, animated forms resembling giant spiders or towering trees. Our new ability to monitor seasonal changes has led to the discovery of possible evidence that traces of briny liquid water can briefly flow down steep crater walls in the hottest days of Martian summer.

Someday, perhaps soon, humans will walk across the Red Planet's dusty, variable vistas (*S&T*: June 2016, p. 84). These adventurers will ride ships powered by the excitement of our current discoveries, and they'll follow the maps made by MRO. ✦

***David Grinspoon** is an astrobiologist, author, and senior scientist at the Planetary Science Institute. Follow him on Twitter at @DrFunkySpoon.*

Astronomy & Big,

PETER TYSON

How will astronomers cope with the tsunamis of raw data soon to pour in from wide-field surveys?

Not long ago Henry "Trae" Winter, an astrophysicist at the Harvard-Smithsonian Center for Astrophysics, gave a talk entitled "Big Data to Big Art." Winter works on NASA's Solar Dynamics Observatory mission, and he wanted to give his audience an idea of just how much image data the SDO's telescope generated each day. The scope's four cameras take pictures of our star every 12 seconds in eight different wavelengths, which results in 3 terabytes' worth of images each day.

How much is that exactly? Winter made an analogy with Blu-ray discs. A standard, dual-layer Blu-ray holds about 50 gigabytes of data, so in one day SDO generates 60 Blu-rays' worth of data. The mission has been running for six years — 131,400 Blu-rays — and the team hopes to observe the Sun's entire 11-year cycle. Imagine trying to watch all those discs, deleted scenes and all.

The same thing is happening all over astronomy. And today's "big data" pales next to what's coming, both with surveys already underway, such as the Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) and with those in development, including the Large Synoptic Survey Telescope (LSST) and the Square Kilometer Array. These and other visual and radio telescopes will blow SDO out of the sky in terms of data output.

To explore what big data means in the astronomy context, and to look at the challenges it presents, let's take a close look at the principal U.S. project being developed in ground-based astronomy for the 2020s: the LSST.

A Data Tsunami

The LSST is currently under construction near La Serena, Chile. When completed, it will share a ridge on Cerro Pachón with the Gemini South and Southern Astrophysical Research telescopes. Its chief funders are the U.S. National Science Foundation (for its facility and telescope), the U.S. Department of Energy (its camera), and various philanthropists (its mirror). This year alone LSST will consume about $140 million, with an estimated $1 billion over its lifetime.

The LSST will have three components: an 8-meter wide-field telescope, a 3.2-billion-pixel camera, and an automated data-processing system. The scope's field of view will be much larger than that of any other 8-meter telescope: 3.5° degrees, or about seven times the diameter of the full Moon. Every 40 seconds or so the telescope will point to a new area of the sky, and its camera will take two 15-second exposures (to efficiently reject cosmic rays). The camera will record using six different visual and near-infrared filters, and over its anticipated 10-year run it will capture some 40 billion objects in an unprecedentedly large volume of the universe.

Besides being wide, fast, and deep, LSST will add the *time domain*. After those 10 years, this will result in a sort of stop-motion movie of much of the celestial sphere. All told, the camera will image about 10,000 square degrees of sky every three clear nights. LSST will not stop for follow-up observations but will simply keep harvesting night after night.

LSST leaders expect astronomers to use the output from this technological juggernaut to explore many key science areas. Four in particular will be counting asteroids and other moving objects in our solar system, mapping the structure and evolution of the Milky Way, exploring transient phenomena such as supernovae and other variable stars, and constraining the nature of dark energy and dark matter. But the science will be up to the scientific community. LSST will simply collect the data — a continuous tsunami of it.

The project expects to accumulate 15 terabytes of raw data each night — five times what SDO garners daily. Fifteen terabytes a night is a lot, but within a few years, the cumulative data will become *petabytes* in size. (A petabyte is 1,000 terabytes; see the table above right.) "That's a scale we're not typically used to," says Andrew

Big Data

Byting Off More . . .

1 Byte	8 bits
1 Kilobyte (KB)	1,000 bytes (10^3)
1 Megabyte (MB)	1,000,000 bytes (10^6)
1 Gigabyte (GB)	1,000,000,000 bytes (10^9)
1 Terabyte (TB)	1,000,000,000,000 bytes (10^{12})
1 Petabyte (PB)	1,000,000,000,000,000 bytes (10^{15})
1 Exabyte (EB)	1,000,000,000,000,000,000 bytes (10^{18})
1 Zettabyte (ZB)	1,000,000,000,000,000,000,000 bytes (10^{21})

Connolly (University of Washington) of his fellow astronomers.

After its initially budgeted 10-year run, LSST will have amassed 54,750 terabytes of raw data, or 1,095,000 Blu-rays' worth. How high a stack of discs would that be, one lying flat atop the other, with no cases? Just over 4,300 feet (1,300 m), or about 2½ times the height of the 1,776-foot Freedom Tower in New York City (see diagram on page 17).

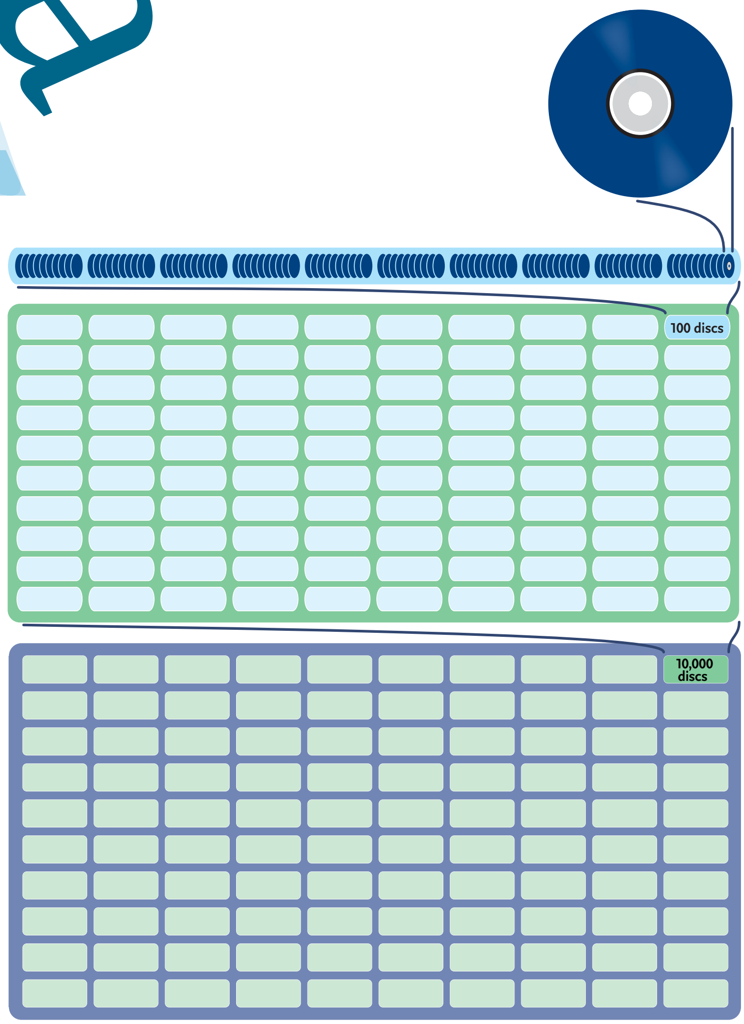
But that's just the raw data. When all the processed data and such are included, the total for that 10-year stretch will amount to about 200 petabytes, says LSST director Steven Kahn (Stanford University).

How can astronomers possibly deal with that much input? How will they actually *use* it? No one really knows. But they're working double-time to find out.

Small Data Gets Big

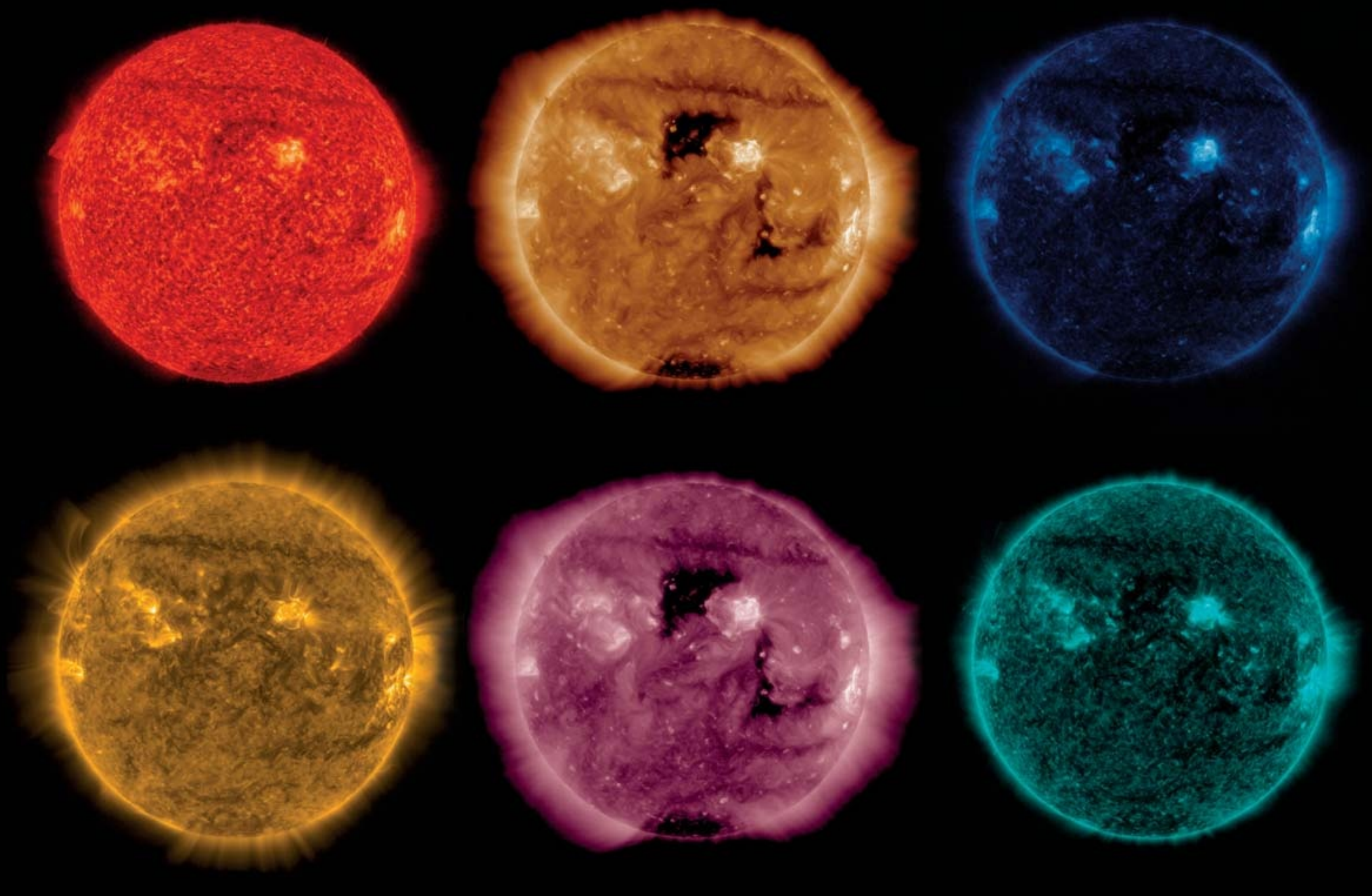
For centuries after Galileo first aimed a telescope at the heavens, astronomers mostly trained their instruments on individual objects or small samples of cosmic sources. Data sets were totally manageable, even into the modern era. As Winter said in his SDO talk, "When I was a graduate student, the way you picked out interesting things on the Sun was you locked a graduate student in the basement to go through the day's files, and they would tag what was interesting."

But in recent decades, large survey projects increasingly have been displacing single-object studies. One



S&T: GREGG DINDERMAN

100 TIMES 10,000 What does one million look like? Above shows one way to visualize a million Blu-ray discs. This is still 95,000 Blu-rays short of those needed, at 50 gigabytes apiece, to store all the raw data from stars, galaxies, and other objects that the Large Synoptic Survey Telescope will drink in over its currently planned 10-year run.



HIGH RESOLUTION In its ongoing study of the Sun, the Solar Dynamics Observatory, using its telescope's four cameras, takes images in eight different wavelengths of light every 12 seconds. The result? Three trillion bytes of image data per day.

NASA SDO / AIA / HENRY "TRAE" WINTER (CFA)

example is the Sloan Digital Sky Survey. Its 2.5-meter telescope in New Mexico conducted a thorough visible-light survey of one-third of the observable sky. All told, SDSS recorded position and brightness for a billion stars, galaxies, and quasars, along with spectra of a million objects. And that was just SDSS's first phase; follow-up survey work has continued ever since.

There had been other wide-field sky surveys — most notably, the photographic Palomar Sky Surveys during the 1950s and 1980s — but SDSS pulled astronomy straight into the big-data era. The project resulted in a spectacular amount of groundbreaking science, much of it unforeseen by the venture's designers. Among other findings, SDSS enabled major discoveries regarding active galactic nuclei, the substructure of the Milky Way, and baryon acoustic oscillations (*S&T:* Apr. 2016, p. 22). Since routine operations began in 2000, SDSS data have been used in more than 5,800 peer-reviewed publications in astronomy and other sciences, and those papers have been cited nearly 250,000 times.

"Every science agency around the world, every observatory manager, saw this and said, '5,000 papers for only $100 million?'" says astronomer Eric Feigelson (Pennsylvania State University), citing the estimated cost of SDSS over about 10 years. "It was probably the cheapest science-per-dollar ever achieved. And so everyone said, 'Let's do it, too.'"

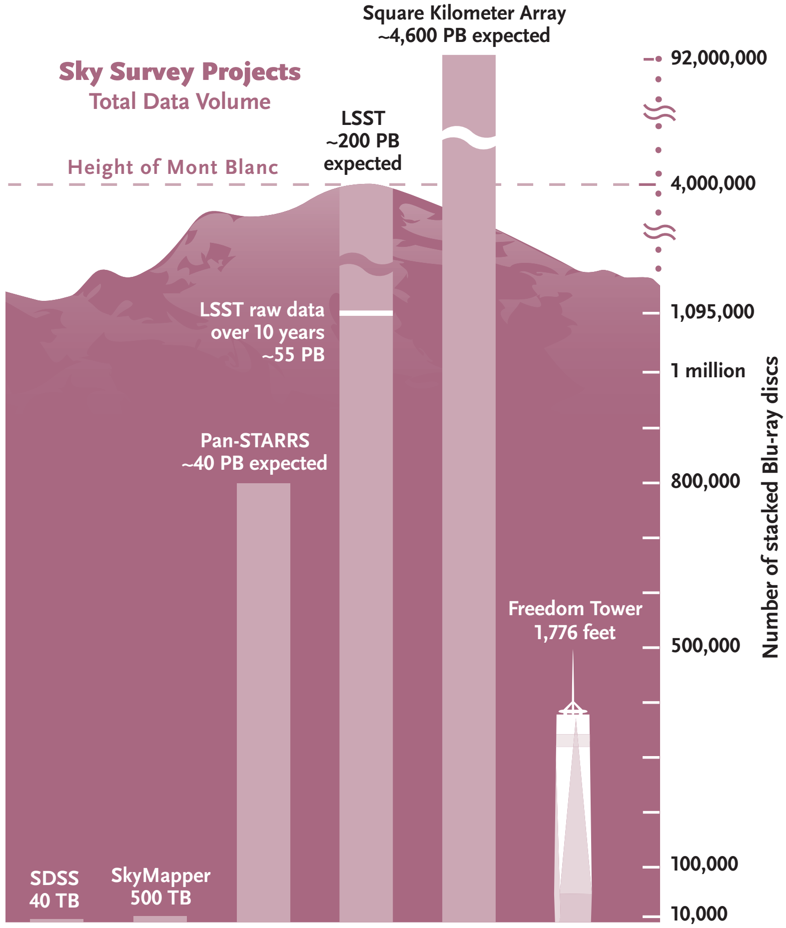
Today an alphabet soup of wide-field surveys is either already or soon to be in operation (some of the largest are shown in the diagram above right). There are also biggish-data instruments planned for space. Traditionally, NASA hasn't designed its missions to transmit telemetry in megabytes per second, so previously any heavy data-processing was done aboard Kepler, Chandra, and other space-based instruments. But besides the SDO, we'll soon have NASA's Wide Field Infrared Survey Telescope (WFIRST) and the European Space Agency's Euclid. Both are wide-field-survey space telescopes designed to help answer questions about dark energy, exoplanets, and other hot topics in astronomy and astrophysics.

A Nightly Ritual

Once the LSST survey starts — currently scheduled for October 2022 — the project team will handle initial processing so that astronomers can quickly and easily make use of the observations to do science. This upfront work will comprise basic data analysis, including characterizing sources in terms of their color, shape, motion on the sky, and time variability. The LSST team will also ensure consistent data quality and assemble the object catalog. Much of this standard pipeline processing will be highly automated: the data volumes are so massive that they preclude human examination of all but the tiniest fraction.

The LSST team can't get behind on processing the raw data, because if they do, they'll never catch up. To help protect against this, the project plans to staff two primary data centers, the main one at the National Center for Supercomputing Applications in Urbana, Illinois, and a backup center in Lyons, France. It will also furnish multiple copies of the full data, and each year a new run will reprocess the entire available survey data set.

But LSST leaders are confident that such advance efforts will not present an obstacle, nor will storage. As the project explains on its website, "While LSST is making a novel use of advanced information technology, it is not taking the risk of pushing the expected technology to the limit." LSST will have two redundant, 40-gigabyte-per-second optical-fiber links from La Serena to Urbana. Such dedicated long-haul networks mean that even transferring that amount of information is not expected

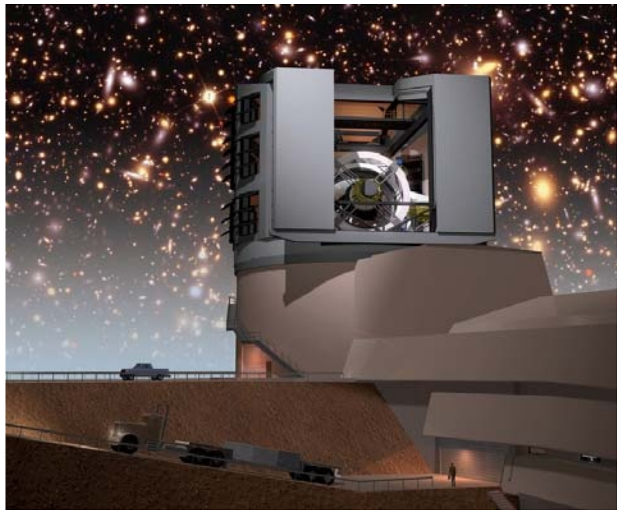


S&T: GREGG DINDERMAN, SOURCE: Y. ZHANG & Y. ZHAO / *DATA SCIENCE JOURNAL* 2015

AERIAL EDIFICES *Below:* The Large Synoptic Survey Telescope under construction in Chile, March 2016. *Above:* New York's 1,776-foot Freedom Tower is dwarfed by the stacks of Blu-ray discs, each about 0.05 inch (1.2 mm) thick, that would be needed to store the total data volume from the three largest wide-field survey projects. Note the comparatively minuscule stack required for the SDSS data set.

LSST PROJECT / NSF / AURA

to be difficult, Kahn says. "What *is* a difficult problem," he adds, "is finding anything in it."



LSST

NOCTURNAL EYE An artist's view of the Large Synoptic Survey Telescope against a simulated background of stars. The LSST will gather 15 terabytes of raw data every night for a decade.

Algorithm as Instrument

For each object that ends up in the LSST catalog, the team will typically measure tens of parameters: its position, shape, brightness, color, and so on. Over its planned 10-year run, LSST will make about 1,000 observations of every object, giving astronomers information about stars, galaxies, and other entities as a function of time — that stop-motion movie. So, in addition to astronomical amounts of data, the *phase space* that the data occupy will have thousands of dimensions. How are astronomers expected to deal with that? One word: software.

In the old days, astronomers went to the observatory to make discoveries. Now more often they go to the database — in fact, to extremely large databases, or XLDBs. The XLDBs arising from LSST will be trillions of lines long, Kahn says. Searching them in a linear way, row by row, would be too time-intensive even for the world's fastest computers, he says. As such, beyond thorough indexing, inventive new algorithms will be critical to effectively mine the LSST data.

We're entering an era in which the algorithm *is* the instrument, says astrostatistician Thomas Loredo (Cornell University). It's as the telescope used to be, in the sense of being the intermediary between the sky and discovery. "The knowledge comes not from opening a dome on the sky — that's happening every night for you — but from making the right types of queries of the database and then knowing what to do with the numbers," Loredo says.

Kahn agrees. The greatest innovations in working with reams of wide-field survey data will come from creative querying. In the project's XLDBs, for example, how will astronomers ferret out what they like to call "unknown unknowns"? As Kahn puts it, "What sort of new phenomena are out there that we never knew about before? So of all the kinds of things we already know about, how do we identify those in the data and *exclude* them so we can find the things that don't look like that?"

The most unexpected findings will likely come from probing regions astronomers haven't been able to probe before. "There are holes in our knowledge — you know, time scales of variability and rareness, like things that only happen once per year per cubic gigaparsec," says Loredo, chuckling. (A gigaparsec equals about 3.26 billion light-years.) "That's a region of phase space that we haven't been able to look in before."

Altogether, astronomers have to change how they think about and work with databases. SDSS was transformative in that it made its results available to anyone. But astronomers did science with SDSS by querying the database for the observations they were interested in, then downloading those to their local machine and manipulating them there. With mega data sets such as LSST's, this model might no longer work. "Can I continue to pull the data down onto my own local disk?" says Connolly. "Or do I now have to start moving my analysis to the database itself? That's what we're trying to learn now."

Discoveries will ride on those sophisticated new algorithms, on clever ways to seek correlations, and on testing predicted statistical relationships across XLDBs. Innovative visualizations are another way. "When you have 1,000 points and you've measured three of their properties, you can put them on a couple of graphs and publish them on a flat piece of paper — that's been done for centuries," Feigelson says. "When you have a billion objects, and you've measured hundreds of things about them, you literally can't even look at [that data set] directly."

Astronomers will need imaginative techniques, such as using color or time in inspired ways. For instance, researchers might project higher-dimensional data sets onto rotatable, 3D frames, then make a movie of those data sets in time and study the movie for anything compelling going on. By interacting with the data while viewing the movie, they have a greater hope of spotting and understanding things using the human eye and mind, Feigelson says, than by relying solely on algorithms.

Alerting the Community

Besides gathering and processing incoming data, another task the LSST project will do every night in real time is issue alerts when something has changed at a specific location on the sky — perhaps an object's brightness or position, or a serendipitous appearance

SDSS-III

SLOAN WORKHORSE The 2.5-meter telescope at Apache Point Observatory in New Mexico has hosted the Sloan Digital Sky Survey and all its follow-up projects.

SKA TOTAL DATA VOLUME: HIGHER THAN SPACE

Think the LSST's anticipated total data volume (TDV) is large? The Square Kilometer Array TDV is expected to be about 4,600 petabytes. In stacked Blu-ray discs, that's about 68.6 miles high. Space "officially" begins about 62 miles (100 kilometers) up.

has occurred. This will happen automatically, with each incoming image being "subtracted" from a deep template built from prior observations of the same spot. For any given object of interest, an alert will go out within 60 seconds of when the target was observed.

Not surprisingly given the LSST's stupendous capabilities, there will be *a lot* of these alerts — about 10 million per night. Individual astronomers who subscribe to the project's feed won't receive 10 million emails overnight; rather, with each visit to the subscription service, they'll receive a small number of alerts, say 20 or so, satisfying criteria they themselves specify. And LSST itself will tag easily identifiable asteroids, variable stars, and other known objects. "So without a huge amount of effort, people will be able to filter out the mundane things from a small subset of the exotic," Kahn says.

But LSST won't go beyond basic processing and alerting. That is, the LSST team will stop short of making scientific decisions; as with SDSS, they will leave that up to the astronomical community.

In light of this, Kahn expects there will be what he calls *event brokers*. These experts will determine what astronomers are interested in, cross-match those choices to other catalogs, and perform extra filtering accordingly. Which objects highlighted in the alerts are time-critical and should be viewed with other telescopes as soon as possible? Which should astronomers follow up on spectroscopically? Which should they observe with radio, infrared, X-ray, or gamma-ray facilities?

Event brokers will have a job on their hands classifying the alerts so astronomers can jump on the most important ones. "You don't just want to say, 'Something happened over here,'" Loredo says. "You want to try to say, 'Well, based on the previous 10 or 100 measurements we have there, our best guess of what happened there is this.' And then people who control the other observing resources can try to make more informed decisions, either with algorithms or just manually. It's a big issue."

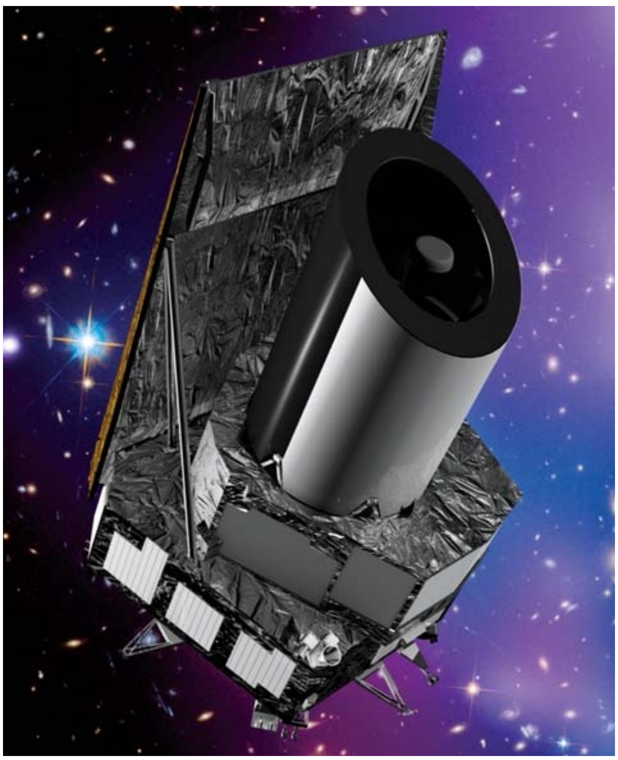
Are Astronomers Ready?

Getting astronomers prepped for the torrent from LSST and other wide-field surveys is a formidable challenge. There are two issues, Kahn says: energizing the astronomical community to prime itself for this flood of data, and securing adequate financial support so it can do so. The latter commonly occurs in fields like particle physics, he says: in advance of big facilities like the Large Hadron Collider turning on, strong support for the community exists to ensure they're ready to conduct scientific analyses as soon as the faucet is turned on.

"In astronomy, there's been more of a culture of 'Let's wait till the data come and then we'll figure it out,'" Kahn says. Astronomers can't do that with the LSST or they'll find themselves drinking from a fire hose. "And you know what happens when you drink from a fire hose," Kahn says. "Your head gets blown off!" The task, he says, is to get astronomers to change their culture a bit and acknowledge that while the start of the survey is over six years away, they need to start preparing now.

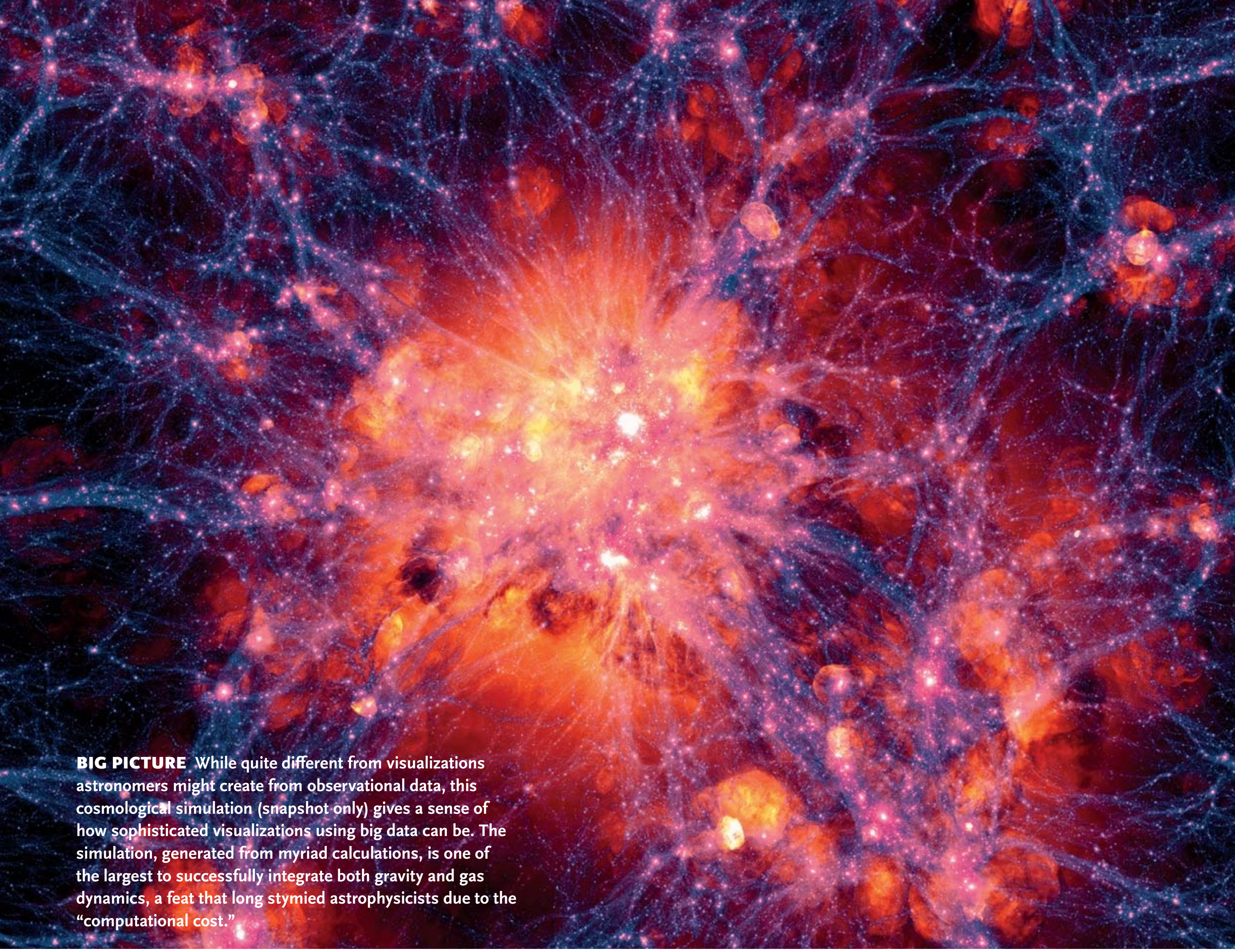
Even if astronomers grasp the urgency, they're often not adequately trained in techniques they'll require. To work in that many-dimensional phase space, for example, astronomers need to learn what Loredo terms "a little nontrivial math." And data visualization of the type Feigelson described? "Nobody does good data visualization," Feigelson said flatly, referring to astronomers in general.

Traditionally, astronomers haven't been schooled in the necessary statistics and information technology. For instance, the number of classes in statistics required for a Ph.D. in astronomy at a U.S. university is zero, Feigelson says. Until recently there weren't even tenure-track positions available for astrostatisticians. Yet an under-



ESA / C. CARREAU

THE LITTLE SPACECRAFT THAT WILL The European Space Agency's Euclid mission will help bring a semblance of "big data" to space-based projects.



BIG PICTURE While quite different from visualizations astronomers might create from observational data, this cosmological simulation (snapshot only) gives a sense of how sophisticated visualizations using big data can be. The simulation, generated from myriad calculations, is one of the largest to successfully integrate both gravity and gas dynamics, a feat that long stymied astrophysicists due to the "computational cost."

ILLUSTRIS COLLABORATION / ILLUSTRIS SIMULATION

standing of statistics will be crucial to sifting treasures from the information overload. As Feigelson and his longtime Penn State collaborator, statistician Jogesh Babu, write in one of their papers, "Scientific insights simply cannot be extracted from massive data sets without statistical analysis."

Astronomers will just have to get comfortable with statistical techniques such as "advanced regression" and "Bayesian inference" and "multivariate classification." The same goes for tools in informatics. All the experts interviewed for this article agreed that collaborations among astronomers, statisticians, and information scientists must be greatly expanded. Some astronomers are on top of this, such as those associated with the Department of Energy's SLAC National Accelerator Laboratory, which is building the LSST's camera. But many others are not.

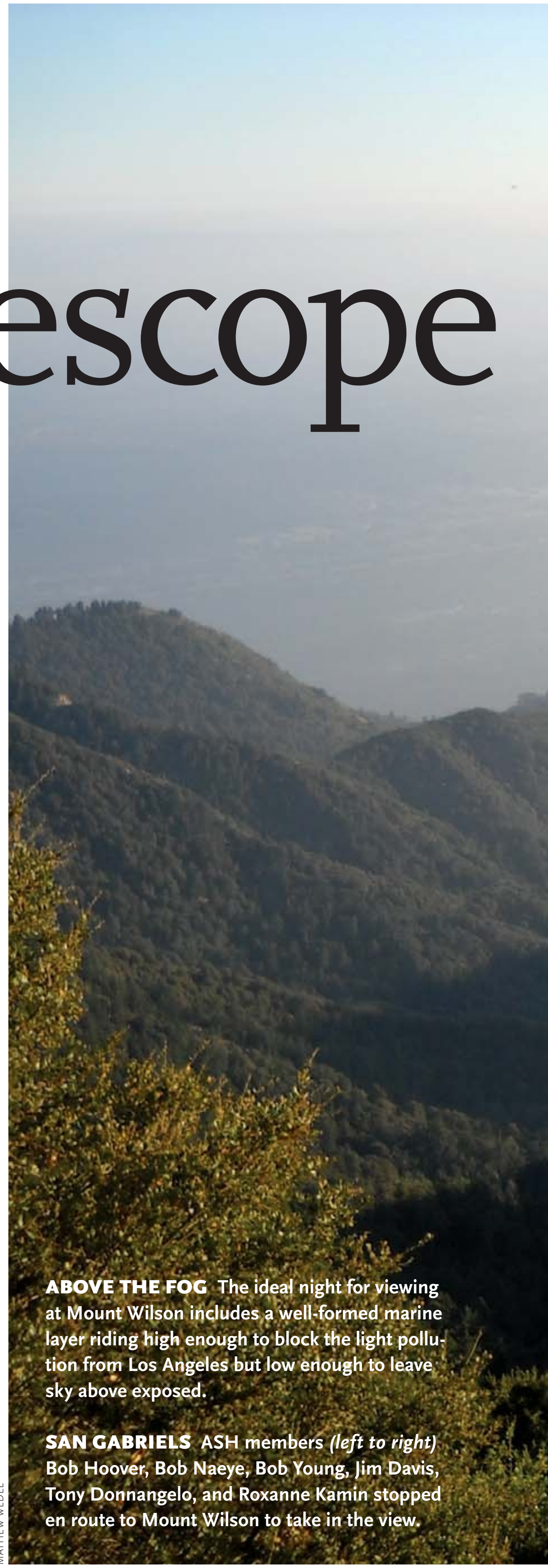
To that end, Feigelson spends a lot of time training astronomers in astrostatistics. "I've been in an airplane maybe 20 times in the last two or three years," he says, "where they fly me out to give tutorials in astrostatistics." He and colleagues have given instruction to about 10% of the world's astronomers, he estimates. "Which means we've had some inroads, but not enough to really modernize the methodology used by the entire field."

All the issues raised here really come down to one question: how well prepared will astronomers be when the goods begin gushing forth from the LSST, the Square Kilometer Array, and other such projects? "You don't fail by not being ready," Kahn says. "You can still do something. The question is, are you fully exploiting the data? That's really the challenge."

Incidentally, what is 200 petabytes of data — Kahn's estimate for the entire LSST data set, raw and processed, after 10 years — in stacked Blu-rays? It's about 15,750 feet, or roughly the height of Mont Blanc, the highest mountain in the Alps. ✦

***Peter Tyson** is editor in chief of* Sky & Telescope.

Observing Through a Truly Large Telescope



Robert Naeye

The author and friends enjoyed a memorable night of observing through what was once the world's largest telescope.

When it comes to visual observing, what constitutes a truly large telescope? Over the years I've observed through various instruments that meet any reasonable definition of that criterion. I looked through a friend's 32-inch relay scope (*S&T:* May 2011, p. 32). At star parties I've gazed at galaxies, clusters, and nebulae through apertures of 40 inches and more. And in 2002 I had the privilege of observing through the Mount Wilson 60-inch reflector, an unforgettable session I described in my Spectrum column (*S&T:* Nov. 2008, p. 8).

But when it comes to sheer size, nothing will ever top my experience on the night of November 4–5, 2015. Together with five friends from the Astronomical Society of Harrisburg, PA (ASH), I observed 20 objects through the Mount Wilson 100-inch Hooker Telescope, which was the world's largest from 1917 to 1949, the year the 200-inch Hale Telescope on Palomar Mountain saw first light. Edwin Hubble used the 100-inch in the early 1920s to prove that M31 and other spiral nebulae were in fact separate island universes, and later that decade, working on the 100-inch with Milton Humason, he discovered the expansion of the universe.

ROBERT NAEYE

The great news is that any observer or club can sign up for a night on the 100-inch, for a price. Even though my fellow ASH members and I were not treated to Mount Wilson's legendary subarcsecond seeing, it was still a thrilling experience, and there's a good chance you'd enjoy even better views.

MATHEW WEDEL

ABOVE THE FOG The ideal night for viewing at Mount Wilson includes a well-formed marine layer riding high enough to block the light pollution from Los Angeles but low enough to leave sky above exposed.

SAN GABRIELS ASH members *(left to right)* Bob Hoover, Bob Naeye, Bob Young, Jim Davis, Tony Donnangelo, and Roxanne Kamin stopped en route to Mount Wilson to take in the view.

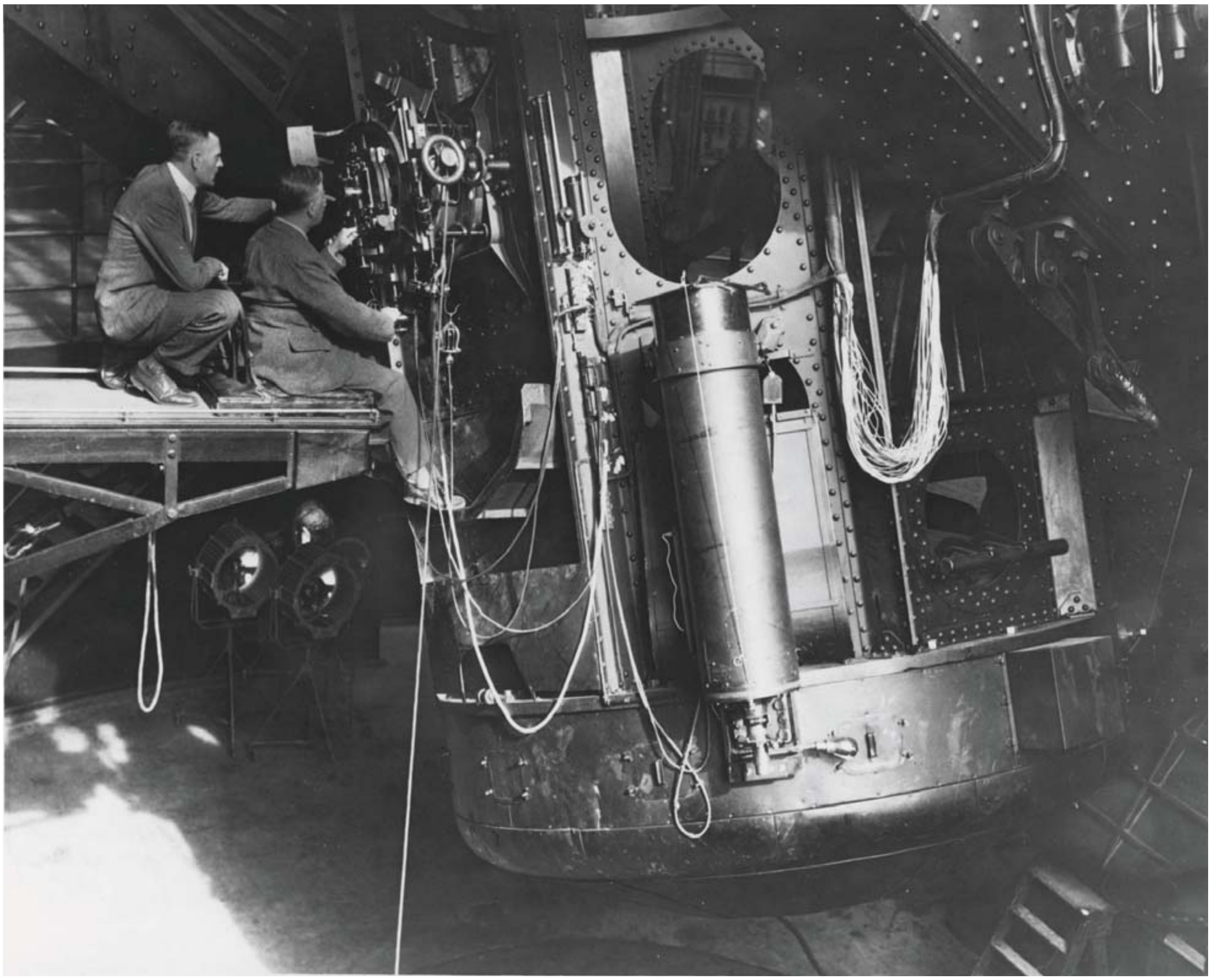
Hallowed Ground

The 60- and 100-inch reflectors were erected on Mount Wilson after astronomers recognized its outstanding seeing conditions, made possible by the laminar airflow over the 5,700-foot summit. With the large aperture and excellent seeing, the 100-inch telescope remained a research powerhouse for decades. Besides Hubble's great discoveries, astronomers used it to perform much of the spectroscopy required to classify stars and understand their evolution. Without question, the 100-inch is one of the most productive instruments in the history of science, and by proving the value of large reflectors, it paved the way for much larger telescopes.

When the 60- and 100-inch reflectors were built under the direction of George Ellery Hale in the early 1900s, Los Angeles was small enough that its light pollution didn't pose a significant threat. But the metro area has since expanded to 18 million people, who emit a vast amount of artificial light that creates a bright sky background over Mount Wilson. Typical moonless nights have a limiting visual magnitude of about 5. As a result, the glory days of the 100-inch have long since passed. It was last used for research in 2012.

The director of the observatory at that time, Harold McAlister, realized that the 100-inch needed a new purpose. For that, he looked to the public observing program on the 60-inch, which had started in the 1990s. "The great success of the 60-inch public access program inspired me to want to replicate that on the 100-inch as a means for producing an important new income stream for the Mount Wilson Institute," says McAlister.

But modifications were necessary before public observing could begin on the mountain. The 100-inch telescope was built during the era when photographic plates and spectrographs had taken over scientific research, so it wasn't constructed with the visual observer in mind. The telescope's Cassegrain focus rests 15 feet above the observing floor when the telescope points to the zenith, a significant safety concern for public observing in the dark.



OBSERVATORIES OF THE CARNEGIE INSTITUTION FOR SCIENCE COLLECTION AT THE HUNTINGTON LIBRARY, SAN MARINO, CALIFORNIA

SUPER-SIZE SIDE SHOW Perched on an elevated platform, Edwin Hubble (left) and James Jeans look through the Cassegrain focus at the side of the 100-inch scope during Jeans' visit to the observatory in May 1931.

To solve this problem, McAlister asked his Georgia State University colleague Laszlo Sturmann to develop an optical system that would let the public observe from a more accessible location. Sturmann finished the design in early 2012, and by September of that year his relay system had seen first light. Meanwhile, Dave Jurasevich, then Mount Wilson Superintendent, coordinated efforts to improve the telescope's pointing and tracking. The first public observing sessions commenced in 2013, and the program in its current form started in the spring of 2015.

In Sturmann's relay system, the light from the 100-inch telescope reflects off a 6-inch flat mirror before the Cassegrain focus. The light next goes "backward" through a Meade 152ED f/9 apochromatic refractor, which acts like a 1,368-mm eyepiece and recollimates the beam. The light is then brought to new focus by a 5-inch Explore Scientific refractor. As Sturmann says, "This is a very simple system, and the beauty of it is that both the Meade objective and the Explore Scientific refractor are used as they were intended, therefore the relay system itself has excellent image quality. It doesn't degrade the 100-inch telescope."

The relay system changed the original Cassegrain's focal ratio from f/16 to f/11.25 and made it possible to observe from a short ladder. The Explore Scientific refractor accommodates standard 2-inch eyepieces.

The Road to Mount Wilson

Ever since my 2002 observing session on the 60-inch, I've wondered what some of my favorite objects would look like if I could view them through this grand old reflector. So it was with particular good fortune that my longtime friend Bob Young informed me that he and a small group of ASH members were planning an observing night on the 100-inch. Bob is a retired planetarium educator with the State Museum of Pennsylvania in Harrisburg, and he served as president of the Astronomical League from 1978 to 1980.

Using the Mount Wilson Observatory's website (**mtwilson.edu/100in.html**), Bob reserved a half night on November 2, 2015, for a fee of $2,700 (a full night goes for $5,000). Bob kept the invitation list small so each person could enjoy ample time at the eyepiece. Besides Bob and me, the other ASH members who flew to Southern California (and split the cost) were Jim Davis, Tony Donnangelo, Bob Hoover, and Roxanne Kamin.

Though we'd planned to observe that Monday night, Shelley Bonus, our contact at the Mount Wilson Institute, called on both Monday and Tuesday mornings with bad news: a weather front in the area meant it was very likely we'd be clouded out and so we shouldn't bother to drive up the mountain. Fortunately, there's plenty to do in the L.A. metro area, so we spent the daylight hours on Monday and Tuesday touring Griffith Observatory, the California Science Center, and Warner Brothers Studios.

BEHEMOTH Be prepared to be awed by the size of the 100-inch when you visit it in its dome on Mount Wilson. When aimed near the zenith, the 87-ton telescope towers some 40 feet above observers' heads.

CINDY HUNT / MOUNT WILSON INSTITUTE

All of us had arranged to stay in the area a few extra days, so when Shelley called Bob with good weather news on Wednesday morning, we were ready to go. After lunch we visited a grocery store in La Cañada Flintridge to pick up food for dinner, then drove for about an hour up winding roads that offered picturesque views of the San Gabriel Mountains. After stopping at several overlooks to take photos, we arrived at the observatory's lower parking lot around 2:45 p.m. Fifteen minutes later Gale Gant of the Mount Wilson Institute met our group and gave us a highly informative 3-hour tour of the observatory, which included visits inside the 60- and 100-inch domes. Among the many highlights was seeing Edwin Hubble's storage locker, with his name still affixed to the front.

FRED ESPENAK

Twenty Targets

I had seen the 100-inch telescope on two prior visits, but walking into the dome and gazing at this magnificent instrument is an experience that never gets old. The scope and its surroundings exude history and wonder in a way that can only be appreciated in person. As Tony puts it, "I walked into the dome, and my jaw dropped. It was speechless exhilaration. We were going to observe through this historic behemoth!"

Gale concluded the tour by introducing us to our three assistants, who are contractors for the Mount Wilson Institute: telescope operator Jeff Schroeder and session directors Norm Vargas and Tom Mason. I can't speak highly enough of their friendliness, knowledge, and efficiency. Jeff slewed the telescope from a console one level above the observing floor. Norm was stationed at the eyepiece and let Jeff know when our target was in view. Norm and Tom provided expert commentary throughout the evening, and for the most part, our ASH group let them select the targets.

It usually took Jeff several minutes to slew from one object to the next. We were immediately struck by the quiet movement of the 100-ton yoke mount. The relay system was beautifully constructed for eyeball-to-eyepiece observing. When the telescope was aimed near the zenith, all I had to do was stand straight up and the eyepiece was at eye level. Even when the scope was aimed relatively low, we only needed to climb a few steps up a ladder to view our target.

My fellow ASH members brought several of their own eyepieces, but we mostly used the observatory's Tele Vue 55-mm Plössl, which yields a magnification of 520× and a true field of view about 5.5 arcminutes across.

We ended up observing 20 objects under clear skies starting at 6:10 p.m. Based on double-star observations, the three assistants estimated that the seeing ranged from 1 to 1.5 arcseconds, good in many circumstances but mediocre for Mount Wilson. Each of us spent several minutes soaking in individual targets — sufficient time for me to develop a good idea of how the view compared to what I've seen in various amateur scopes under different sky conditions. After I observed an object, I dashed across the room to jot down my impressions on a notepad under a red light. Here are my notes for each object, in order and edited for clarity and brevity:

1 **Epsilon (ε) Lyrae** (the Double Double) — We observed this object first to check seeing conditions. The scope easily split both doubles, but all four stars were swimming with halos around them. Not as bright as I expected it to be.

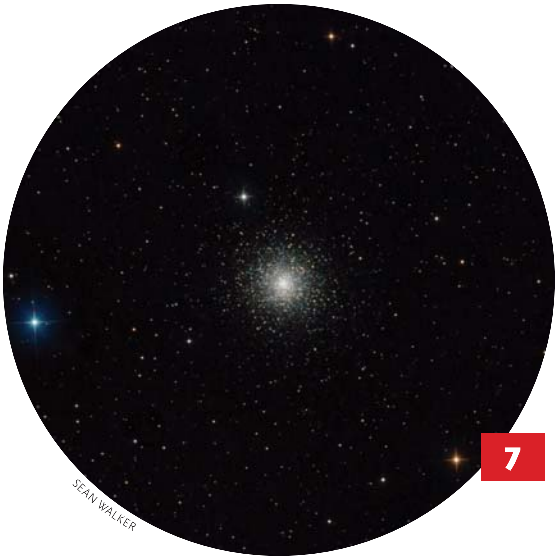
2 **M57** (Ring Nebula) — Very diffuse, not great surface brightness. Fleeting glimpses of the central star with averted vision. Gauzy central region. Bob Young: "I didn't notice any color other than the usual green." Roxanne: "Central green along with red outer ring colors."

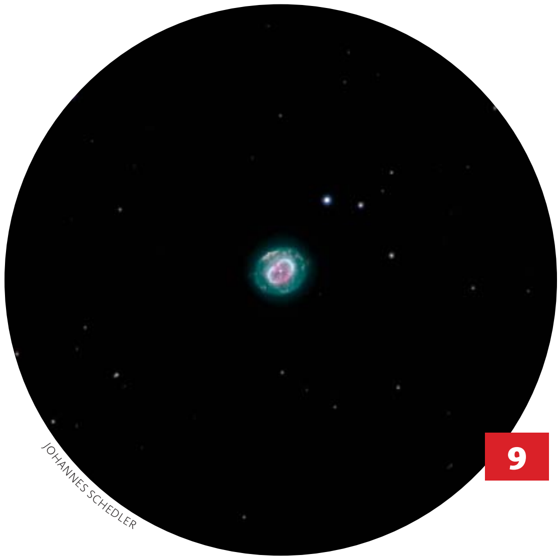
3 **Beta (β) Cygni** (double star Albireo) — This is the brightest I've ever seen the two stars in an eyepiece; the famous gold and blue colors are impressive. But the stars are fuzzy due to poor seeing; I couldn't bring them to a sharp focus. Bob Young: "Like two searchlights in your face." Jim: "Like two bright balls of flame."

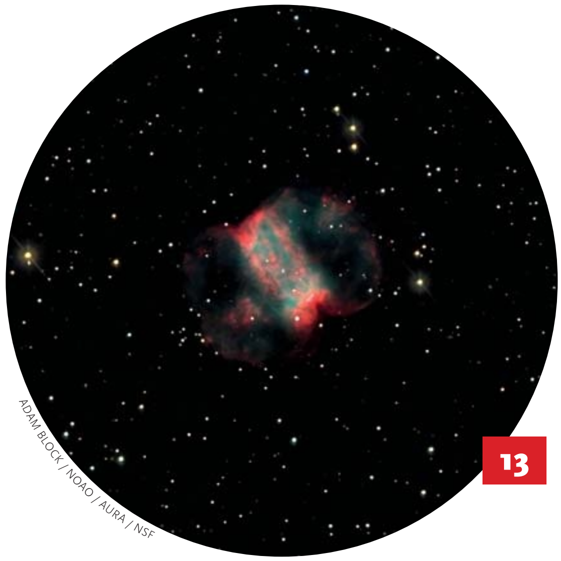
4 **NGC 7009** (Saturn Nebula, planetary nebula in Aquarius) — Target suggested by Jim. The blue-green color is very obvious, the brightest I've ever seen it. Hints of internal structure. The famous ansae seen in Hubble images are easily visible but not prominent. But the nebula clearly looks like its namesake planet, very impressive. No hint of a central star.

5 **Neptune** — The characteristic blue hue is impressive, but the disk was a smudgy glow, not a sharp disk. Triton was continuously and easily visible at about 8:45 on a clock face. Norm Vargas: "We don't get excited unless the seeing is better than 1 arcsecond. That's why the telescope was built here."

6 **M2** (globular cluster in Aquarius) — It's a nice, but not spectacular, view. A smudgy, unresolved central concentration of stars. Looks like bright individual outer







SOMEWHAT SPARKLY (6) Globular cluster M2 can be disappointing in small-aperture scopes, appearing as a regular but unexciting smudge with a slightly concentrated center. Even in the 100-inch, the core of the globular remained unresolved, but the outer stars filled the field of view.

BRIGHT AND IMPRESSIVE (7) Charles Messier was unable to resolve individual stars in globular cluster M15 — smaller scopes show it as a haze with a brighter halo. Even with less-than-ideal seeing, the outer stars of the cluster put on a good show through the 100-inch.

IN YOUR FACE (9) NGC 7662, also known as the Blue Snowball Nebula, offered one of the author's favorite views. The planetary nebula's inner shell was bright and easily visible, offering good contrast to the faint outer shell.

TWIN-LOBED CHALLENGE (13) M76, the Little Dumbbell Nebula, looks like a slightly anemic form of its big brother, M27. This is a tough catch for small scopes, especially in an area suffering from light pollution.

stars have been slingshot out of the central region in scattershot fashion. Stars fill the view.

7 M15 (globular cluster in Pegasus) — Couldn't bring the stars into a sharp focus. The central concentration of stars is easily visible but indistinct. The outer stars were bright and impressive.

8 NGC 7331 (spiral galaxy in Pegasus, brightest member of the Deer Lick galaxy group) — The main galaxy itself is quite bright, and three companions were easily visible at 6:30, 8:30, and 12:00 (the farthest) on a clock face. NGC 7331's nucleus is very easy, the rest of the disk looked tipped, like M31. Fairly symmetrical on right and left. Not much hint of spiral arms or dust lanes. Two other companions were visible but very difficult to see even with averted vision.

9 NGC 7662 (Blue Snowball Nebula, planetary nebula in Andromeda) — My favorite object of the night so far. The blue color is "in your face." A bright inner shell is very prominent and easy to resolve against the faint outer shell, which is unaligned. No central star.

10 NGC 7814 (spiral galaxy in Pegasus) — Unfortunately, I saw virtually nothing due to the light-polluted sky background.

11 Uranus — Pale blue color easy to discern. But the planet is a blob rather than a resolved disk. One moon was two planet diameters away at 12:30, another about four diameters away at 5:00. Later, with guidance from Tony, I saw two additional moons, but they were very, very faint, in and out, at 6:00 and 8:00, and very close to the planet. Norm said that on a good night, one can easily see four or five moons.

12 NGC 604 (H II star-forming region in the galaxy M33) — An indistinct, faint smudge about 1 arcminute across. No hint of the bright central star cluster seen in

SWEET SPIRAL Although M77 can be detected with hand-held binoculars, it really takes some aperture to reveal its core and spiral arms. In good seeing, the arms may be seen with 20 inches of glass. In bad seeing, even 100 inches aren't enough!

HUNTER WILSON

Hubble Space Telescope images. I see a few other bright spots in the field, but no hint of larger structure of M33 (the Triangulum Galaxy).

13 **M76** (Little Dumbbell, planetary nebula in Pegasus) — The little dumbbell shape was easy to discern, but was still very faint against a bright sky background. The right side of the right dumbbell was the brightest part.

14 **Gamma (γ) Andromedae** (double star) — Intense blue and gold colors. Stars look like little sparklers due to bad seeing. Still, the stars are easily split. Jeff Schroeder: "The scope has no hint of astigmatism, so the lack of sharpness is all due to the atmosphere."

15 **G1** (Mayall II, globular cluster in M31) — The cluster is the left "star" in an equilateral triangle. Brighter than the other two stars and less resolved. Roxanne inserted her 20-mm 100-degree Explore Scientific eyepiece she won at a star-party raffle, so it's seeing first light on a 100-inch scope! It spread out the triangle but otherwise there was no major difference.

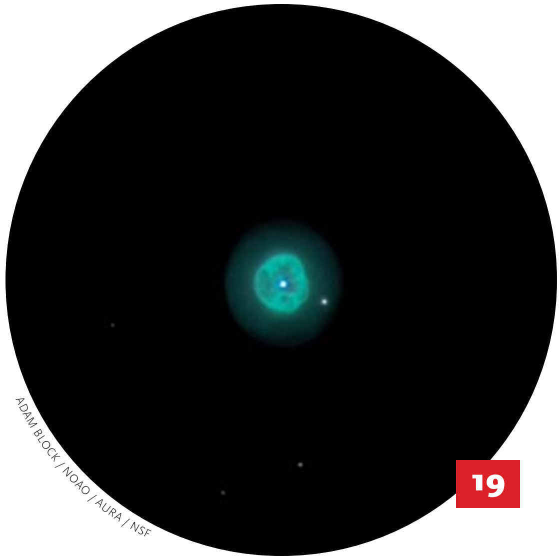
16 **Core of M31** — Detected a bright central spot just a few arcminutes across, surrounded by a semi-bright glowing region. The entire field looked brighter than the sky background. Averted vision reveals the barest hints of dust lanes on the opposite sides of the core.

17 **TX Piscium** (carbon star) — This looks like an intense orange sparkler, not well focused. Jim commented that it seemed about as bright as Aldebaran in a normal scope to him. Roxanne: "an intense harvest orange color."

18 **M77** (barred spiral galaxy in Cetus) — The bright, cigar-shaped nucleus was well defined. It's a faint tipped galaxy, and I saw no suggestion of spiral arms or dust lanes. But others saw hints of spiral arms that looked like hooked appendages.

19 **NGC 1535** (Cleopatra's Eye, planetary nebula in Eridanus) — Norm: "I call it the Liz Taylor Nebula." Best object of the night so far, a true "Wow!" view. A very bright central star with a bright glowing ring around it that has a tinge of blue-green, like M57 through a 16-inch scope. Easily discernible outer glow. Looks like a glowing bull's eye with a central dot and two outer rings.

20 **Trapezium Region of M42** — We saved the best for last. Four blazing bright stars, and two fainter Trapezium stars are easy to see, both reddish with the one on the right quite distinctly red. Tremendous detail in the mottling of the surrounding nebulosity, which has a noticeably bluish cast with a tinge of green. The most color I have ever seen in this region. We tried Roxanne's



AZURE BEAUTY **Planetary nebula NGC 1535 was one of the best objects of the night for the author and his group. Seeing was good enough that they could make out the star centering the blue-green glow, a beautiful bull's eye.**

20-mm eyepiece but couldn't bring the view into sharp focus because the higher power magnified the poor seeing. Jim: "Okay, that wins tonight."

Jeff and Norm shut things down at 12:45 a.m., when a third-quarter Moon was rising over the eastern horizon. Still giddy with excitement, we spent several minutes taking group photos under the giant reflector before heading outside for our drive back to Los Angeles.

Experience of a Lifetime

From a pure observing perspective, I've had better views of many of these objects through much smaller scopes operating under darker and steadier skies. I recall from my experience on the 60-inch that the seeing makes a world of difference. On that night we enjoyed subarcsecond seeing, and the high-magnification views of Jupiter and Saturn (both near opposition) were like looking at them up close through a spaceship portal.

The other factor, of course, is light pollution. The bright sky background partially washes out deep-sky objects with low surface brightness, and this effect was particularly noticeable with galaxies. The objects with high surface brightness, particularly the planetary nebulae and the Trapezium region, were showstoppers. Norm informed us that on some nights, a marine layer covers metro L.A., reducing light pollution.

Even though the relatively poor seeing degraded some of the views, this was one of my most thrilling astronomical adventures. The 100-inch brought out more nebula colors than I've ever seen. The combination of the exceptional views of several objects and just knowing I was looking through the same scope used by Hubble to discover the expanding universe made it a night never to forget. As Bob Young expressed as we were driving down the mountain, "It was an experience of a lifetime."

Word is just beginning to spread that the 100-inch is available for visual observing, so there are many open nights in the coming year. My ASH friends and I heartily recommend that you check it out. As Roxanne said at the end of the night, "Even if the seeing wasn't the greatest, the magic was still there."

To sum up, if you want to enjoy a beautiful night of observing at a historic observatory with a legendary (and giant!) instrument, all while supporting a venerable institution, check out the Mount Wilson Observatory website and sign up! ✦

***Robert Naeye** was editor in chief of* Sky & Telescope *from 2008 to 2014. He joined the Astronomical Society of Harrisburg, PA in 1986, shortly after graduating from college and while he was living in nearby Hershey. He extends his gratitude to Bob Young for arranging the observing session.*

Tips for Mount Wilson Visual Observers

Both telescopes are available from April through December. They're closed January through March for maintenance and because of frequent inclement weather.

The summer months have the best weather and seeing, but the nights are shorter, so you may feel pressed for time.

Weekend nights near new Moon are booked far in advance, but weeknights are usually open.

The maximum group size is 18 people for the 100-inch, and the maximum group size for the 60-inch is 25 people. I strongly recommend keeping your group relatively small so you won't spend too much time waiting in line.

At present, the fee is $950 for a half night and $1,700 for a full night with the 60-inch; the 100-inch is $2700 for half a night, $5000 for a full night of fun.

Ask for permission before bringing your own eyepieces.

Bring plenty of warm layers, especially if you go in the spring or fall. When we closed shop around 1:00 a.m. in November, the temperature inside the dome was barely above freezing.

If you get cold or hungry, you can go downstairs to a small room where you can warm up, eat a sandwich, or make a hot drink. Bring your own food and drink!

Don't show up in Los Angeles expecting the first night to have perfect weather. Build some flexibility into your schedule and travel plans in case you have to wait several nights for clear skies.

Find your Dawes Limit

Phillip Kane

The famous resolving-power rule that William Rutter Dawes determined for telescopes may not apply to you. Try these close double stars to find out.

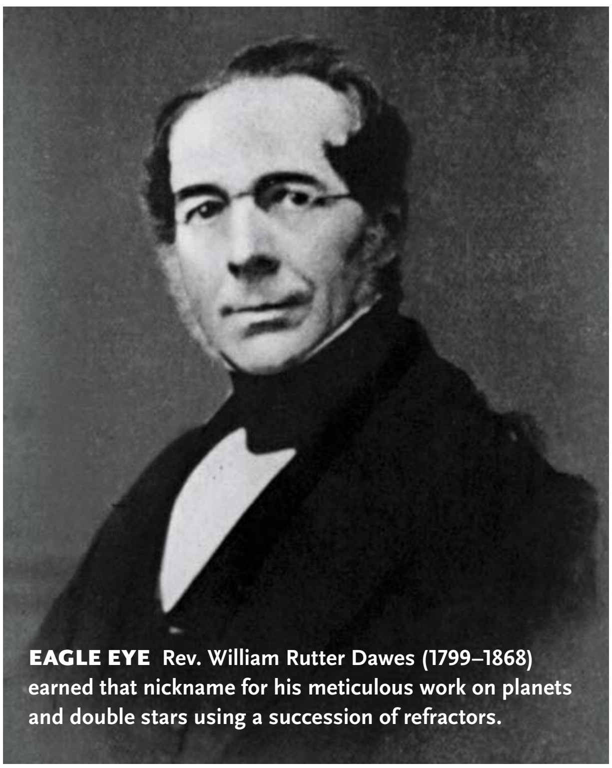
The Reverend William R. Dawes was one of the most outstanding observers during the golden age of gentleman astronomers in mid-19th-century England. His prolific double-star and planetary observations are still highly regarded today (see, for example, "William Dawes' Jupiter" in last November's *Sky & Telescope,* page 48). Dawes is most remembered, though, for his simple rule for how sharply a telescope of any given size ought to resolve. His formula is

$$r = 4.56''/a$$

where r is the resolving power in arcseconds and a is the aperture in inches. Or if you prefer,

$$r = 116''/a$$

when a is in millimeters.



EAGLE EYE Rev. William Rutter Dawes (1799–1868) earned that nickname for his meticulous work on planets and double stars using a succession of refractors.

THE OBSERVATORY / PUBLIC DOMAIN

In other words, a 4.56-inch (116-mm) telescope should have a resolving power of exactly 1 arcsecond, a scope twice that diameter should resolve 0.5″, and so on.

Dawes, however, was more circumspect about his rule than many astronomers now realize. He described it as being specifically for double stars with "two stars of the sixth magnitude." As he wrote in 1867,

> I examined with a great variety of apertures a vast number of double stars, whose distances [separations] seemed to be well determined, and not liable to rapid change, in order to ascertain the separating power of those apertures, as expressed in inches of aperture and seconds of distance. I thus determined as a constant, that a 1-inch aperture would just separate a double star composed of two stars of the sixth magnitude, if their central distance was 4.56″, the atmospheric circumstances being moderately favourable . . .

Notice the specific limitation to doubles composed of two stars of the 6th magnitude. Others also stressed this qualification over the years in their paraphrasing of the Dawes standard. But many observers today take it as a hard and fast property of a given telescope aperture, and telescope manufacturers typically list it as such on their specifications page.

Several things complicate the picture. For one, *unequal* double stars must be wider to be resolved with the same telescope, sometimes much wider (see the box on page 31). And for equal pairs, Dawes' selection of 6th magnitude was a good choice; some research suggests that both brighter and fainter equal-magnitude pairs are harder to resolve and thus would not provide the finest test. Louis Bell, in his 1922 book *The Telescope,* wrote:

> If the stars are decidedly bright there is increase of apparent diameter of the [stellar] disc due to the phenomenon known as irradiation, the spreading of light about its true image on the retina which corresponds quite closely to the halation produced by a bright spot on a photographic plate. If, on the contrary, the stars are very faint the total amount of light available is not sufficient to make contrast over and above the background sufficient to disclose the two points as separate.

TIGHT PAIRS **Close doubles are tiny! Longtime binary-star observer Bill Boublitz drew these two to match the view in his 7-inch Maksutov telescope at 300×. The comments are his.**

As for fainter doubles, in 1914 Thomas Lewis concluded that for equal pairs at 9th magnitude, the Dawes limit was not 4.56″/*a,* but a much larger 8.5″/*a*. The great double-star measurer R. G. Aitken wrote in 1935 that his own limit for 9th-magnitude pairs was 6.1″/*a,* though he was using the Lick Observatory 36-inch refractor, certainly an outlier in terms of size.

There seems to be no similar study for the few tight equal-magnitude pairs that are brighter than 6th magnitude. But as Bell noted, irradiation — glare within the retina — is real and clearly interferes with distinguishing things very close together.

Even for his ideal test case, Dawes concluded that his constant (4.56″/inch) could differ for other people even using the same telescopes:

> It is, therefore, my confirmed opinion that a list of test objects is of comparatively small importance in the trial of a telescope, especially as so much must depend on the eye and the habit of the observer, and the circumstances under which the scrutiny is performed.

Testing Your Limits

My challenge is this: is your own resolution equation $r = 4.56''/a$, or something different? It’s worth figuring out, because Dawes’ equation remains a useful standard for comparing our scopes, ourselves to other observers, and our personal capabilities over time — as long as we play by the rules and limit ourselves to 6th-magnitude pairs. In my own experience, I have never matched Dawes’ standard of $r = 4.56''/a$. My personal resolution parameter has changed over the last 20 years from 5.1″/*a* to 6.0″/*a*. I’ve also discovered that my 6-inch and 4-inch

The Uneven Double Stars Project

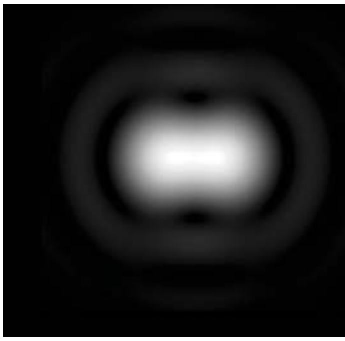
Trickier than equal doubles is the resolvability of unequal binary stars — which means the vast majority of them.

In the November 2015 issue, longtime double-star enthusiast and observer Sissy Haas sought more observers for her Uneven Double Stars Project (first announced in the September 2012 issue, page 68). She’s seeking many users of every size of telescope, in hopes of generalizing Chris Lord’s pioneering study of unequal binaries that was based on 20 years of his own observations (*S&T:* Jan. 2002, p. 120).

The November 2015 article, Haas writes, “reignited our project and led to us making some extremely rapid headway. We gained a number of new participants. Many put forth the time and effort to make aperture-stop masks. This let them go from one aperture to a smaller one, until they found the aperture where resolution first failed. Their reports spurred many older members of the project to do the same.

“Just last week we gained enough new observations of Struve 1881 (3.5″ separation, 2.0 mags unequal) to confidently say it needs a 100-mm aperture. There are 11 positive observations out of 13 attempts with 100 mm, but only 5 positive out of 14 attempts with 80 mm. Saying that 100 mm is the smallest aperture for this pair seems reasonable — for most nights and most observers.”

To derive a formula covering all apertures, star brightnesses, and brightness differences, she and her colleagues need lots more data. It’s easy to participate. See **http://is.gd/HaasProject** and its support site **http://is.gd/udstars**, which has full instructions. Email Haas at **has103@comcast.net**.



GEEK3 / WIKIMEDIA COMMONS / CC BY-SA 3.0

THE IDEAL This is the computer-generated diffraction pattern of an equal double star seen precisely at the Dawes limit. The two central Airy disks overlap, but a slight notch appears at their edges.

refractors resolve somewhat more sharply (both 6.0″/*a*) than a 4-inch Schmidt-Cassegrain that I also use (6.4″/*a*).

In the other direction, on a night of almost rock-steady seeing, *S&T*'s Alan MacRobert detected the duplicity of an 0.32″ pair of 7th-magnitude stars at 800× in his 12.5-inch f/6 reflector. It has a mirror whose figure is fine-tunable by a knob at the eyepiece that applies electric warmth to the center of the mirror's back (*S&T:* Feb. 1996, p. 76). He estimated the position angle of the pair as seen in the eyepiece, and this proved to be correct. Those numbers yield a Dawes parameter of 4.0″/*a*.

Several factors further confound the idea of a standard resolution limit. Few telescopes are optically perfect. Seeing affects large apertures more than small ones. A scope with a central obstruction shows a slightly larger Airy disk (the bright center of a star's diffraction pattern) than an unobstructed aperture. And what exactly did Dawes mean by "moderately favorable" atmospheric steadiness?

Moreover, Dawes defined a double star as being resolved if he could discern a "notch" between the overlapping Airy disks of the two components, as in the computed simulation at left. But it's possible to detect that a star is double even if the Airy disk is merely elongated a trace, the way MacRobert described his 0.32″ pair, rather than notched to show the beginnings of a figure-8.

Lastly, what exactly did Dawes mean by "two stars of the sixth magnitude"?

To create my grand list of test stars on the facing page, I had to be specific. The table lists doubles in which the primary component is between visual magnitude 5.7 and 6.9 and the secondary is 0.0 to 0.4 magnitude fainter than the primary. I think this definition is reasonable, but it's somewhat arbitrary.

Close pairs this similar are indeed unusual. In searching the primary double-star sources — the Washington Double Star Catalog (WDS) and the Sixth Catalog of Orbits (CO), for instance — I found only 49 such pairs visible from my location (latitude 41° N). I may have missed a pair or two, but my searches were careful and earnest. I did my own searches of the catalogs and also used T. V. Bryant's online search tool for the WDS (available at **http://is.gd/WDSsearch**).

Have at it! ✦

__Phil Kane__'s increasing Dawes constant over the years has induced a slow panic, but he still counts his blessings for dark ranch skies and plenty of doubles to observe. He welcomes mail at ***icycomet1944@gmail.com***.

Star-Test Your Telescope

If you're going to be focusing stars at very high power, you'll be star-testing your telescope's optics whether you know it or not. So here's what to look for. The star test is so simple, yet so stringent, that every telescope user should know it.

Give your scope a good hour to cool to the surrounding temperature. If you have astigmatism, wear your glasses. Center a moderately bright star, then switch to your highest power.

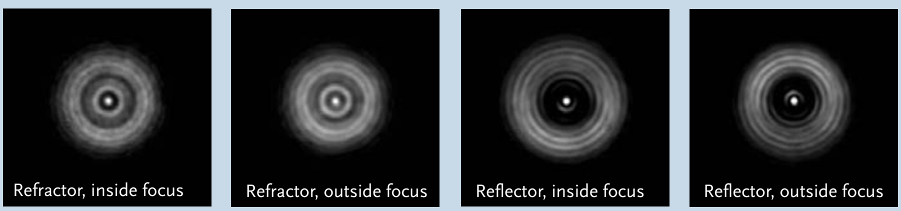
1. Turn the focuser slightly to one side of best focus, then slightly to the other side. As the star moves out of focus, it will swell to a little disk with subtle rings and maybe a dark spot at or near the center.

This slightly out-of-focus disk should *look the same on both sides of best focus.*

This test is so powerful that few telescopes pass it perfectly. A little difference in how the star disk looks on either side of focus is acceptable. But a really obvious difference means the scope is a reject.

2. Next, on a night of very steady seeing, focus the star as *sharply* as you can. You should see it as a tiny bright dot surrounded by a few thin little rings. This is the diffraction pattern caused by the wave nature of light. When the air settles way down, it should be tight, crisp, and high-contrast — not messy, spiky, or vague.

3. Still at very high power, move the focus slightly in and out again. Look for what telescope users call "snap." This means that the star, or anything else, should "snap" into sharp focus at a fairly precise point. What you don't want to see is the star "mush" through focus, with some distortions and aberrations growing into view even before others disappear.



TWO WINNERS These are the kind of star tests that telescope owners yearn to see. For each scope, the diffraction patterns are nearly identical on either side of sharp focus. These are photos of an artificial star shot through a high-quality 85-mm refractor and a 90-mm Maksutov telescope in an indoor test setup.

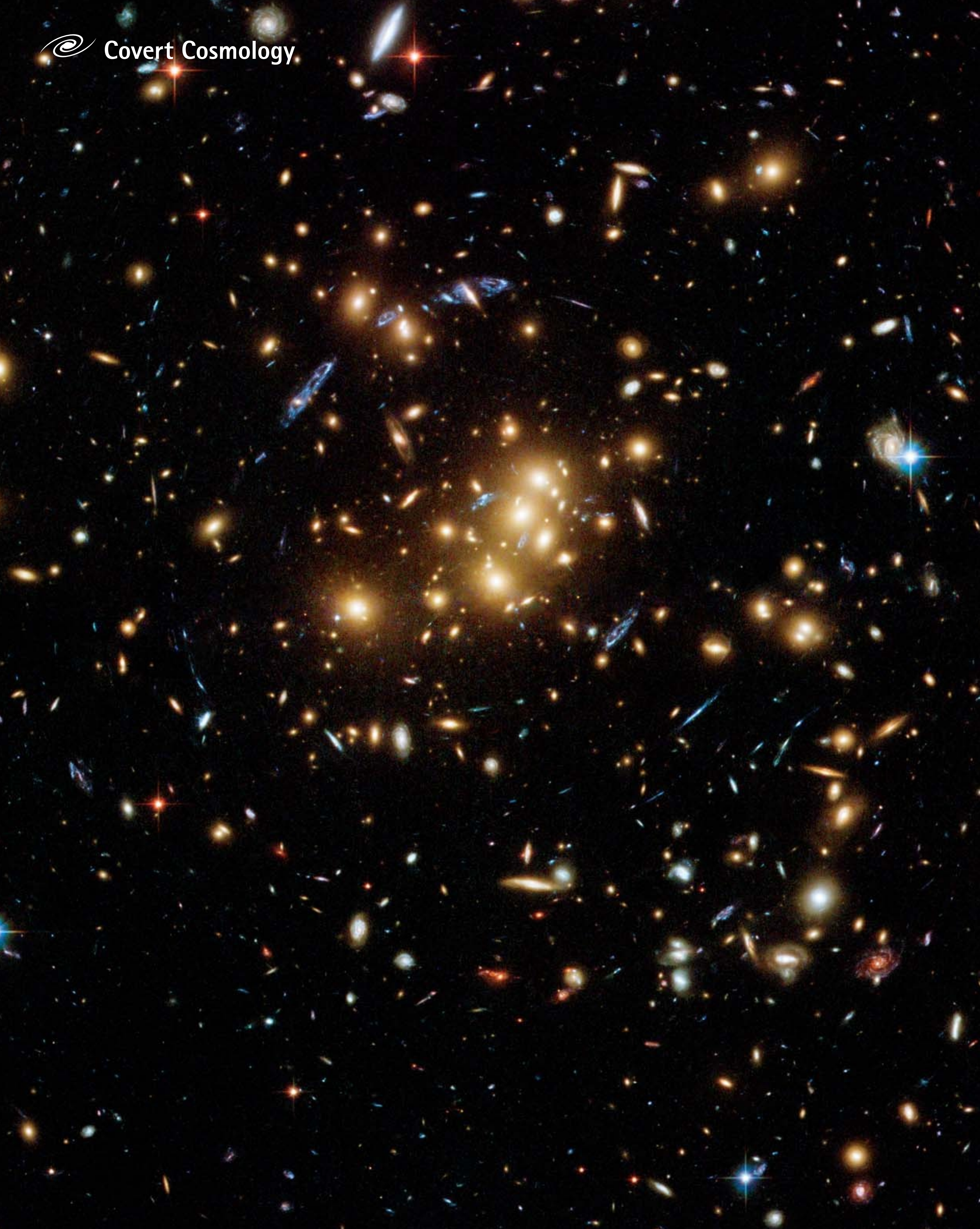
S&T: DENNIS DI CICCO

Stars for Finding Your Personal Dawes Limit

In order of separation for 2016.0

Star	Con	RA (2000.0)	Dec.	∆Mag	Mag1	Mag2	2016.0 Sep.	2016.0 PA	2018.0 Sep.	2018.0 PA	Notes
BU 1163	Cet	1^h 24.3^m	−6° 55′	0.4	6.6	7.0	0.35″	211°	0.28″	208°	
BU 341	Vir	13^h 03.8^m	−20° 35′	0.3	6.2	6.5	0.39″	131°	0.31″	130°	
BU 311	Eri	04^h 26.9^m	−24° 05′	0.3	6.8	7.1	0.44″	157°	0.43″	159°	
51 Aquarii	Aqr	22^h 24.1^m	−4° 50′	0.2	6.4	6.6	0.47″	30°	0.48″	28°	Has 3 distant 10th-mag stars.
52 Arietis	Ari	3^h 05.4^m	+25° 15′	0.0	6.2	6.2	0.50″	258°	0.51″	258°	Component C: mag 10, 4.7″
72 Pegasi	Peg	23^h 34.0^m	+31° 20′	0.4	5.7	6.1	0.57″	105°	0.58″	106°	
STF 1555	Leo	11^h 36.3^m	+27° 47′	0.4	6.4	6.8	0.67″	150°	0.65″	151°	
STT 517	Ori	5^h 13.5^m	+1° 58′	0.2	6.8	7.0	0.69″	241°	0.70″	241°	
STF 2173	Oph	17^h 30.4^m	−1° 04′	0.1	6.1	6.2	0.69″	144°	0.52″	138°	
I 78	Cen	11^h 33.6^m	−40° 35′	0.1	6.1	6.2	0.70″	99°	(no change)		
STF 2244	Oph	17^h 57.7^m	+0° 04′	0.3	6.6	6.9	0.70″	279°	(no change)		
STF 186	Cet	1^h 55.9^m	+1° 51′	0.0	6.8	6.8	0.73″	71°	0.69″	73°	
BU 395	Cet	0^h 37.3^m	−24° 46′	0.4	6.2	6.6	0.75″	113°	0.60″	119°	
7 Tauri	Tau	3^h 34.4^m	+24° 28′	0.3	6.6	6.9	0.75″	351°	0.76″	351°	
STT 359	Her	18^h 35.5^m	+23° 36′	0.3	6.3	6.6	0.75″	4°	0.75″	4°	
Lambda Scl	Scl	0^h 42.7^m	−38° 28′	0.4	6.6	7.0	0.80″	23°	(no change)		HDO 182
31 Tauri	Tau	3^h 52.0^m	+6° 32′	0.3	6.3	6.6	0.80″	204°	(no change)		
STF 1126	CMi	7^h 40.1^m	+5° 14′	0.4	6.6	7.0	0.84″	177°	0.83″	178°	12′ east of Procyon
16 Vul	Vul	20^h 02.0^m	+24° 56′	0.4	5.8	6.2	0.85″	127°	0.85″	127°	A mag. 5.9 star is 9′ SW.
STT 410	Cyg	20^h 39.6^m	+40° 35′	0.1	6.7	6.8	0.87″	4°	0.87″	4°	Component C: mag 8.7, 69″
STF 2	Cep	0^h 09.3^m	+79° 43′	0.2	6.7	6.9	0.91″	15°	0.92″	15°	
STF 1338	Lyn	9^h 21.0^m	+38° 11′	0.4	6.7	7.1	1.0″	315°	1.0″	318°	
HWE 28	Cen	13^h 53.5^m	−35° 40′	0.1	6.3	6.4	1.0″	315°	1.0″	316°	Component E: mag 8.6, 67″
24 Ophiuchi	Oph	16^h 56.8^m	−23° 09′	0.1	6.2	6.3	1.0″	300°	(no change)		BU 1117
36 And	And	0^h 55.0^m	+23° 38′	0.4	6.1	6.5	1.1″	330°	1.1″	332°	STF 73
STF 749	Tau	5^h 37.1^m	+26° 55′	0.0	6.5	6.5	1.2″	320°	1.2″	319°	
52 Orionis	Ori	5^h 48.0^m	+6° 27′	0.0	6.0	6.0	1.2″	222°	(no change)		STF 795
Kappa^1 Scl	Scl	0^h 09.4^m	−27° 59′	0.1	6.1	6.2	1.3″	258°	1.3″	258°	BU 391
53 Aquarii	Aqr	22^h 26.6^m	−16° 45′	0.1	6.3	6.4	1.3″	65°	1.3″	73°	SHJ 345
57 Cancri	Cnc	8^h 54.2^m	+30° 35′	0.3	6.1	6.4	1.5″	312°	(no change)		Component C: mag 9.2, 55″
STT 358	Her	18^h 35.9^m	+16° 59′	0.2	6.9	7.1	1.5″	146°	1.5″	145°	
Pi Aquilae	Aql	19^h 48.7^m	+11° 49′	0.4	6.3	6.7	1.5″	105°	(no change)		STF 2583
STF 644	Aur	5^h 10.3^m	+37° 18′	0.2	6.8	7.0	1.6″	221°	(no change)		
HJ 5014	Cra	18^h 06.8^m	−43° 25′	0.0	5.7	5.7	1.7″	359°	1.7″	359°	
STF 1333	Lyn	9^h 18.4^m	+35° 22′	0.1	6.6	6.7	1.9″	50°	(no change)		
HJ 3527	Eri	2^h 43.3^m	−40° 32′	0.3	6.9	7.2	2.3″	40°	(no change)		
STF 2375	Ser	18^h 45.5^m	+05° 30′	0.4	6.3	6.7	2.4″	122°	(no change)		Stars are close 0.1″ pairs.
STF 3050	And	23^h 59.5^m	+33° 43′	0.2	6.5	6.7	2.4″	340°	2.4″	341°	
Mu Draconis	Dra	17^h 05.3^m	+54° 28′	0.0	5.7	5.7	2.5″	2°	2.6″	0°	STF 2130
STF 2644	Aql	20^h 12.6^m	+0° 52′	0.2	6.9	7.1	2.5″	205°	(no change)		
39 Boötis	Boo	14^h 49.7^m	+48° 43′	0.4	6.3	6.7	2.6″	46°	(no change)		STF 1890
WNC 2	Ori	5^h 23.9^m	−0° 52′	0.1	6.9	7.0	3.1″	158°	3.1″	158°	
54 Virginis	Vir	13^h 13.4^m	−18° 50′	0.4	6.8	7.2	4.0″	35°	(no change)		
17 Hydrae	Hya	8^h 55.5^m	−7° 58′	0.2	6.7	6.9	4.1″	4°	(no change)		STF 1295
STF 1009	Lyn	7^h 05.7^m	+52° 45′	0.1	6.9	7.0	4.2″	148°	(no change)		
65 Piscium	Psc	0^h 49.9^m	+27° 43′	0.0	6.3	6.3	4.5″	115°	(no change)		STF 61
STF 958	Lyn	6^h 48.2^m	+55° 42′	0.0	6.3	6.3	4.6″	77°	(no change)		Component C: mag 7.9, 96″
Phi^2 Cancri	Cnc	8^h 26.8^m	+26° 56′	0.0	6.2	6.2	5.1″	218°	(no change)		STF 1223
STF 1669	Crv	12^h 41.3^m	−13° 01′	0.0	5.9	5.9	5.2″	314°	(no change)		Two mag 10 stars are at 60″.

Stars are listed in order of their separation for 2016.0 (0^h UT January 1, 2016). Interpolate for your date if the change by 2018.0 is significant. Position angle (PA) tells the direction of the fainter star from the brighter one, counting clockwise from north (0°) through east (90°), south (180°), and west (270°). Data are from the Washington Double Star Catalog (WDS) or, when a pair has a calculated orbit, the Sixth Catalog of [binary star] Orbits. Both are maintained by the U.S. Naval Observatory and are available at usno.navy.mil. In double-star names, BU = S. W. Burnham, HJ = John Herschel, HWE = H. A. Howe, I = R. T. A. Innes, STF = F. G. Wilhelm Struve (Σ), STT = Otto Struve (OΣ), WNC = A. Winnecke.



Strong Prospects for WEAK LENSING

Astronomers are mapping tiny distortions in the images of distant galaxies to study the invisible — dark matter and dark energy.

Govert Schilling

Nothing is what it seems.

That's often the case in daily life. But it's also true in the universe at large. Take a long-exposure photo of remote galaxies, and you'll find that none of them are what they appear to be.

First of all, we see faraway galaxies as much younger than they really are right now — their light took billions of years to reach us. We also see them as much redder than they used to be. That's because, during the long trip to Earth, the universe's expansion stretched the galaxies' emitted light to longer wavelengths. It's as though we look at an old greybeard and see a red-haired schoolboy instead.

But that's not all. Even the observed shape of a distant galaxy isn't real: it doesn't reflect the galaxy's true physical appearance. During the billions-year-long journey the galaxy's light takes through the fabric of spacetime, its path bends ever so slightly under the gravitational influence of intervening matter. The result: a minute distortion of the galaxy's shape, as if astronomers were looking at the universe through a glass of water. In space that effect is known as *gravitational lensing*. And it has become a powerful tool for cosmologists.

MORE THAN MEETS THE EYE **A massive foreground cluster rich with galaxies (and their invisible dark matter halos) smears the light from bluer background galaxies into arcs. This effect, known as *strong gravitational lensing*, is obvious. The subtler effect of *weak lensing* is present too, but it's invisible to the eye. Only computer algorithms can tease out the slight stretch in the shape of background galaxies lying at the cluster's edge.**

NASA / ESA / M. J. JEE & H. FORD (JOHNS HOPKINS UNIVERSITY)

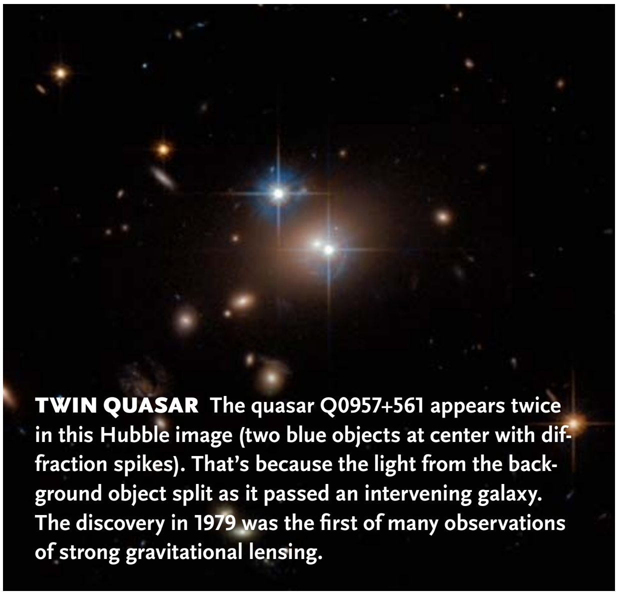
Anything that exerts a gravitational force — not just galaxies and clusters, but also the enigmatic dark matter that makes up more than 80% of all mass in the universe — can cause gravitational lensing. And therein lies the technique's power. Astronomers know almost nothing about invisible dark matter, but by measuring the distortions it generates, they can outline the stuff's cosmic distribution. These observations can then be compared against cosmological simulations to better understand the properties of dark matter.

Comprehensive lensing surveys might even shed light on dark energy — the equally perplexing cosmic constituent that's responsible for the present acceleration of the expansion of the universe.

A Brief History of Lensing

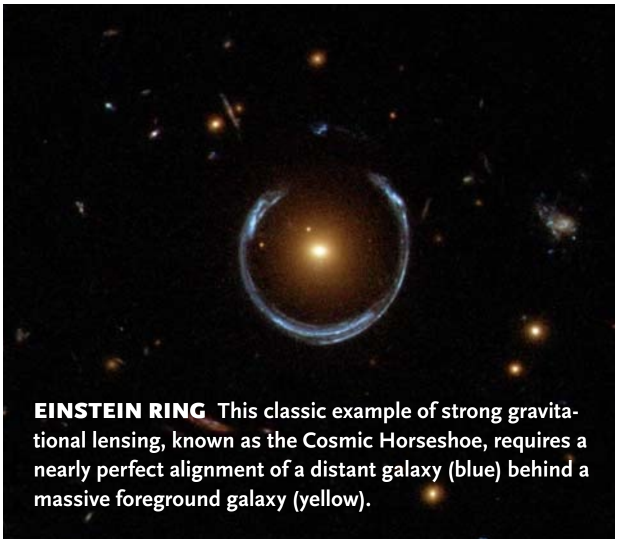
Albert Einstein first thought about gravity's ability to bend light paths in 1912, three years before he penned his general theory of relativity. Relativity's predictions were famously confirmed during the 1919 total solar eclipse (*S&T:* Dec. 2015, p. 18). But it wasn't until 1936 that Einstein wrote a detailed paper in *Science* describing what we now call *strong gravitational lensing*. As he explained, the light from a distant source can split into multiple images or even bend into a ring when it passes by another massive object on its way to us.

Einstein, who calculated the effect for individual stars, was convinced that not only would such a chance alignment be rare, but it would also be far too small to observe. But never say never in science. Although the effect of a chance alignment between two stars would indeed be negligible, such alignments are far more likely for galaxies, and the observable effect is much larger,



TWIN QUASAR The quasar Q0957+561 appears twice in this Hubble image (two blue objects at center with diffraction spikes). That's because the light from the background object split as it passed an intervening galaxy. The discovery in 1979 was the first of many observations of strong gravitational lensing.

ESA / HUBBLE & NASA



EINSTEIN RING This classic example of strong gravitational lensing, known as the Cosmic Horseshoe, requires a nearly perfect alignment of a distant galaxy (blue) behind a massive foreground galaxy (yellow).

ESA / HUBBLE & NASA

HIDDEN RING Using both strong and weak lensing, astronomers mapped out the dark matter (blue) present in the same galaxy cluster seen on page 34. The ghostly ring is the result of a collision with another cluster 1 to 2 billion years ago.

NASA / ESA / M. J. JEE & H. FORD (JOHNS HOPKINS UNIVERSITY)

too. In 1979 British astronomer Dennis Walsh and his colleagues discovered a "twin quasar," Q0957+561, which turned out to be a single background object whose light had split into two separate images as it passed by an intervening galaxy.

In the 1980s astronomers continued to discover strong gravitational lenses, such as Einstein crosses (four images of a single background source), elongated light arcs (the greatly distorted images of distant galaxies), and even complete Einstein rings. Today, such strong lenses are observed on a routine basis, such as in the Frontier Fields program (*S&T:* Jan. 2015, p. 20), the Hubble Space Telescope's long look at six massive clusters and the galaxies behind them.

Gravitational lensing doesn't just distort images, it magnifies them, too. That benefit enables astronomers to study extremely remote galaxies and better understand the cosmic dawn. It's as if the universe had provided us with a huge natural telescope — for free.

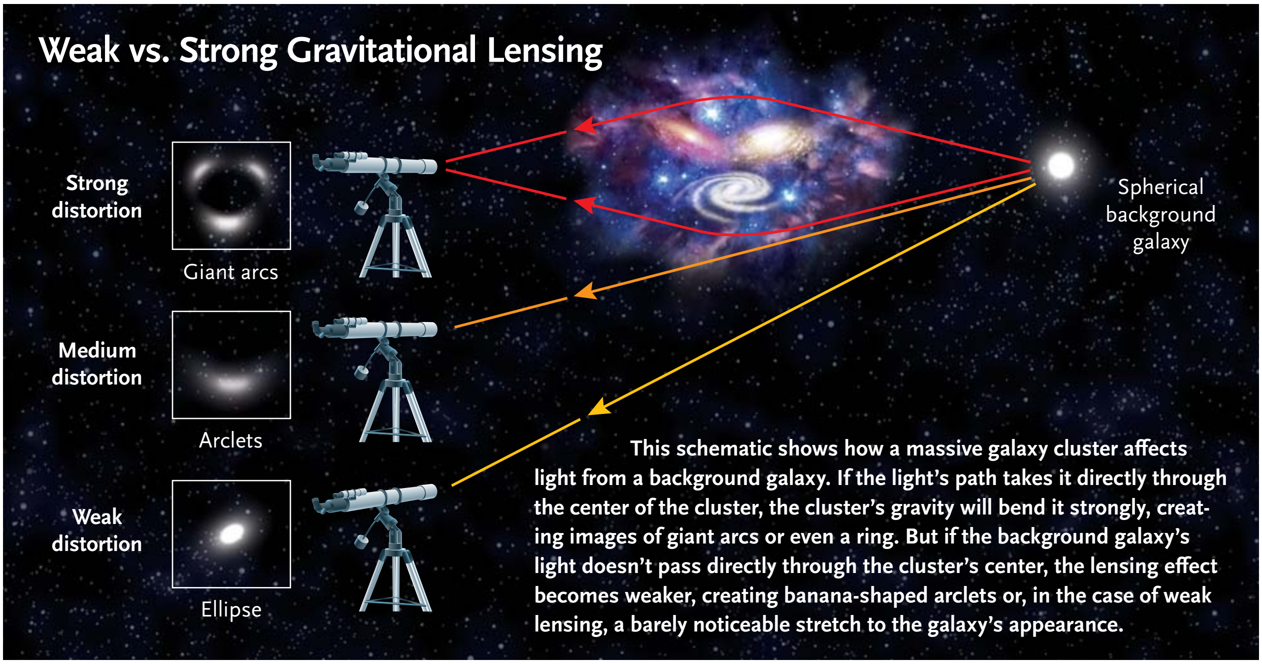
But multiple images, light arcs, and rings are just the conspicuous tip of the proverbial iceberg. There's also *weak gravitational lensing*, which induces distortions in images of background galaxies at a level of only a few percent or less. After all, there's gravitating matter all over the universe, even tenuous gas that lies between galaxies, so spacetime is never completely "flat." The result, as 29-year-old astronomer James Gunn realized in 1967, is that *every* distant galaxy's image is distorted.

Since weak lensing only slightly magnifies and stretches an image, astronomers can't just study the effect on a single background galaxy. As Henk Hoekstra (Leiden Observatory, The Netherlands) puts it: "If you can't see it by eye, it's weak lensing." Galaxies already have elongated shapes, both because they're generally not perfectly spherical and because they orient themselves in random directions. With just one galaxy, it's impossible to distinguish just how much weak lensing contributes to its elongation.

Instead, astronomers study as many background galaxy images as possible, looking for a slight departure from the expected random distribution of galaxy elongations. "It's a fundamentally statistical approach," says Rachel Mandelbaum (Carnegie Mellon University).

So here's the general idea: Observe hundreds (or thousands, or even millions) of faint background galaxies. Check for departures from random orientations. Map the strength of the weak lensing effect that's responsible for these minute distortions. Then derive the corresponding mass distribution in the foreground. Presto: you've just arrived at a mass map of part of the universe. And since most of the universe's gravitating mass is dark matter, the map you've produced basically charts the dark matter along the line of sight.

Weak lensing wasn't convincingly detected until the late 1980s. J. Anthony Tyson (then in the physics division



This schematic shows how a massive galaxy cluster affects light from a background galaxy. If the light's path takes it directly through the center of the cluster, the cluster's gravity will bend it strongly, creating images of giant arcs or even a ring. But if the background galaxy's light doesn't pass directly through the cluster's center, the lensing effect becomes weaker, creating banana-shaped arclets or, in the case of weak lensing, a barely noticeable stretch to the galaxy's appearance.

S&T: LEAH TISCIONE

of AT&T Bell Laboratories) and his colleagues noticed the systematic alignment of a few dozen faint blue galaxies behind two massive foreground galaxy clusters, Abell 1689 and CL 1409+52. As the authors wrote in the January 20, 1990, *Astrophysical Journal*, "A gravitational lens distorts most background galaxies by stretching [them] along a circle centered on the lens." (See illustration on page 38.) From their observations, the team deduced dark matter's distribution among the two clusters. They even hoped that "study of a large sample of galaxy cluster fields can constrain the nature of the dark matter."

Weak Lensing, Three Ways

Douglas Clowe (now at Ohio University) and colleagues beautifully demonstrated the power of one form of weak lensing, known as *cluster weak lensing*, when they studied more than 500 galaxies behind the now-famous Bullet Cluster (1E 0657-558).

At this collision site, two galaxy clusters met and passed through each other a couple hundred million years ago. X-ray observations show that hot gas between the two swarms of galaxies has since slowed down and piled up in the center, between the two clusters. That's just what's expected for colliding gas masses that interact as they pass each other by.

However, the team's analysis revealed that the dark matter still clumps around the cluster galaxies, which kept moving right past one another during the cluster collision. Like the galaxies, the associated dark matter particles didn't interact with each other.

The Bullet Cluster result is generally considered to be convincing evidence for the existence of dark matter. It's easy to understand why. Alternative theories that try to do without dark matter, such as MOND (*modified Newtonian dynamics*, see *S&T:* Apr. 2007, p. 30), predict that the strongest lensing effects should concentrate around the hot gas masses in between the two clusters. That's because these masses contain the majority of the clusters' baryonic (i.e., "normal," non-dark matter) mass. But in real life, the lensing effects concentrate around the cluster galaxies: there must be more matter there than meets the eye.

Equally important results come from a second type of weak gravitational lensing known as *galaxy-galaxy lensing*. Here, tiny distortions are caused not by the gravity of

X-RAY: NASA / CXC / CFA / M. MARKEVITCH ET AL.; OPTICAL: NASA / STSCI / MAGELLAN / U. ARIZONA / D. CLOWE ET AL.; LENSING MAP: NASA / STSCI / ESO WFI / MAGELLAN / U. ARIZONA / D. CLOWE ET AL.

BITING THE BULLET **Observations of the Bullet galaxy cluster (1E 0657-558) first showed the power of weak gravitational lensing. By using weak lensing to map the cluster's dark matter distribution (blue), astronomers saw that the unseen matter flew along with the cluster galaxies rather than sloshing about with the hot, X-ray-emitting gas (pink) that contains most of the cluster's "ordinary" mass.**

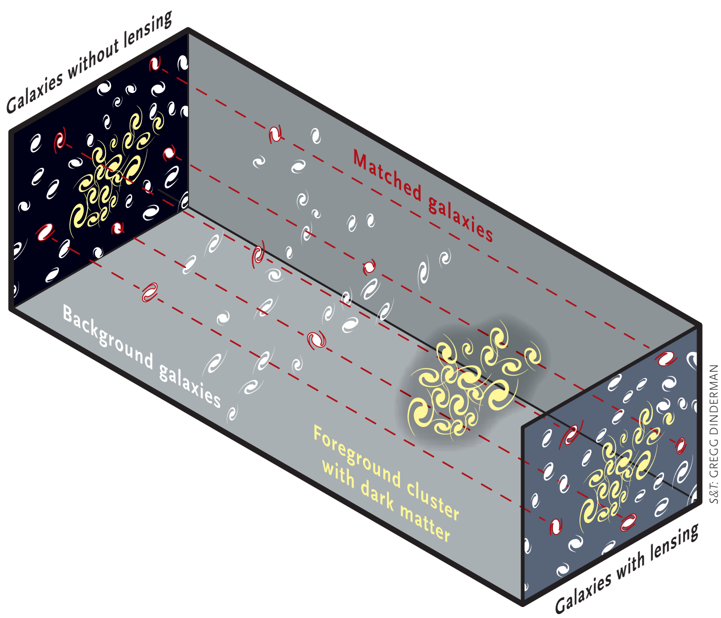
a cluster, but by the lightpath-bending power of a single, massive foreground galaxy.

"Galaxy weak lensing tells us about the dark matter halos surrounding visible galaxies," Mandelbaum explains. Current models of galaxy evolution predict that huge dark matter halos surround large galaxies like our own Milky Way. And the Atacama Cosmology Telescope (ACT) conducted a recent weak lensing study involving the cosmic microwave background radiation (the Big Bang's afterglow) that supports this scenario.

The ACT is surveying microwaves emitted 370,000 years after the Big Bang. Intervening galaxies, imaged by the Sloan Digital Sky Survey, smear this light. These sharp, small-scale changes in the background radiation intensity reveal massive dark matter halos around individual galaxies. So far, these measurements match what's expected from popular cosmological simulations, where galaxies begin their lives as concentrations of dark matter. Eventually, with more data, the team of astronomers hopes to trace the growth of dark matter halos over time.

The third and subtlest form of weak lensing, called *cosmic shear*, is caused when background light passes through the uneven distribution of matter across space, as Gunn predicted in 1967. The universe's large-scale structure — the clusters, superclusters, and great walls of galaxies, as well as the vast, largely empty voids — exerts a quiet influence on the trajectory of every single light ray passing through the depths of space. It's like an uneven floor that causes a marble to roll along a wiggling path instead of a straight line. By the time a distant galaxy's light arrives at our telescope, even if there's no galaxy or cluster directly in front of it, its shape is nonetheless slightly distorted.

SUBTLE STRETCH While the effect of weak lensing is impossible to measure for an individual galaxy, it can be teased out of larger samples. As the photons from background galaxies skirt through the outer edges of a cluster's mass, the galaxy shapes are stretched ever so slightly along a circle around the lensing mass. The subtle effect is magnified here to be clearly visible.



First observed by no less than four separate teams of astronomers in 2000, cosmic shear sheds light on the growth of large-scale structure. It could also teach us about dark energy's role in cosmic evolution.

Right now, no one knows what dark energy is. The most popular scenario suggests that dark energy is a constant property of empty space. But other scenarios leave room for dark energy to fluctuate over time. By probing the universe's large-scale structure, whose form depends on dark energy's properties, studies of cosmic shear can test these alternate scenarios.

For these studies to work, Hoekstra explains, astronomers must study many millions of background galaxies over large swaths of sky. A technique known as *cosmic tomography* — comparable to a 3D MRI scan of all the mass in the universe — then enables astronomers to examine the cosmic web at different distances, corresponding to different look-back times. The process is a bit like reconstructing the evolution of life on Earth by studying fossil evidence from various epochs.

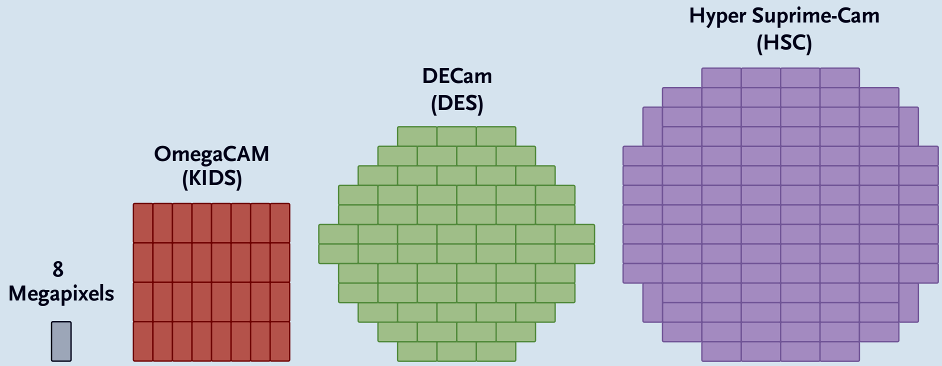
Wide and Deep

Not that studying the universe's fossil record makes for an easy task. Lensing maps require photographic sky surveys that are both very wide and very deep — sensitive to faint sources across large portions of the celestial sphere. Observations must also be conducted at multiple wavelengths to enable measurements of photometric redshifts, which provide distance estimates to faint galaxies based on their brightness levels at different wavelengths (see box on page 40).

Then observations need to be corrected for all kinds of artificial effects that might mimic weak lensing, such as systematic distortions introduced by the telescope and detector, as well as the effects of atmospheric turbulence. Resolution is also an issue: if two galaxies lie close together on the sky, they might blend into a single elongated smudge of light.

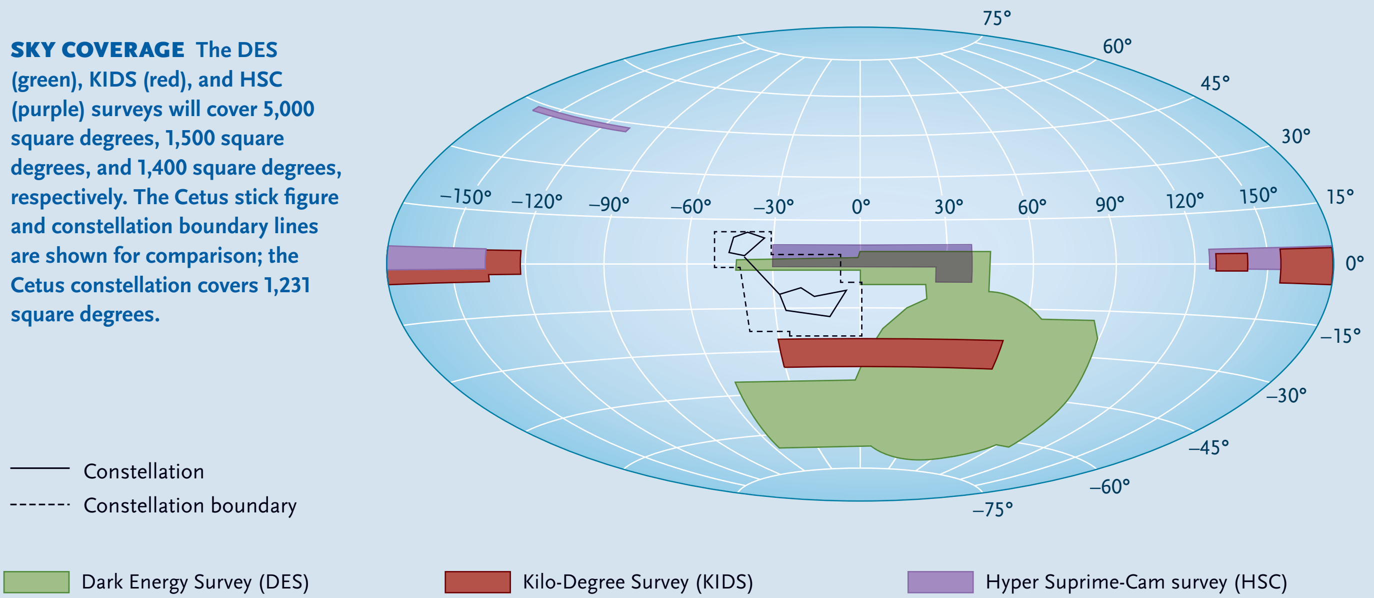
Finally, there's another very real effect called *intrinsic alignment*. The collective formation history of a group of galaxies can align galaxies in a non-random way that has nothing to do with cosmic shear. According to Hoekstra, "this is one of the biggest problems in the field." One straightforward way to mitigate this issue is to carry out extremely large surveys, to improve the statistics.

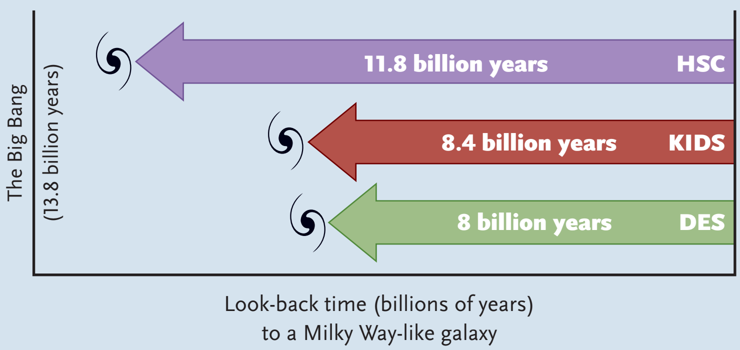
That's exactly what astronomers are working on right now, using wide-field telescopes, sensitive detectors, and powerful data-analysis software. Some of the first weak lensing surveys have already been carried out as part of the Sloan Digital Sky Survey, based in New Mexico, as well as by the 3.6-meter Canada-France-Hawaii



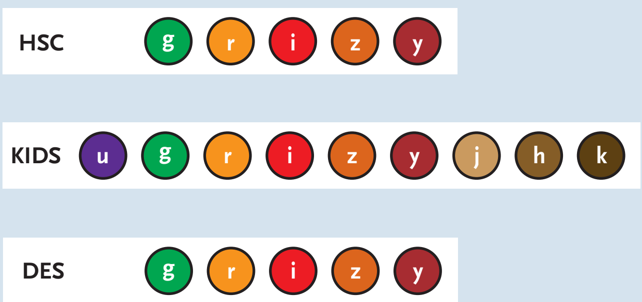
EYES ON THE SKY Three projects — the Kilo-Degree Survey (KIDS, red), the Dark Energy Survey (DES, green), and the Hyper Suprime-Cam survey (HSC, purple) — are surveying the sky with complementary capabilities. The surveys' cameras, OmegaCAM, DECam, and Hyper Suprime-Cam, record the sky with 268, 570, and 870 megapixels, respectively. The rectangular detectors that make up the cameras have roughly 8 megapixels, like the camera that comes with the iPhone 6. (Pixel and detector sizes vary.)

SKY COVERAGE The DES (green), KIDS (red), and HSC (purple) surveys will cover 5,000 square degrees, 1,500 square degrees, and 1,400 square degrees, respectively. The Cetus stick figure and constellation boundary lines are shown for comparison; the Cetus constellation covers 1,231 square degrees.





SURVEY DEPTH This estimate shows how far back in the universe each survey camera could see a simplified Milky Way-like galaxy. These numbers are optimistic — a more realistic estimate would rein in the surveys' reach by between 0.5 and 1 billion years or so, with the HSC survey suffering more from the correction.



SURVEY COLORS While the DES and HSC surveys use five "color" filters each, the KIDS survey looks farther into both the ultraviolet and infrared, using nine filters total to get a better handle on the photometric redshifts, and hence distances, of its galaxies. (Filter colors are representative.)

S&T: GREGG DINDERMAN

GOING THE DISTANCE: SPECTROSCOPIC VS. PHOTOMETRIC REDSHIFT

As light traverses the universe, spacetime's expansion stretches the wavelength. For relatively nearby objects, this is most easily measured by the redward shift of emission (or absorption) lines in an object's spectrum. But measuring *spectroscopic redshifts* becomes impractical for millions of faint, faraway galaxies — collecting a spectrum requires a bright target and lots of time. So astronomers resort to *photometric redshifts*: rather than gathering a galaxy's light into the narrow buckets that make up a spectrum, filters split light into broader buckets. Then astronomers compare this rough approximation of a spectrum to galaxy templates until they find the best match. Although photometric redshifts aren't as precise as spectroscopic measurements, they work well for large samples of faint objects.

Telescope on Mauna Kea in Hawai'i. While these early surveys were generally shallow and/or limited in scope, bigger projects are on the horizon.

One ongoing survey is the Kilo-Degree Survey (KIDS), featuring the 268-megapixel OmegaCAM on the European Southern Observatory's 2.6-meter VLT Survey Telescope at Cerro Paranal. Another project is the Dark Energy Survey (DES), which employs the 570-megapixel Dark Energy Camera on the 4-meter Victor M. Blanco telescope at the Cerro Tololo Inter-American Observatory, also in Chile.

Since 2011 KIDS has focused on two regions in the sky totaling some 1,500 square degrees — slightly bigger than the area covered by Ursa Major. DES started almost two years later and aims to cover no less than 5,000 square degrees — almost one-eighth of the celestial globe.

"In the end, the Dark Energy Survey will probably have better statistics," says Hoekstra, "but KIDS provides better photometric redshifts, because observations are carried out both at optical and infrared wavelengths." Both surveys released preliminary maps mid-year in 2015.

There's also the Hyper Suprime-Cam (HSC) Survey: it goes even deeper than DES or KIDS and covers 1,400 square degrees. The relative newcomer started in March 2014 and makes use of the giant, 870-megapixel ultra-wide-field HSC camera on the 8.2-meter Subaru telescope on Mauna Kea. "That's going to be phenomenal," says Hoekstra.

"There's certainly competition going on between the various teams," Hoekstra adds, "but it's all relatively friendly." Mandelbaum agrees. "We need multiple data sets to carry out all kinds of crosschecks," she says. (For a side-by-side comparison of the three surveys' complementary capabilities, see page 39.)

But Wait, There's More

KIDS, DES, and the HSC Survey are just scratching the surface of cosmologists' new, versatile tool. Scientists expect them to provide a useful proof of principle, but for weak lensing to achieve its full potential, explorations will need to go even wider and deeper.

That's why two huge weak lensing surveys will commence several years from now. One will be carried out on the ground: the 8.4-meter Large Synoptic Survey Telescope (LSST) is currently under construction at Cerro Pachón in Chile and is scheduled to start science operations in 2022 (see p. 14). The other survey comes courtesy of the European Space Agency's Euclid mission, poised for launch in late 2020. Though its 1.2-meter mirror is much smaller than LSST's giant eye, from its vantage point in space (at the L2 Lagrangian point, 1.5 million kilometers from Earth in the anti-sunward direction) it won't suffer from atmospheric turbulence: it will provide Hubble-quality imagery of the whole sky.

The two surveys are complementary. LSST goes deeper — thanks to its larger mirror size — but its lower angular resolution may blend some smaller galaxy images. Euclid doesn't suffer so much from blending, but its observations combine visible light along a quite broad wavelength range. While LSST has multiple wavelength filters, good for estimating photometric redshifts and hence distances, Euclid will instead need supplemental observations from ground-based telescopes.

Another important difference is that weak lensing is just one of the many science drivers for LSST: when completed, the wide-field telescope will also hunt for supernovae, asteroids, and many other kinds of variable, transient, and moving objects. In contrast, Euclid's development has been optimized for cosmology.

No one really knows what to expect from these surveys. Astronomers will need a wide variety of cosmological probes to truly understand the nature of dark energy and the way it has governed the evolution of the large-scale structure of the universe. And the minute distortions of multitudes of tiny galaxies, imperceptible to the human eye, is one probe that will play a decisive role in understanding today's cosmic mysteries.

And then what? "Difficult to say," muses Mandelbaum. If everything is consistent with the current cosmological model, astronomers may delve deeper into the details to better understand the nature of the universe's main components, dark matter and dark energy.

But if the weak lensing results turn out to be incompatible with current thinking — if nothing is what it seems — then we may be in for a cosmological revolution. ✦

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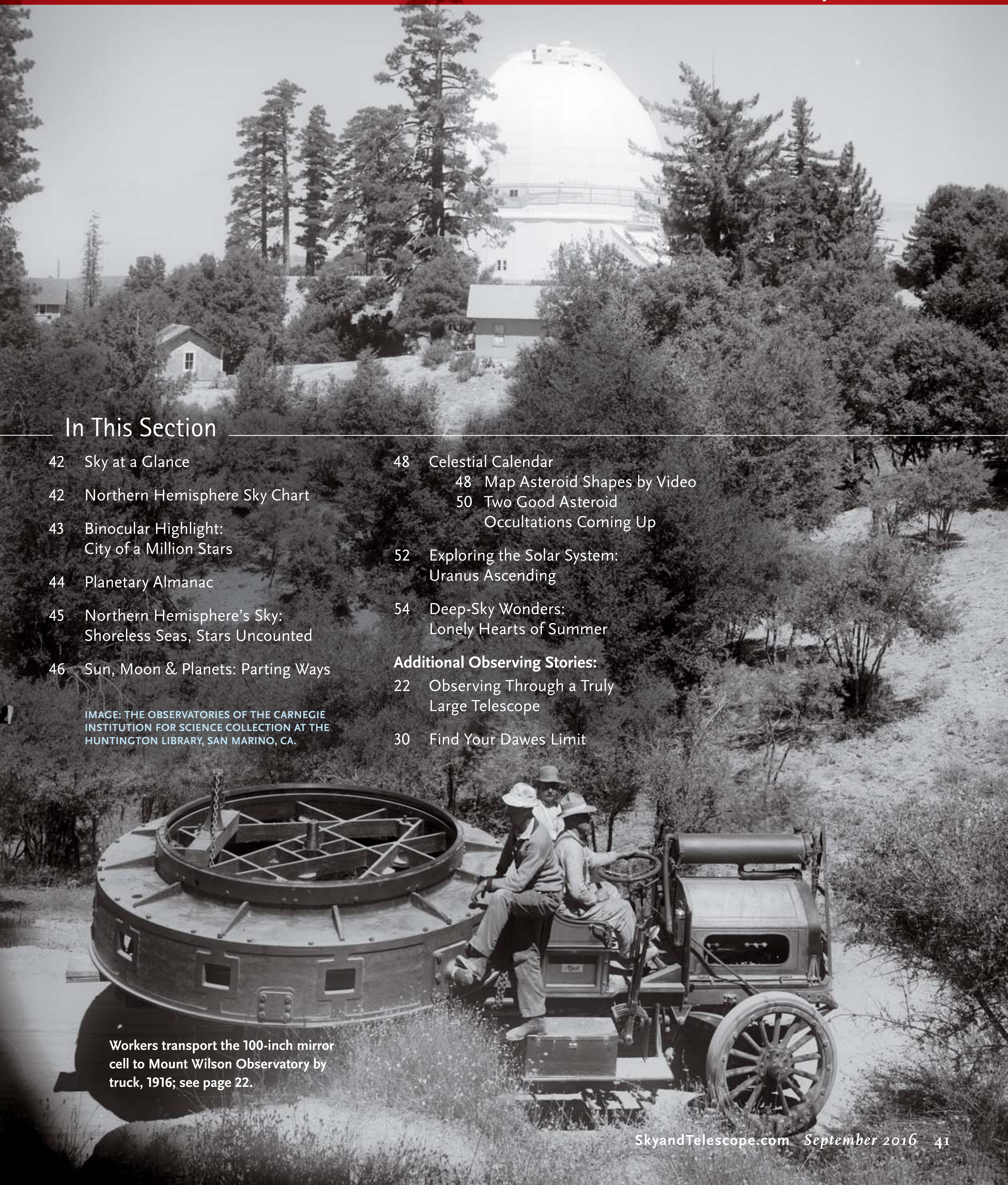
*Contributing Editor **Govert Schilling** writes about astronomy from his hometown in Amersfoort, The Netherlands. His new book on gravitational waves will be published next year by Harvard University Press.*



In This Section

Additional Observing Stories:

IMAGE: THE OBSERVATORIES OF THE CARNEGIE INSTITUTION FOR SCIENCE COLLECTION AT THE HUNTINGTON LIBRARY, SAN MARINO, CA.

Workers transport the 100-inch mirror cell to Mount Wilson Observatory by truck, 1916; see page 22.

Sky at a Glance

SEPTEMBER 2016

1 **MORNING:** For observers in central Africa, an annular eclipse of the Sun is visible along a line from Gabon to Madagascar. The partial phase is viewable from most of Africa and the Indian Ocean. See http://is.gd/Sep2016annulareclipse.

4 **DUSK:** The waxing crescent Moon is low in the west with Spica about 5° to its lower left.

8 **EVENING:** The Moon, just shy of first quarter, is some 3°–4° above Saturn. Brighter Mars flames 9° left of Saturn, while red Antares twinkles 6° below and a bit left of the ringed planet.

16 **EVENING TO NIGHT:** A fairly deep penumbral lunar eclipse is visible from Europe, Africa, Asia, and the Pacific. See http://is.gd/Sep2016penumbraleclipse.

22 **AUTUMN BEGINS** in the Northern Hemisphere at the equinox, 10:21 a.m. EDT.

23 **NIGHT:** Algol shines at minimum brightness, magnitude 3.4 instead of its usual 2.1, for roughly two hours centered at 11:19 p.m. EDT (8:19 p.m. PDT).

27 **MORNING:** The waning crescent Moon is about 6° upper right of Regulus.

28 **DAWN:** The zodiacal light, or "false dawn," is visible in the east before sunrise from dark locations at north temperate latitudes for the next two weeks. Look for a tall, broad pyramid of light rising up through Leo, Cancer, and Gemini.

29 **DAWN:** Use binoculars to search very low in the east 30 or 40 minutes before sunrise to find the thin crescent Moon less than 2° below Mercury.

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

	◀SUNSET	MIDNIGHT	SUNRISE▶
Mercury		Visible September 21 through October 14	E
Venus	W		
Mars	S SW		
Jupiter	W	Visible through September 3	
Saturn	SW		

Moon Phases

New September 1 5:03 a.m. EDT

First Qtr September 9 7:49 a.m. EDT

Full September 16 3:05 p.m. EDT

Last Qtr September 23 5:56 a.m. EDT

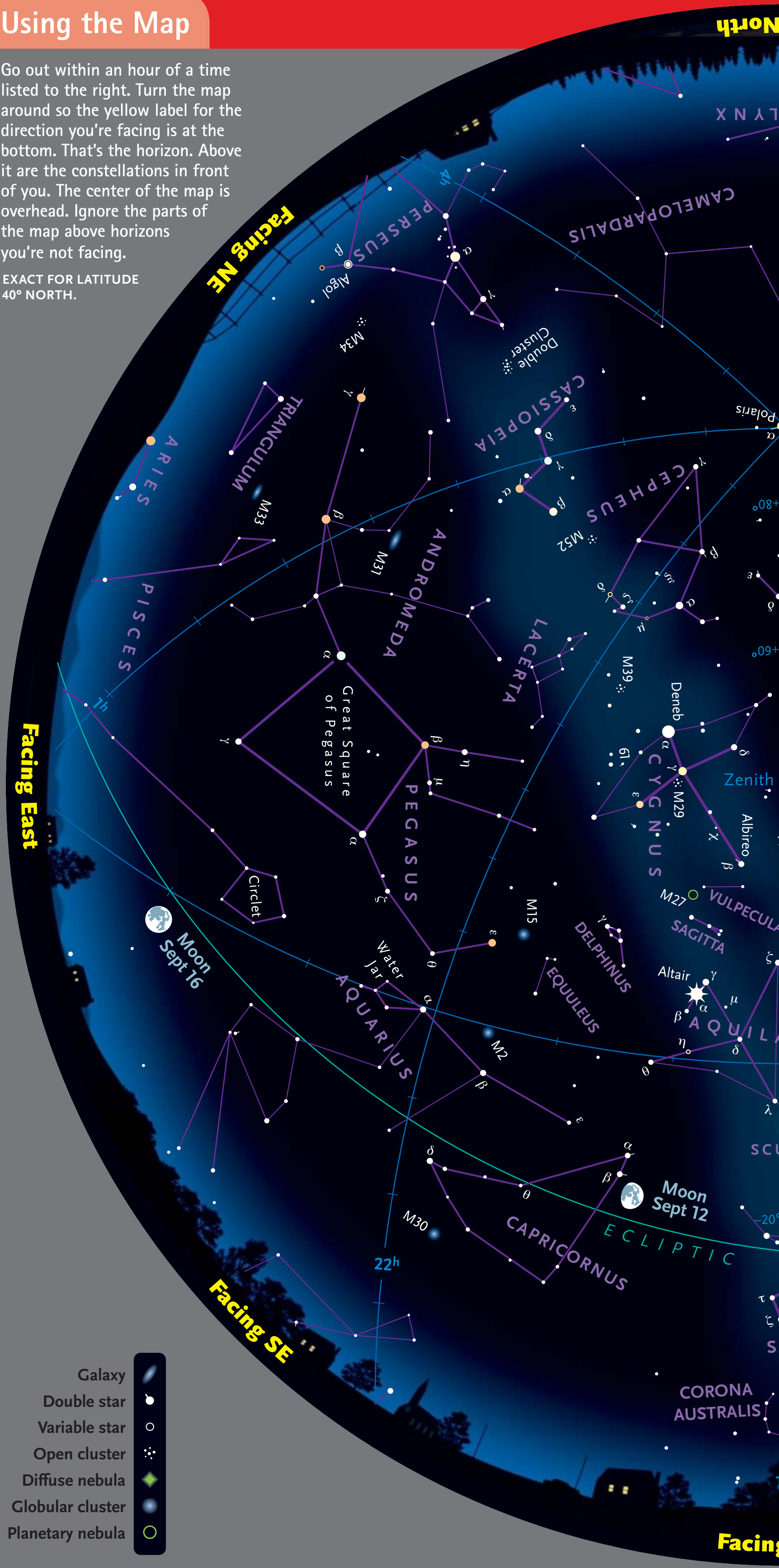
New September 30 8:11 p.m. EDT

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

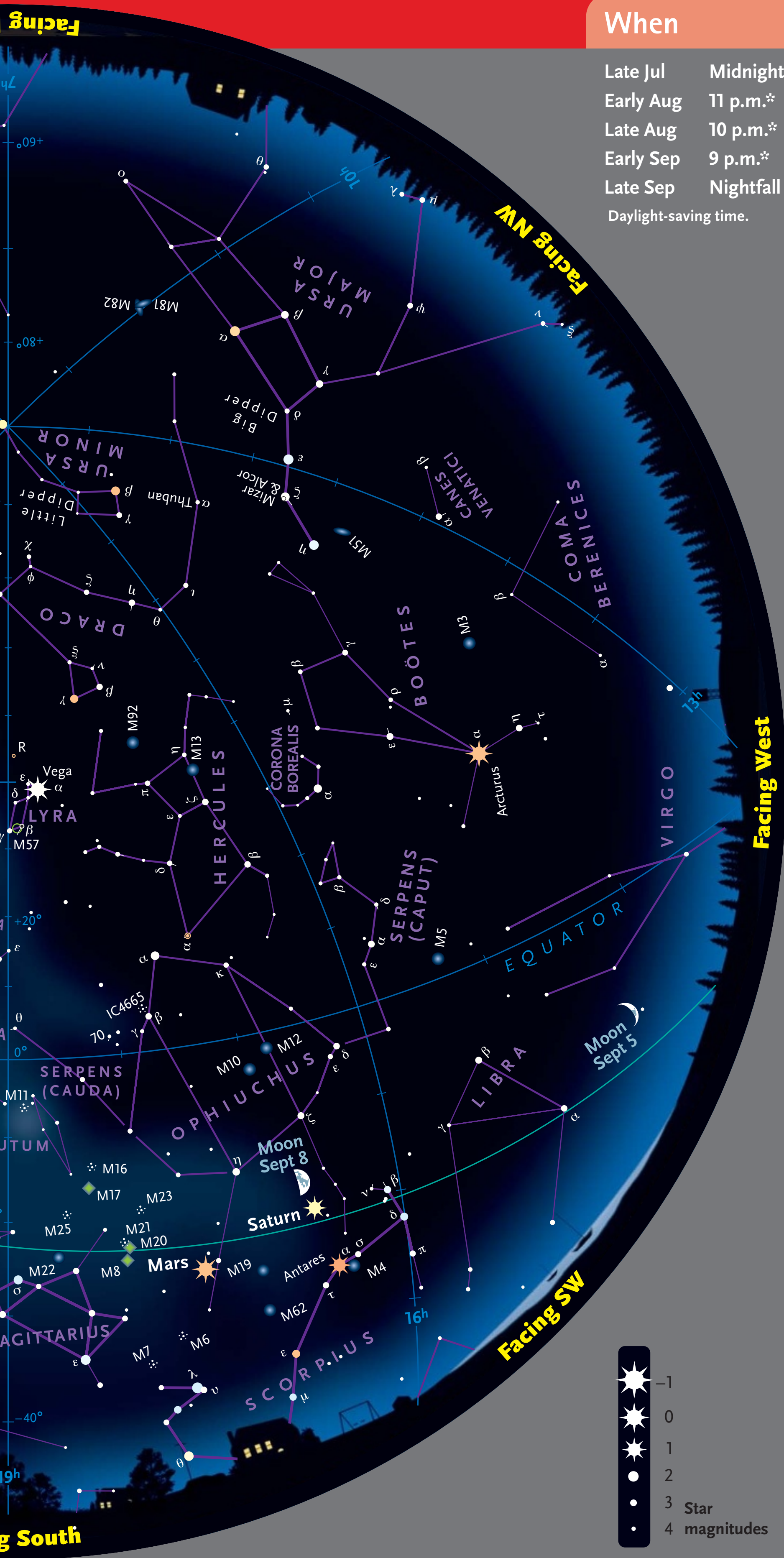
Using the Map

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.



Mathew Wedel



When

Late Jul	Midnight*
Early Aug	11 p.m.*
Late Aug	10 p.m.*
Early Sep	9 p.m.*
Late Sep	Nightfall

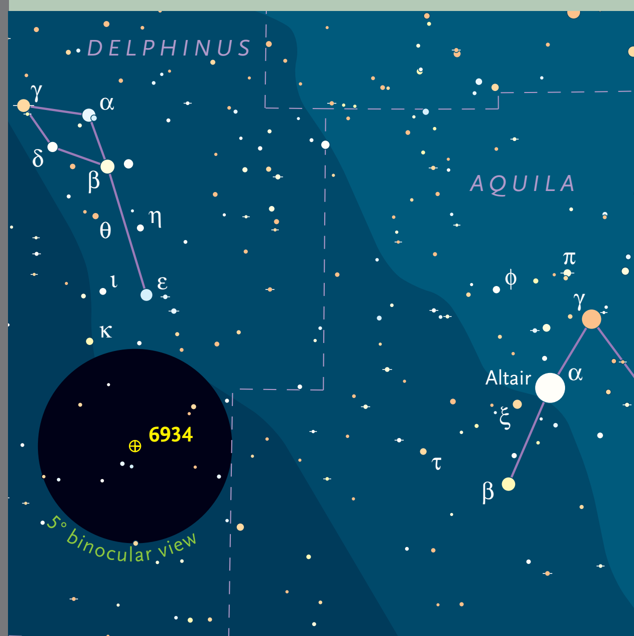
*Daylight-saving time.

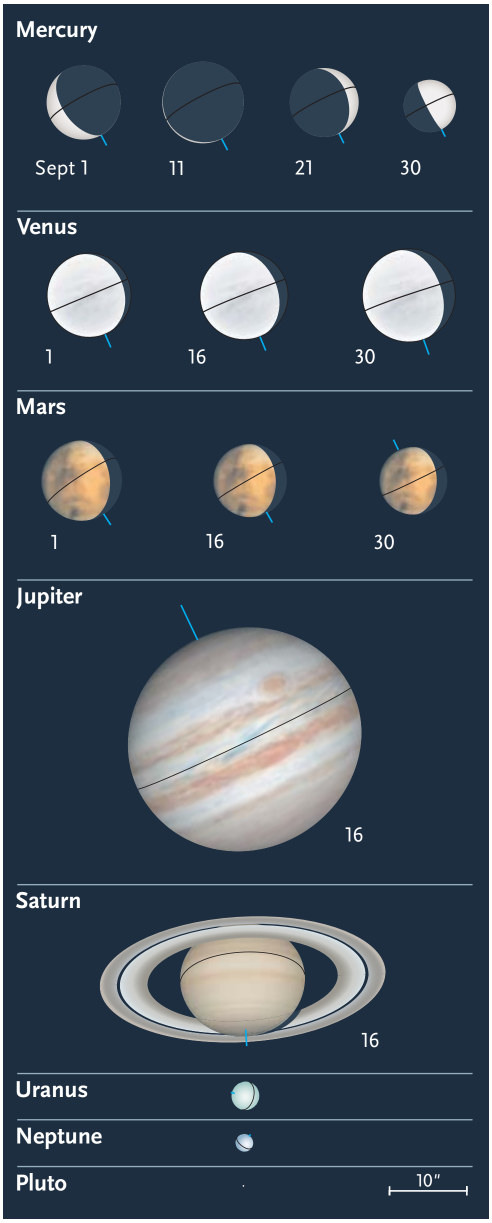
City of a Million Stars

A noted extraterrestrial sage once advised his pupil, “You must unlearn what you have learned.” I think about this all the time while stargazing. Knowing the constellations, the celestial coordinate system, and all the other tips and tricks is great until you get on target. But as soon as you’re there, you have to actively force that geocentric perspective out of your head to grasp what’s really going on.

Take **NGC 6934**, a globular cluster in Delphinus, the Dolphin. It’s about 10° east of Altair, and just a little bit south of the Dolphin pattern on the southeast border of the Milky Way. Like most globulars, NGC 6934 looks like a fuzzy star in binoculars. But to go there in your mind — to see things as they are, rather than as they appear — is to open a series of perceptual windows to the universe.

At 50,000 light-years away, NGC 6934 actually is on the edge of the Milky Way, south (galactic south!) of the Outer Arm. The cluster’s celestial “neighbors” — the bright stars of Aquila, Delphinus, and Pegasus — are in fact our neighbors. At only a few dozen to a few hundred light-years away, they’re practically right next door in our own Orion Spur. The Milky Way star clouds northwest of Delphinus are also thousands of light-years closer to us, in the Cygnus and Perseus Arms. So when you look at NGC 6934, try to consciously look out, past the scattering of bright stars in our own galactic neighborhood, past the other spiral arms that recede like a long road in a rearview mirror, and see this apparent bit of fluff for what it actually is: a city of a million or more stars, perched on the edge of the galaxy, beckoning us to wider vistas and a deeper understanding. ✦



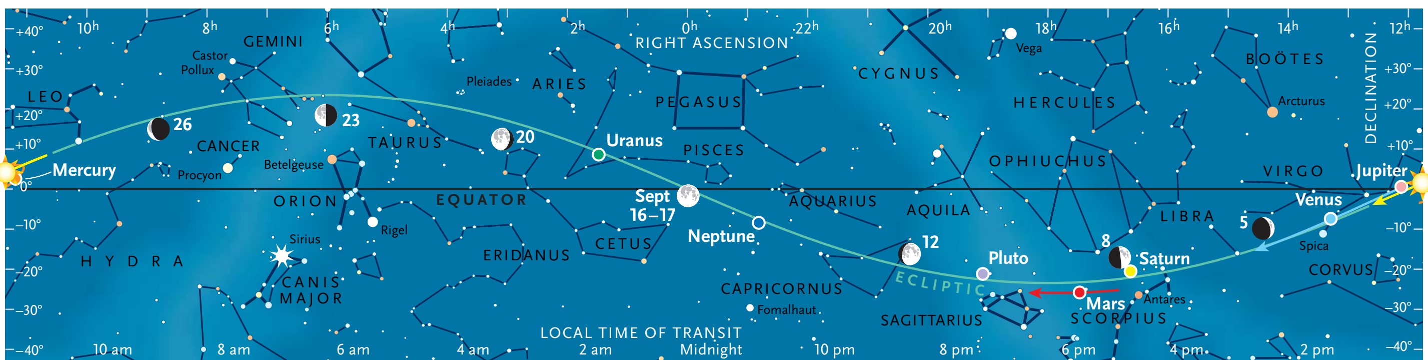


Sun and Planets, September 2016

	September	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$10^h\ 41.5^m$	+8° 17′	—	–26.8	31′ 42″	—	1.009
	30	$12^h\ 25.8^m$	–2° 47′	—	–26.8	31′ 56″	—	1.001
Mercury	1	$11^h\ 48.7^m$	–3° 21′	20° Ev	+1.3	9.6″	21%	0.698
	11	$11^h\ 26.1^m$	–0° 30′	5° Ev	+4.8	10.6″	2%	0.636
	21	$11^h\ 02.3^m$	+5° 11′	14° Mo	+1.5	8.9″	15%	0.752
	30	$11^h\ 22.7^m$	+5° 28′	18° Mo	–0.7	6.8″	56%	0.989
Venus	1	$12^h\ 09.4^m$	+0° 07′	23° Ev	–3.8	10.9″	92%	1.528
	11	$12^h\ 54.0^m$	–5° 01′	26° Ev	–3.8	11.3″	90%	1.481
	21	$13^h\ 39.0^m$	–10° 00′	28° Ev	–3.9	11.7″	88%	1.430
	30	$14^h\ 20.6^m$	–14° 11′	31° Ev	–3.9	12.1″	86%	1.381
Mars	1	$16^h\ 47.9^m$	–25° 09′	95° Ev	–0.3	10.5″	85%	0.895
	16	$17^h\ 26.9^m$	–25° 49′	89° Ev	–0.1	9.5″	85%	0.980
	30	$18^h\ 06.7^m$	–25° 51′	84° Ev	+0.1	8.8″	85%	1.061
Jupiter	1	$11^h\ 54.3^m$	+1° 49′	19° Ev	–1.7	30.8″	100%	6.392
	30	$12^h\ 17.1^m$	–0° 40′	3° Mo	–1.7	30.6″	100%	6.452
Saturn	1	$16^h\ 33.7^m$	–20° 24′	91° Ev	+0.5	16.7″	100%	9.968
	30	$16^h\ 39.9^m$	–20° 42′	64° Ev	+0.5	15.9″	100%	10.434
Uranus	16	$1^h\ 27.6^m$	+8° 30′	150° Mo	+5.7	3.7″	100%	19.075
Neptune	16	$22^h\ 47.6^m$	–8° 37′	167° Ev	+7.8	2.4″	100%	28.975
Pluto	16	$19^h\ 03.3^m$	–21° 24′	111° Ev	+14.2	0.1″	100%	32.796

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-September; 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

Shoreless Seas, Stars Uncounted

This month we finish our fantastical float down the Milky Way.

"The realm of fairy-story is wide and deep and high and filled with many things: all manner of beasts and birds are found there; shoreless seas and stars uncounted; beauty that is an enchantment, and an ever-present peril; both joy and sorrow as sharp as swords. In that realm a man may, perhaps, count himself fortunate to have wandered, but its very richness and strangeness tie the tongue of a traveler who would report them."

— J. R. R. Tolkien, "On Fairy-Stories"

Now we complete our journey down the Heavenly River, the Milky Way. We've come to the final section of the so-called summer Milky Way and, as in the quote from Tolkien above, the "richness and strangeness" of this realm in the sky are so great they defy our attempts to describe them.

The fantastic Milky Way river. One of the major points of Tolkien's essay is that the wonder at the heart of fantasy can sometimes be found even in its simplest stories, those usually considered to be aimed at children. But who would have thought that this wonder, or a large part of it, could also be found in the section of the Milky Way from Scutum to Sagittarius?

Do we have in the summer Milky Way "all manner of beasts and birds" as we do in Faërie (the realm at the heart of fairy-story)? Certainly. We have constellation beasts and birds galore — Scorpius (the scorpion), Sagittarius (half-man/half-horse), Serpens (the serpent), Delphinus (the dolphin), Vulpecula (the fox), Cygnus (the swan), Aquila (a soaring eagle), and Lyra (not just a lyre, but at one time, a stooping eagle or vulture). We also have a bevy of strange "beasts" from the "astrophysical zoo" — things like the variable stars Chi (χ) Cygni and Beta (β) Lyrae, and the visible remnants of the most bizarre stellar corpses, like the Dumbbell and Ring Nebulae, derived from solar-mass stars dying to become white dwarfs, and the more elusive Veil Nebula, derived from a massive star dying in a supernova to become a neutron star or black hole.

The summer Milky Way also has "stars uncounted" and, if not "shoreless seas," at least the shoreless bank of a celestial river, for the edges of the Milky Way band fade off imperceptibly. Are there in the Milky Way joys and sorrows as sharp as swords? Well, with larger aperture telescopes there are innumerable blade-edge sharp images of the stars that incite joy in the observer. And you know in winter there's a sword — Orion's — as sharp as joys or sorrows.

TED NASMITH

Scutum to Sagittarius: a Milky Way river torrent of grandeur. Do we go over a kind of waterfall when we reach the Scutum Star Cloud with its foreground telescopic "avalanche of stars" (or spate of stars) called the star cluster Messier 11? Do we then pour down past the equilateral triangle formed by the Gamma Scuti Star Cloud, M16 (the Eagle Nebula), and M17 (the Omega Nebula)? And onward, through the intense bright "foam" of M24 (the Small Sagittarius Star Cloud), flanked by the open clusters M25 and M23, until we arrive at a vision of the broadly spread central bulge (or river delta?) of the Milky Way with M20 (the Trifid Nebula), M8 (the Lagoon Nebula), and the gorgeous Large Sagittarius Star Cloud? And don't forget Sagittarius's supreme globular cluster, M22, which hangs just upper left of the star at the top of the Sagittarius Teapot, and the pair of big naked-eye clusters levitating above Scorpius's stinger, M6 and M7.

River Anduin or path of souls? Tolkien's fantasy river Anduin has a waterfall, Rauros. Downstream stand the grand cities Osgiliath and Minas Tirith. But maybe the Milky Way more closely resembles the path that dead souls take to their final destination near Antares as envisioned by some Native Americans. If the latter is true, then what do we make of Mars and Saturn passing through that high holy ground this year? ✦

Parting Ways

Mercury & Jupiter exit, but Venus, Mars, and Saturn still grace the nightfall.

In August we saw a marvelous double convergence of planets at dusk: Mercury, Venus, and Jupiter low in the west; Mars and Saturn (plus the brilliant star Antares) in the south.

In September these groups disband. Mercury quickly falls out of dusk, then pops up into its best dawn visibility of the year near month's end. Jupiter also leaves dusk for dawn this month, but it doesn't become easily observable before sunrise until October. Meanwhile, Venus hangs rather low in evening twilight. Fading Mars pulls eastward away from its former close companions, Saturn and Antares, but all three remain visible in the southwest at nightfall.

DUSK

Venus begins September only a few degrees above the western horizon 30 minutes after sunset for viewers at mid-northern latitudes. By the end of the month it appears just slightly higher (the interval between sunset and Venus-set increases from only about 1 hour to 1¼ hours). Venus brightens slightly as well, from magnitude –3.8 to –3.9, by mid-month, while its gibbous disk grows just a bit, fattening from 11″ to 12″ wide by month's end.

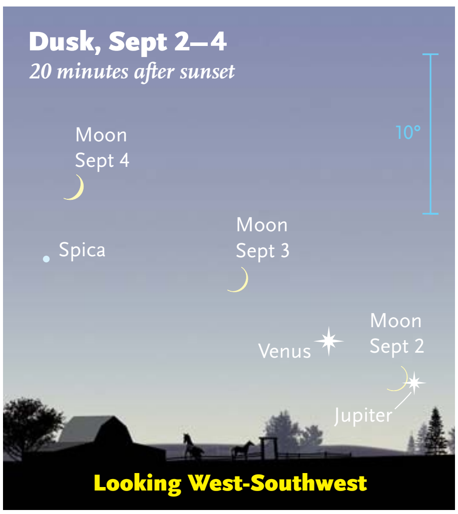
Jupiter glimmers 5° lower right of Venus, quite low in evening twilight, on September 1st. But the separation between Jupiter and Venus increases rapidly after that as Jupiter sinks down and away from the brighter planet. By about September 14th, Jupiter sets less than half an hour after the Sun for viewers around latitude 40° north. The big planet passes through superior conjunction with the Sun on September 26th and so is lost from view. It won't reappear — in the dawn sky — until early October.

EVENING

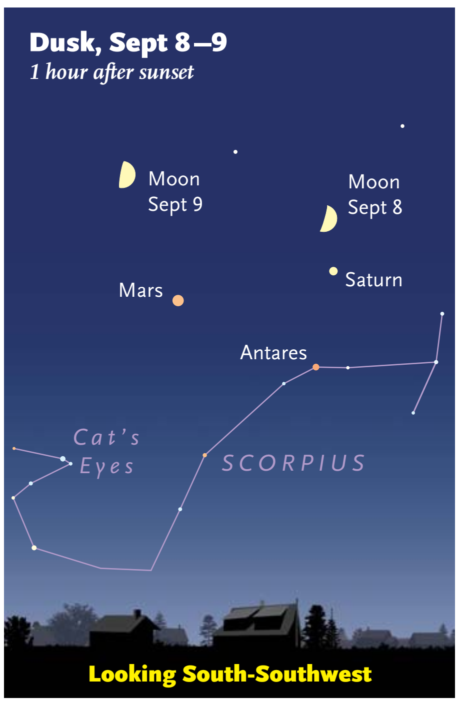
Mars pulls to the left, away from **Saturn** and Antares in the south-southwest at nightfall during September. Watch as the large triangle they make lengthens from week to week.

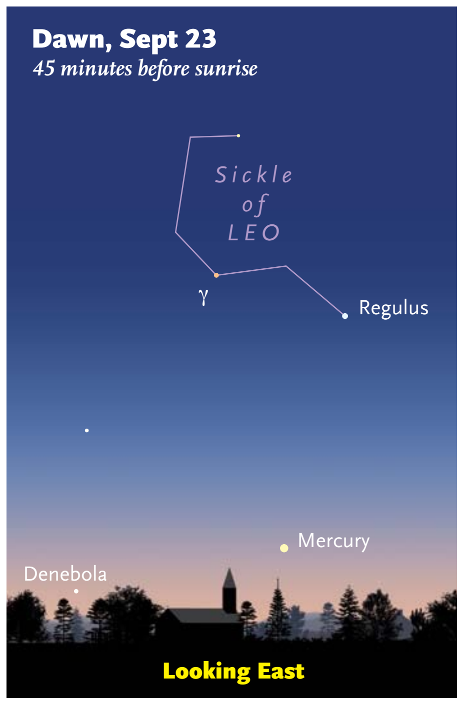
As Mars fades from magnitude –0.3 to +0.1 in the course of the month, it still noticeably outshines magnitude +0.5 Saturn and +1.0 Antares, which are 6° to 7° apart. But while Saturn creeps slowly east in Ophiuchus — it's there for another year or so! — Mars exits the constellation on September 21st. The Red Planet speeds on into Sagittarius to pass just 1.5° south of M8 (the Lagoon Nebula) on the 28th.

Saturn reaches eastern quadrature (90° east of the Sun) on the American evening of September 1st, Mars on September 13th. This means that in telescopes Mars shows a strip of shadow on one side — or rather, looks decidedly gibbous: 85%

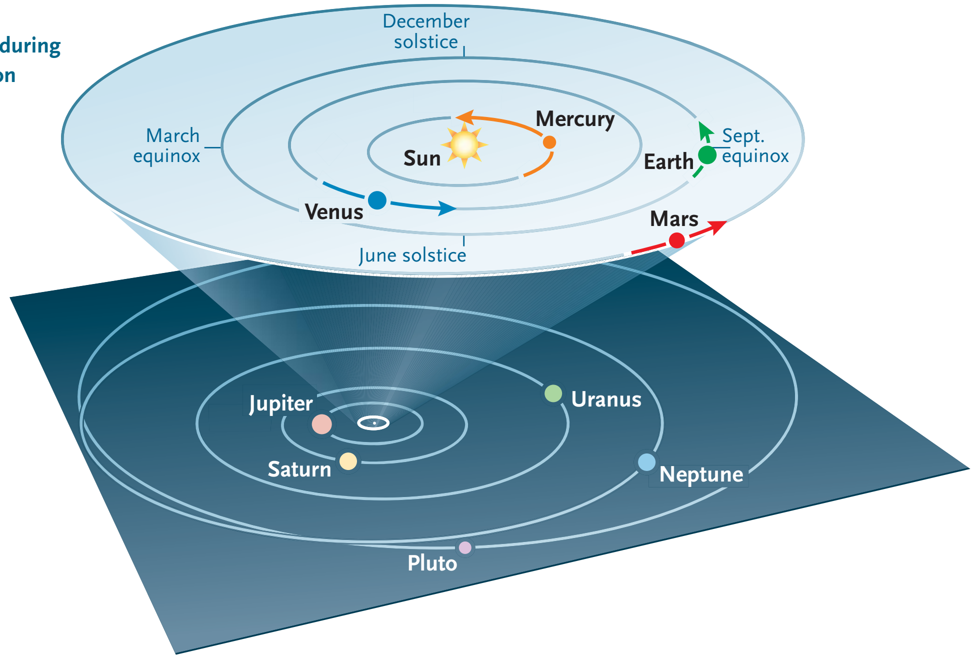


These scenes are drawn for near the middle of North America (latitude 40° north, longitude 90° west). The blue 10° scale bar is about the width of your fist held out at arm's length. For clarity, the Moon is shown three times its actual apparent size.





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



sunlit. Mars recedes to 1 astronomical unit behind the faster Earth on September 19th, its disk dwindling from an apparent diameter of 10½″ to almost 9″ during September. Given its low altitude, that's small enough to make spotting even large surface features hit or miss. Saturn's 16″-wide globe and 37″-span rings offer a thrilling sight as usual, especially considering that the rings remain tilted 26° from edge-on, just short of their maximum openness (which they'll reach next year).

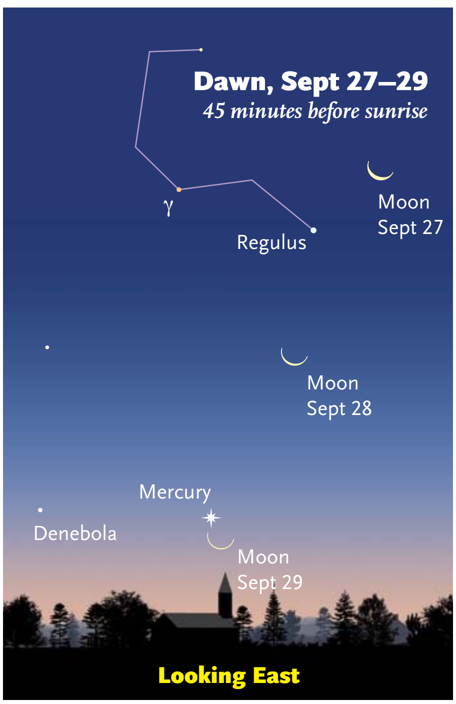
As September starts, both Mars and Saturn set not too long before midnight daylight-saving time. By month's end Mars remains up until about 11 p.m., but Saturn sets well before 10 p.m.

NIGHT

Neptune reaches opposition on September 2nd, at magnitude +7.8 in Aquarius. Although it rises around sunset, the best time to see its tiny 2.3″ dot in the telescope is in the middle of the night. Finder charts for Neptune and for 6th-magnitude **Uranus**, in Pisces (about two hours behind Neptune) can be found at **skyandtelescope.com/urnep**.

14th-magnitude **Pluto** remains in the Teaspoon of Sagittarius. With a 12-inch scope you can still seek it just after nightfall, using the finder charts in the July issue, page 48.

Far easier are two asteroids close together. On the American night of September 8–9, **1 Ceres** (magnitude +8.2) and **18 Melpomene** (magnitude +8.7) are just ⅔° apart near the head of Cetus. See page 51 for details.



DAWN

Mercury, after dropping very low in the dusk in late August, passes through superior conjunction on September 12th. By the last week of September it emerges into its best morning apparition of the year for observers at mid-northern latitudes. Mercury brightens by almost three magnitudes in nine days: from magnitude +2.5 — too faint to see low in bright twilight — on September 19th to –0.4 on the 28th, when it reaches greatest elongation (18° west of the Sun). On that morning Mercury rises about 1½ hours before sunrise, just as dawn is beginning, and it stands about 9° high due east 45 minutes before sunrise.

SUN AND MOON

The **Sun** experiences an annular solar eclipse as seen from parts of Africa on September 1st; see details at **http://is.gd/Sep2016annulareclipse**. The Sun crosses the September equinox at 10:21 a.m. Eastern daylight-saving time on September 22nd, marking the start of autumn in the Northern Hemisphere and spring in the Southern Hemisphere.

The **Moon** undergoes a deep penumbral eclipse visible from much of the Eastern Hemisphere on September 16th. Try for the ultra-thin lunar crescent as it slices very near Jupiter soon after sunset on September 2nd. A thicker Moon is well upper left of Venus on the 3rd, and above faint Spica on the 4th. The Moon is above Saturn on September 8th and far upper left of Mars the next night. A waning lunar crescent is just below Mercury at dawn on September 29th. ✦

Map Asteroid Shapes by Video

Join the worldwide project to time asteroid occultations precisely. It's cheaper and easier than ever.

Have you ever dreamed of doing frontline solar-system research with a small backyard telescope? You actually can, even in an age when spacecraft study planets, moons, asteroids, and comet nuclei close up. One way is by making a particular type of measurement that citizen scientists can perform with very high accuracy using simple equipment: *timing*. In particular, timing the instants when the edge of an asteroid covers and uncovers a background star.

Thousands of asteroids await profiling, but the great space agencies are only going to send $100-million spacecraft to a carefully chosen few. That leaves thousands whose size and shape you can help map with a 3-inch scope and a few accessories that cost about $700 all told.

It's done by video. When asteroid-occultation campaigns began in the 1970s, timings were done by eyeball. You watched the star to be occulted and shouted when it disappeared, and again when it reappeared. A tape machine recorded your shout along with radio time signals playing in the background. If everything went exactly right, you could fix the time of the shout between the time ticks to within a few tenths of a second. Then you corrected for your estimated reaction time. It was barely good enough to get a useful size and shape for some asteroids, and it only worked if enough observers were lucky enough to be within the occultation track.

That was then. Far better is to record the occultation with a modern, ultra-low-light astronomical video camera, and time-stamp each frame. This method reliably times events to within 0.03 second, more than ten times better than the eyeball method.

Predictions of occultation paths have also much improved, allowing observers to position themselves strategically. As a result, amateur asteroid mapping has blossomed.

STEPWISE OCCULTATION

From his home near Boston, *S&T*'s Dennis di Cicco recorded the asteroid 160 Una occulting a previously unresolved double star on January 24, 2011. Watch his video at **http://is.gd/unaoccn**.

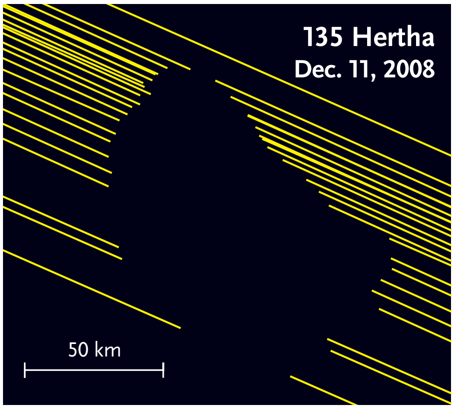
But we need more observers! People used to think video occultation timings were only for techies with soldering irons and advanced computer-interface skills. No more. Described here is everything you need. And if you run into problems, there's an online community eager to help.

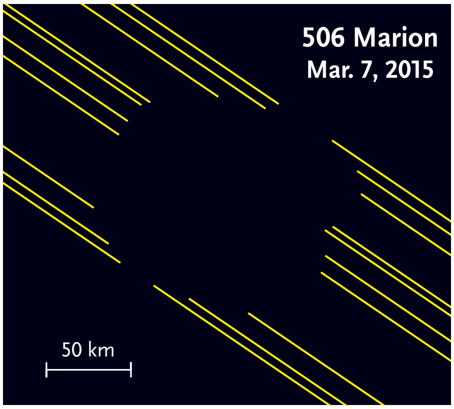
The Parts

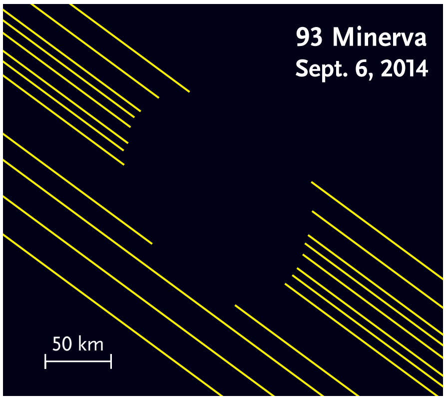
In addition to the telescope of your choice, you'll need the items shown on the facing page to successfully time occultations. They're numbered from the back of the telescope at left to the digital video recorder at the right end:

1. Knight Owl 0.5 Focal Reducer, $29.95.
2. Knight Owl C-mount, to the left of the Watec camera, $16.49.

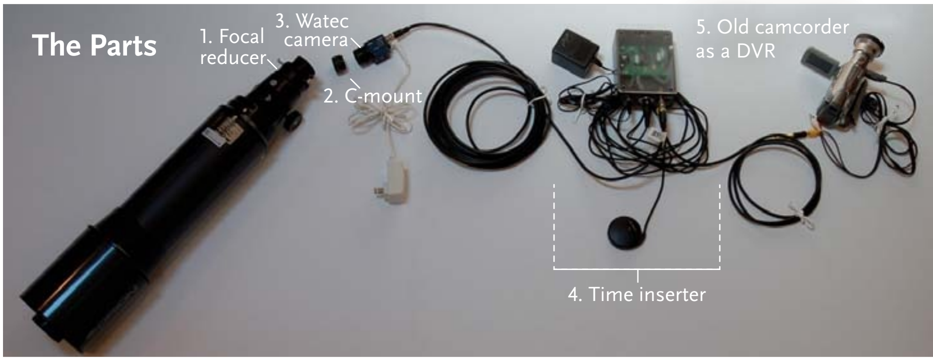
In these silhouettes obtained by IOTA observers, each yellow line represents one observer watching the target star. The gap in a line represents the time when the star wasn't visible. If the lines are assembled according to the observers' locations and other known data, a silhouette of the asteroid results. The more people, the clearer the profile! Most asteroids turn out to be somewhat round, but a few are irregular, elongated, or a disconnected binary pair. Kleopatra seems to be two elongated bodies touching almost end to end. See all results to date at asteroidoccultation.com/observations.







INTERNATIONAL OCCULTATION TIMING ASSOCIATION (4X)



RICHARD WILDS

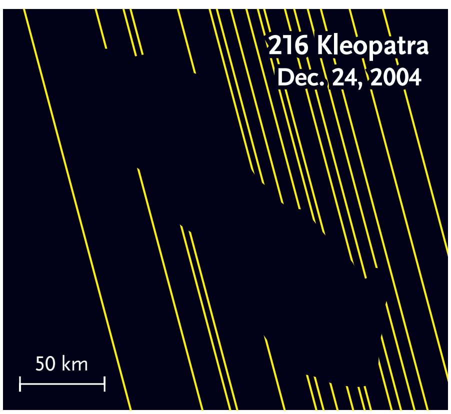
***Left:* Using a 120-mm f/5 refractor, a very-low-light video camera, a GPS time inserter, and an old camcorder serving as a digital video recorder, the author can videorecord a 1° field of view showing stars as faint as 13th magnitude.**

Please join in! Write to the author, or join the IOTA discussion group at groups.yahoo.com/neo/groups/IOTAoccultations.

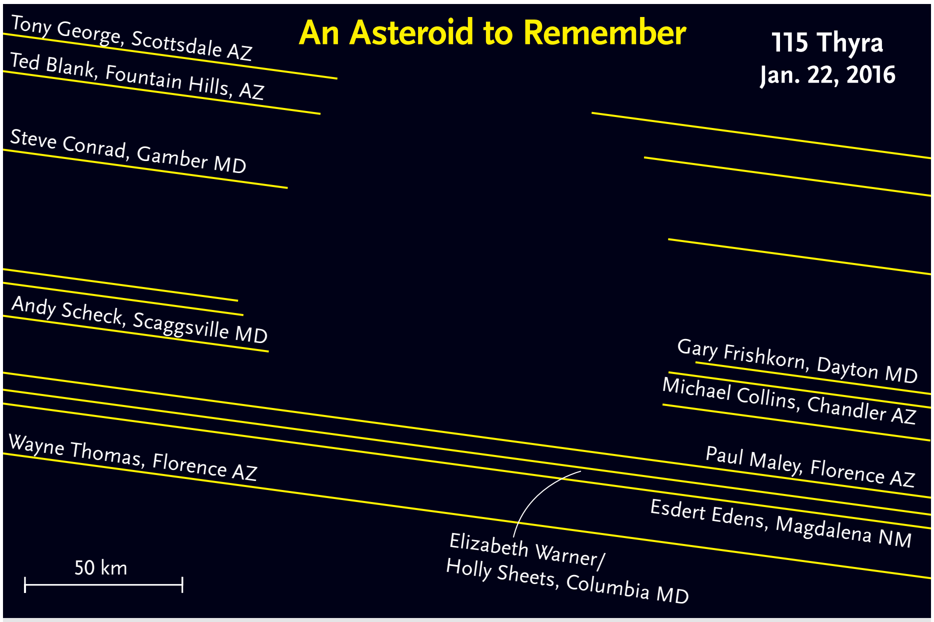
3. Watec 902H2 Ultimate ½-inch Chip CCD Video Camera, $342.40.
4. The International Occultation Timing Association's custom-designed IOTA VTI v.3 GPS Time Insertion System; $292.00.
5. An old Canon ZR300 camcorder or lower found on eBay, about $50.00.

The Watec camera, the IOTA GPS time inserter, and the camcorder have power plugs that want 120 volts AC. You can get this in the field from a 12-volt deep-cycle battery and a power converter, which many observers already use to run their telescopes.

In the picture you see the Watec 902H2 Ultimate (not the Supreme, which is less sensitive) with its white power cord. The Knight Owl C-mount (similar to a T-adapter) sits next to the Watec camera. The Knight Owl 0.5 Focal Reducer is on the scope. You should use the Watec with no focal reducer when you're recording a bright object like the edge of the Moon during a grazing occultation. But for asteroid occultations, you want the focal reducer for two reasons. It enlarges your



An Asteroid to Remember



INTERNATIONAL OCCULTATION TIMING ASSOCIATION

Eleven timers recorded an occultation or a near miss. When they correlated their timings, this was the result. Not a bad night's work! This could be our best look at Thyra for ages to come.

Occultation astronomy is a team sport. But the team for every event is different, chosen by the predicted occultation track. For any given month, you can find more than a hundred shadow-track predictions worldwide mapped at **https://is.gd/occlt**.

I was part of a team last January that caught 115 Thyra crossing an 8.8-magnitude star in Cancer. The evening brought thin clouds and wind. Worse, from where I was, the star was partially occulted from moment to moment by tree branches waving in the wind! But my system saw through this noise. Once I got the correct star in view, I defocused it to prevent its bright image from saturating the pixel array in my CCD video camera.

I began recording a minute or two before the predicted time. Success! The star disappeared onscreen for several seconds. Later I stepped through the video, frame by frame, to find the precise times of the disappearance and reappearance.

Many on our team were successful. Six had positive observations; five recorded misses, helping to define where the asteroid wasn't. Combining all the data, we plotted the size and shape of Thyra's silhouette as then presented to Earth.

But such profiles are tantalizing. We could see the profile better if we just had a few more observations! That's where your efforts come in to play.

—Tony George

field of view, making it easier to locate the target star, and it increases the speed of your optical system and thus the camera's ability to record faint stars.

You need an RCA cable with a BNC adapter at one end to connect the Watec to the "camera in" RCA socket on the IOTA time inserter (the photo actually shows a KIWI GPS Time Inserter). The time inserter includes a GPS antenna with a magnetic end to attach to some high location. I set up my telescope next to the rear of my SUV and attach the GPS antenna to the SUV's rear door, which lifts high when open. This brings in a quality signal from GPS satellites in all directions.

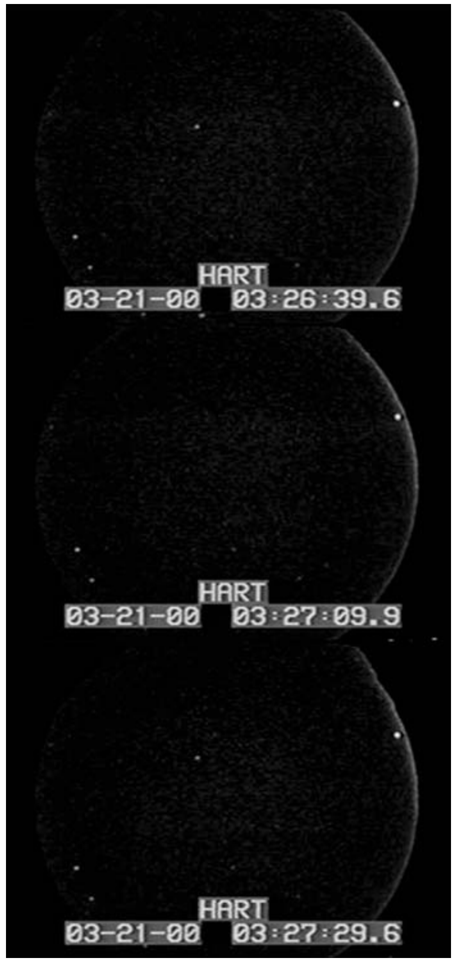
The time inserter also has an RCA "recorder out" socket. In the picture, a black RCA cable runs from there to the Canon ZR300's yellow "analog to digital video cable" socket, by way of a small double-female RCA plug. The Canon ZR300 thus becomes a compact digital video recorder that you can hold in your hand to watch what the telescope is seeing.

As you record, the time inserter prints the time on every frame of your video within an accuracy of 0.03 second, if you're recording at 30 frames per second. When you're done recording, press the reset button on the time inserter and it will display your exact GPS longitude, latitude, and altitude. It does double duty for location as well as time!

That blink-of-an-eye time resolution is the heart of the system's scientific power. The greatest telescopes on mountaintops or in space can, at the very best, resolve an object in the asteroid belt to about 40 kilometers. Our little rig determines the position of an asteroid's edge in space to just hundreds of meters — hundreds of millions of kilometers away. Is there anything else an amateur astronomer can measure to 1 part per billion accuracy?

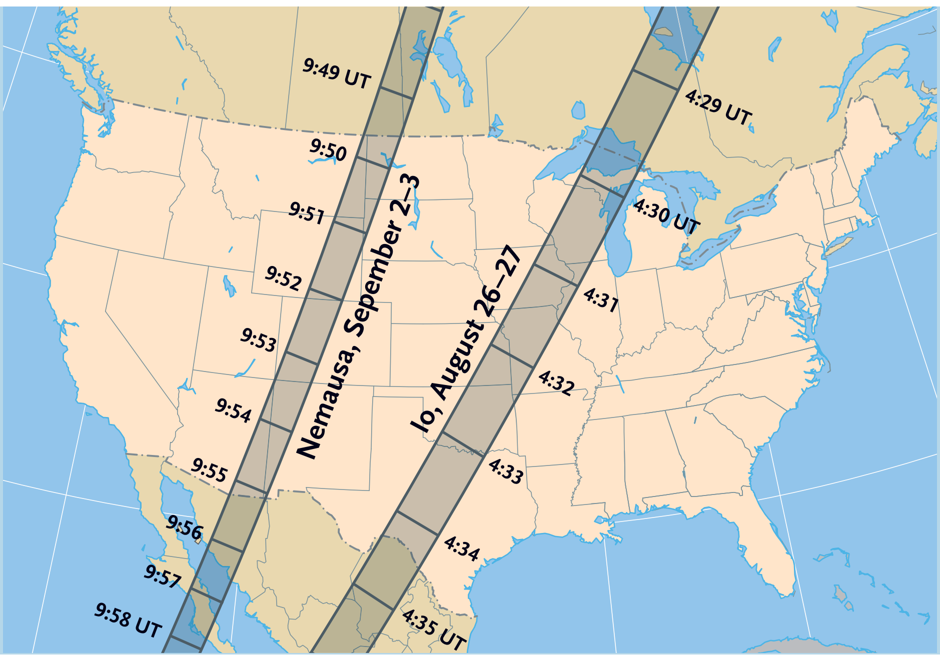
No space agency will ever spend what it would take to get closeups of a great many minor bodies of the solar system, from near-Earth objects to main-belt asteroids to comet nuclei, Trojans, Centaurs, and Kuiper Belt objects.

—Richard P. Wilds



HEARTLAND ASTRONOMICAL RESEARCH TEAM

Right: **These three frames are from a video taken by the Heartland Astronomical Research Team. The faint star near center is seen just before the Trojan asteroid 911 Agamemnon (invisibly faint) occults it, then during the brief blackout, then afterward. Trojans are asteroids that have become locked into Jupiter's orbit, carrying clues to past solar-system dynamics.**

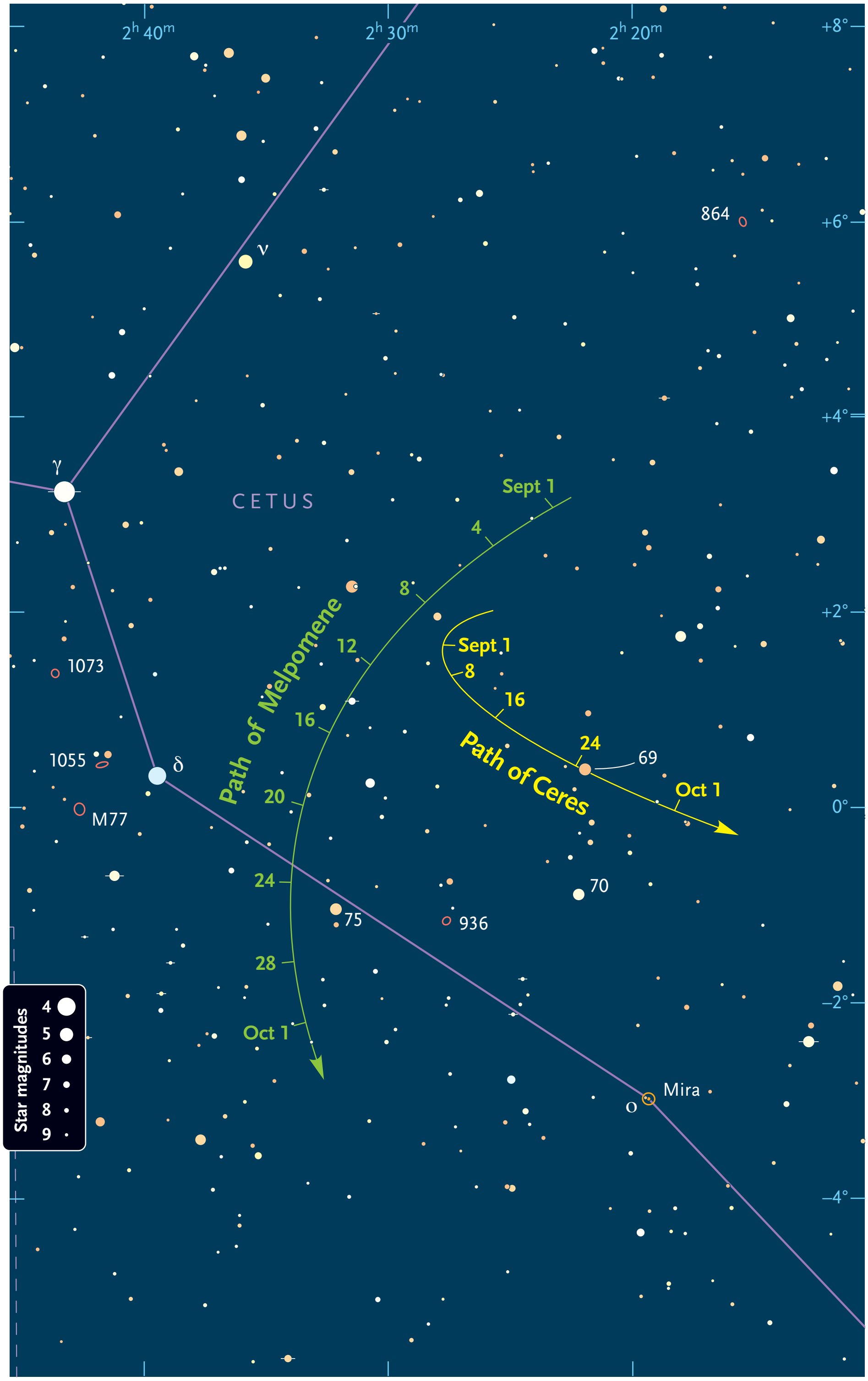


S&T: LEAH TISCIONE; DATA: IOTA

Two Good Asteroid Occultations Coming Up

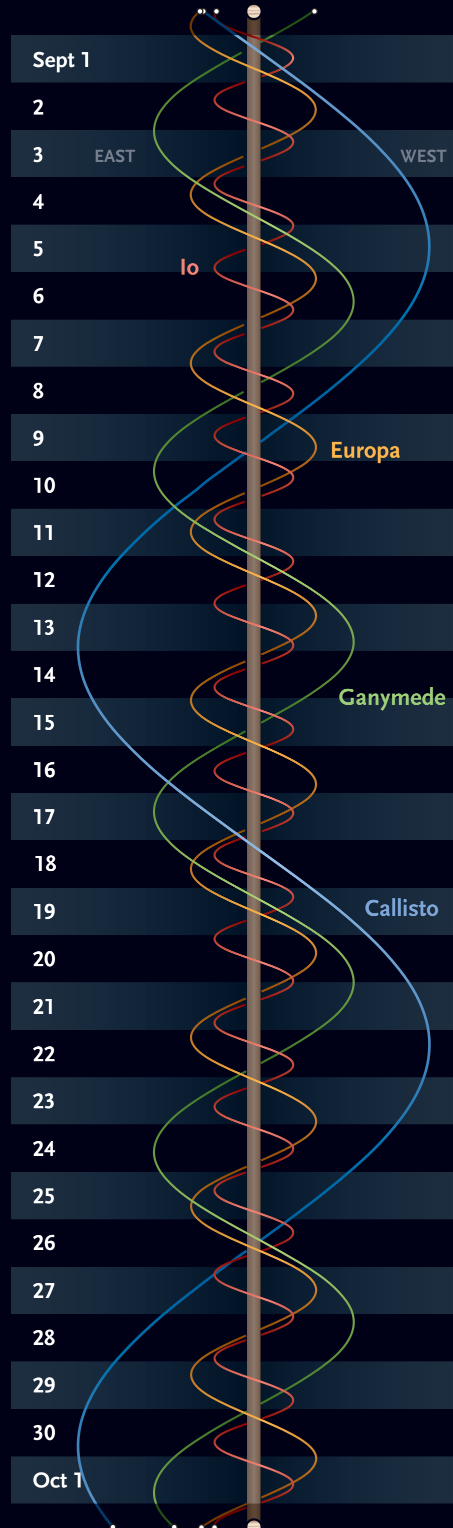
The medium-large asteroids 85 Io and 51 Nemausa will occult 7.5-magnitude stars high in the sky just a few days apart in late August and early September. That's brighter than usual for stars predicted to be covered by asteroids, and with asteroids this large, the stars could vanish for up to 7 or 8 seconds. The predicted paths here are probably correct to within a small fraction of their widths. (The second date in the title is the UT date.)

Even without video, these events will be interesting visually. And even if you can only report whether the star was occulted or not at your site, this could still constrain the location of the asteroid's edge. ✦



Two big asteroids for small scopes, 1 Ceres and 18 Melpomene, fit in the same low-power view near the head of Cetus for a few nights around September 7th and 8th. They'll be 0.8° apart those nights, with Ceres magnitude 8.2 and Melpomene 8.8. They remain within 1° of each other from September 5th through 10th, well up in the east after about 1 a.m. By September's end, when they're farther apart, they'll be a half magnitude brighter and well up by 11 or midnight.

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.

Uranus Ascending

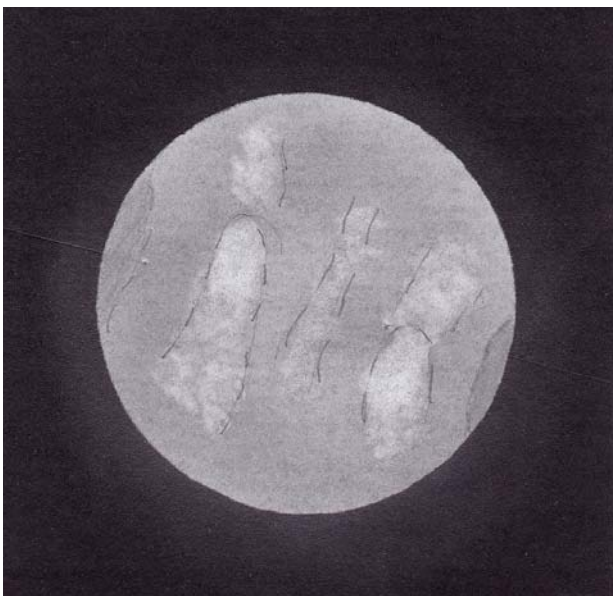
Careful observing reveals this distant planet as more than a simple disk.

At the 1970 Christmas meeting of the British Astronomical Association (BAA), I had a chance conversation with the late Patrick Moore regarding the color of Uranus as seen through a telescope. He was adamant that its color is green — whereas I, then as now, see it displaying a diverse range of blues.

The various astronomy books I later consulted for definitive Uranian "facts" proved as disparate as Moore and I had been — though they confidently stated that any amateur observation of Uranus was pointless (save for brightness estimates) because of the planet's very small apparent size and the presumed inadequacy of amateur equipment.

This planet had never been subject to the kind of unified, long-term amateur observation that can complement more detailed but time-limited professional work. For example, the late Andrew Hollis's 1989 summary of BAA planetary observations made between 1954 and 1986 covers just four pages and includes only one Uranus report.

That paucity prompted me to start observing Uranus regularly and systematically. Only after sending my initial results to the BAA did I discover that I was not alone — a small, diverse group of other observers had likewise decided to focus on Uranus. This presented an opportunity to objectively compare and correlate observations, and our preliminary Uranus report appeared in the April 2015 *Journal of the British Astronomical Association*.


KEVIN BAILEY

You'll need lots of aperture, high magnification, and good seeing to glimpse faint details on the disk of Uranus (sketched here with exaggerated contrast on July 22, 2014). South is up.

Our summary offered an equal split between visual and digital observations, in sufficient numbers to enable the corroboration of surface markings between them. Amateurs first noticed bright clouds in the northern mid-latitudes of Uranus in July 2014, and some observers (notably Anthony Wesley in Australia) recorded a particularly distinctive cloud both visually and digitally in early October 2014.

Our initial BAA report has gone a long way toward proving that credible visual (and digital) observations of Uranus can be made with medium-sized amateur telescopes. But regular Uranus observers are still very few in number, and so I hope that some relevant observing advice might encourage you to include Uranus in your own annual observing schedule.

In 2016 Uranus comes to opposition on October 15th and thereafter only 5 days later each year. So for the next decade, the core observing period for this planet will be from August to December.

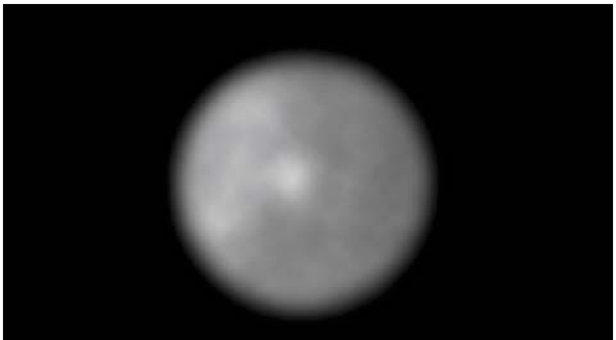
A Delicate Cloudscape

As features on Uranus generally show very low contrast, you'll need a telescope that provides maximum light-gathering and definition. A long-focus, 10-inch-aperture instrument is probably a basic requirement, combined with quality eyepieces and a Barlow lens that yields magnifications of 400× to 500×. Prior to observing, prepare blank disks to sketch your observations; printouts from *CalSky* (**calsky.com/cs.cgi/Planets/8/1**), *Uranus Viewer 2.9* (**pds-rings.seti.org/tools/viewer2_ura.html**), or *WinJUPOS* (**jupos.org/gh/download.htm**) are useful.

I prefer the traditional "south up" orientation, as shown here and in the chart on page 44. In this orientation, and because Uranus presents "horizontally" due to its extreme axial tilt, the planet's north pole is on the left of your blank disk (slightly above the 9 o'clock position). This is the preceding edge, and when your telescope's drive is turned off, it will lead out of the field of view. You might have to rotate your sketching blank accordingly, but this trick will ensure that over time you

***Kevin Bailey** is a Fellow of the Royal Astronomical Society and Uranus Coordinator for the BAA's Saturn Section.*

Kevin Bailey



A near-infrared composite video image made on October 2, 2014, captures a bright "storm" cloud high in the atmosphere of Uranus. Bright haze also covers the north polar region at left.

ANTHONY WESLEY

develop an instinctive sense of the correct orientation.

Sit comfortably at the eyepiece with a fully dark-adapted eye, and after focusing on a convenient nearby star, concentrate on the planet's tiny disk (currently just 4 arcseconds across) and record first impressions: then shift the planet to a different place in the field of view and refocus. Do this whenever your eye becomes fatigued — and stop observing when it becomes overtired.

The final drawing will be a culmination of many visual impressions of the planet snatched during moments of good seeing. Note the positions of disk features (typically bright clouds of methane ice crystals) using a latitude-longitude grid. All of the resources mentioned earlier can provide central-meridian longitudes for specific times.

Although the standard rotation of Uranus is 17.24 hours, the spin rate of its cloud deck varies with latitude: roughly 18 hours at the equator, 16½ hours at ±30°, 15½ hours at ±45°, and 14½ hours at ±60°. So bear this in mind if you time when discrete features cross the disk's central meridian and make follow-up observations.

Visually and digitally, a light-yellow filter will often sharpen the image and improve feature contrast. You can use various red filters (for example, Baader's Red 610-nm Long-pass filter) for near-infrared imaging, but this requires video rates of just a few frames per second and fairly long runs with steady mounts and drives. Image processing should be minimal to avoid artifacts.

When drawing, try to make intensity estimates using a 1-to-10 (light-to-dark) scale, as these can be measured against other observations. Likewise note overall surface color. However, as my 1970 encounter with Patrick Moore illustrates, the perception of color is variable, so it's safer to render your final drawing in monochrome. If you exaggerate drawing details for clarity, make that clear in your notes.

Finally, send your observations, along with a record of time, location, and equipment, to remote-planets coordinator Richard Schmude, Jr. (**schmude@gordonstate.edu**) at the Association of Lunar and Planetary Observers, or to the Uranus Coordinator of the BAA's Saturn Section, a position currently held by me (**hqbailey@googlemail.com**). By the way, Schmude's book *Uranus, Neptune, and Pluto and How to Observe Them* is a "must read."

By 2030 our view of Uranus will have changed from the present equatorial aspect to a "top down" view of the north polar latitudes — a view of the planet not seen since the 1940s. Veteran observers might recall that Voyager 2 saw the planet's south pole during its 1986 flyby. No other planet offers its poles up to scrutiny in this way. Observers in the Northern Hemisphere also benefit because Uranus is currently at a declination of about +8½° and will continue moving northward in the night sky for the next 20 years.

There's some historical evidence that the Uranian atmosphere shows more activity visually during sunspot maxima (Voyager 2 arrived during a minimum and saw few discrete clouds). So as the Sun goes through its activity cycle over the next several years, comparative visual observations of Uranus by amateurs will be valuable in establishing, or disproving, this association.

All this offers a wonderful opportunity for amateurs to make useful, long-term observations of Uranus. So become a "Uranus pioneer" — get out there and start observing this beautiful blue (green?) planet. ✦

The Moon • September 2016

Phases

NEW MOON
September 1, 9:03 UT

FIRST QUARTER
September 9, 11:49 UT

FULL MOON
September 16, 19:05 UT

LAST QUARTER
September 23, 9:56 UT

Distances

Apogee	**Sept. 6, 19h UT**
405,055 km	diam. 29′ 30″
Perigee	**Sept. 18, 17h UT**
361,896 km	diam. 33′ 1″

Favorable Librations

Lyot (crater)	Sept. 4
Shoemaker (crater)	Sept. 8
Montes Cordillera	Sept. 16
Pascal (crater)	Sept. 19

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

NASA / LRO

Lonely Hearts of Summer

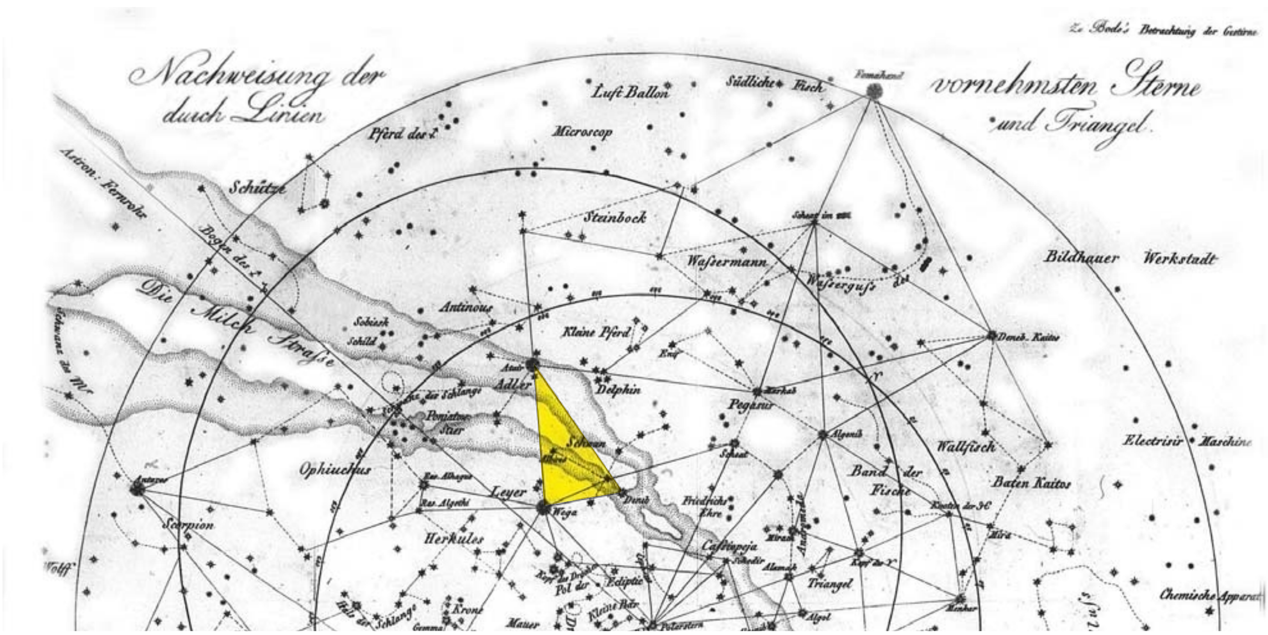
Visit some of these less-frequented destinations this season.

The Summer Triangle now dominates our evening sky, each of its three bright stars belonging to a separate constellation. On the all-sky chart at the center of this magazine, Vega bathes the sky's zenith with its brilliance, while Altair and Deneb sharpen the triangle's remaining points.

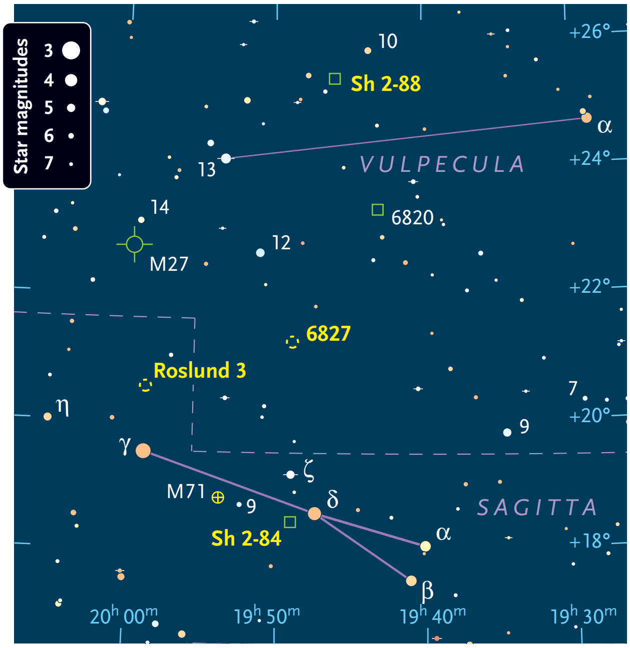
The moniker "Summer Triangle" was first applied by Alice Mary Matlock Griffith in her 1913 book, *The Stars and Their Stories*, but the triangle itself was certainly noted earlier. Johann Joseph von Littrow mentions it in his 1839 *Atlas des gestirnten Himmels* (Atlas of the Starry Heavens) as "a very striking isosceles triangle in the sky." The star chart in Johann Elert Bode's 1816 *Betrachtung der Gestirne und des Weltgebäudes* (Observation of the Stars and the Universe) is often credited as having one of the earliest representations of the Summer Triangle. Vega, Deneb, and Altair are indeed connected by lines, but so are many of the chart's other stars — resulting in triangles wherever you look!

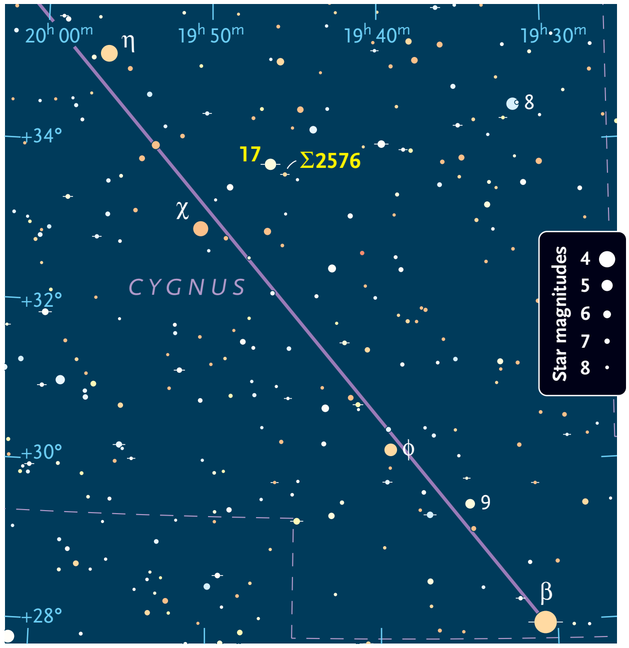
The area enclosed by the Summer Triangle is home to so many well-known wonders that the more obscure ones are often passed by. Let's make time to visit some of these celestial lonely hearts, starting with the double star **Pi (π) Aquilae**. Although many observers are devoted to viewing multiple stars, there are some who don't consider them deep-sky objects. But why not? They're certainly beyond our solar system, which is sometimes referred to as the shallow sky, and they're the truest gems of the deep. Through my 130-mm refractor at 164×, Pi Aquilae is a pretty pair made up of a 6.3-magnitude topaz mated with a 6.8-magnitude diamond 1.5″ to its east-southeast. The pair glitters at us from a distance of about 510 light-years (plus or minus 8.2%).

Climbing northward into Sagitta, we'll find the little-known emission nebula **Sharpless 2-84**. Its brightest section is a wide chevron hunkered 26′ east-southeast of Delta (δ) Sagittae and 4½′ east of 8th-magnitude HD 187323 (SAO 105291). In my 10-inch reflector at 115×, Sh 2-84 is as elusive as a scrap of mist in moonlight. A narrowband nebula filter helps lure it into view, showing the chevron pointing south-southwest. A magnification of 187× improves the scene, with or without a filter. The 3′ chevron's brighter bar reaches north-northeast, and its tip is bracketed by two 12th-magnitude stars, the eastern one closely guarding the nebula's edge. A more tenuous bar strikes out east-northeastward from the other's southern end. The chevron more readily surrenders itself to my 15-inch reflector at 216×. Its brighter side spans 2¾′ and shows a bit more contrast with a narrowband filter Although the Wolf-Rayet star WR 128 (HD 187282) 13′



BETRACHTUNG DER GESTIRNE UND DES WELTGEBÄUDES, 1823





southwest of Sh 2-84 is often mentioned in the same breath as the nebula, it isn't widely accepted as the nebula's illuminating star.

Also in Sagitta, the open cluster **Roslund 3** finds its home 1.0° due north of Gamma (γ). Look for it along a prominent, 3/4° smile of stars, concave north-northeast. My 130-mm refractor at 37× plucks out a circlet of several stars within the cluster, 10th magnitude and fainter. At 117× the group morphs into a 5′ × 3′, east-west ovoid composed of a dozen moderately bright stars and about as many faint ones. The 15-inch scope at 216× discloses 29 stars, the brightest forming a circle in the ovoid's eastern half.

Roslund 3 is one of seven new clusters found in 1960 by Curt Roslund during a survey of high-luminosity stars in the northern Milky Way.

Crossing over the border into Vulpecula, we can pay a visit to **NGC 6827**, 1.5° south-southwest of 12 Vulpeculae. This cluster hosts throngs of stars, mostly too faint to see through small telescopes. We owe this to the cluster's distance of 13,000 light-years and a heavy dose of interstellar dust along our line of sight. The dust absorbs and scatters light, thus dimming the stars by more than three magnitudes. Hundreds of stars are considered possible members of this cluster.

With my 130-mm refractor at 102×, I see NGC 6827 as a weak, ashen glow accompanied by 11th-magnitude stars 2′ south-southeast and 3′ north. At 164× the cluster appears slightly granular and spans about 2½′. A few extremely faint stars peek out from the haze. Even through a friend's 12.5-inch scope at 249×, I counted only eight stars in the cluster. Can you do better?

One evening with my 15-inch scope and no particular plan, I looked in on **Sharpless 2-88**, an emission nebula 40′ southeast of 10 Vulpeculae. At 79× an amorphous nebula appeared, sprawling about 14½′ north-south and 8′ east-west. Two 10th-magnitude stars line the nebula's western side, the northern one supplying the energy that makes Sh 2-88 shine. Several stars are superimposed on the nebula, including a 2′ trapezoid of stars (magnitudes 11.5 to 12.6) embedded in the eastern side.

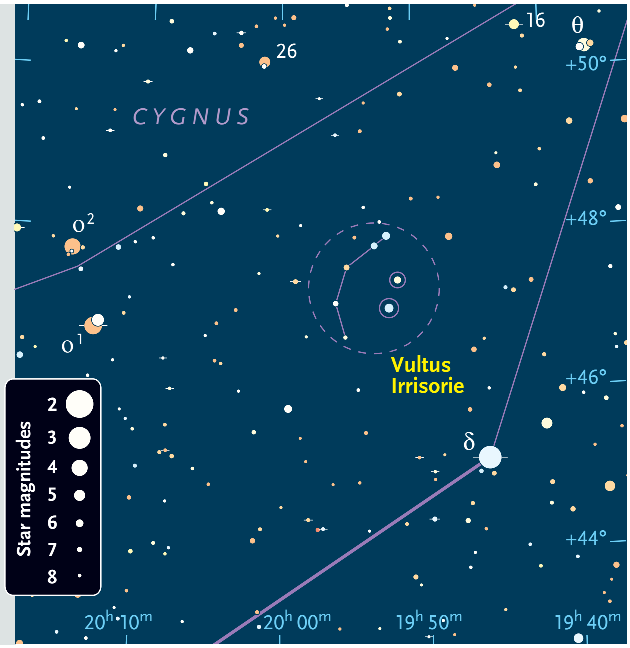
While observing Sh 2-88, I noticed a small, detached glow containing an 11.8-magnitude star slightly offset from its center. To locate it, look for a widely spaced pair of bright stars (magnitudes 6.7 and 8.8) about 12′ south-southeast of Sh 2-88. The little wisp floats 3.5′ north of the brighter star and is named **Sh 2-88A**. Boosting the power to 102×, Sh 2-88 stood out much better, and I spotted a fainter fragment of fluff just 2.6′ east-northeast of the first. Designated **Sh 2-88B**, it's tipped north-northwest and wears three faint stars: one at its southern tip and two in its northern end. These petite nebulae each span about 1′ and shine by both reflection (scattering) and emission of light.

With a separation of only 1.5″, Pi Aquilae is a tight double, but it can be split with a 60-mm refractor at 120×. The image at left was captured through a 6-inch f/10 Schmidt-Cassegrain.

Around the Summer Triangle

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Pi (π) Aquilae	Double star	6.3, 6.8	1.5″	19^h 48.7^m	+11° 49′
Sh 2-84	Emission nebula	—	5′	19^h 49.1^m	+18° 23′
Roslund 3	Open cluster	—	5′	19^h 58.7^m	+20° 31′
NGC 6827	Open cluster	—	2′	19^h 48.9^m	+21° 13′
Sh 2-88	Emission nebula	—	17.5′ × 9.0′	19^h 46.0^m	+25° 20′
Sh 2-88A	Bright nebula	—	1.2′ × 1′	19^h 46.6^m	+25° 12′
Sh 2-88B	Bright nebula	—	1.2′ × 1′	19^h 46.8^m	+25° 13′
17 Cygni	Multiple star	5.1, 9.3, 9.4	26″, 108″	19^h 46.4^m	+33° 44′
Struve 2576	Double star	8.5, 8.6	3.0″	19^h 45.6^m	+33° 36′
Vultus Irrisorie	Asterism	4.2	84′ × 42′	19^h 53.6^m	+47° 17′

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

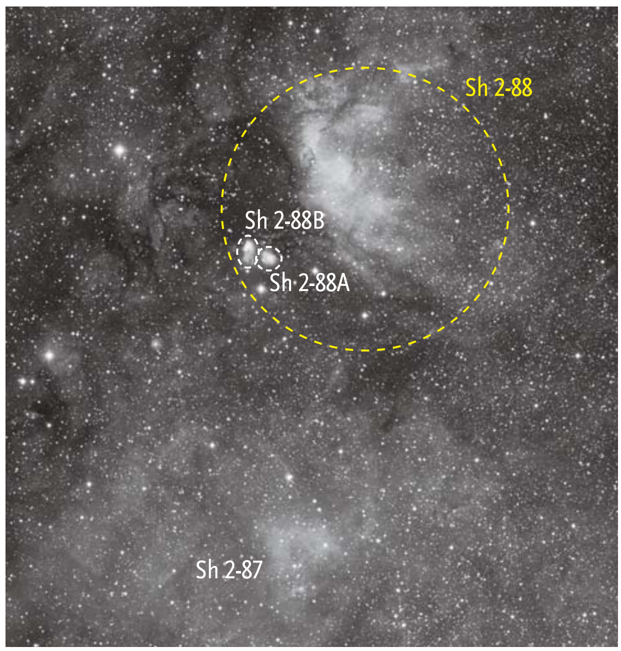


The Sh 2-88 complex is about 8,000 light-years distant. Sh 2-88A's source of excitation is the visible star within. Sh 2-88B houses a youthful star cluster that can be seen on some infrared images. One of its stars is the suspected power source for the observable part of the nebula.

Sweeping northward into Cygnus, we'll find a set of multiple stars bejeweled with colorful suns, all sharing the field of view through my 105-mm refractor at 68×. **17 Cygni** is a bright, yellow-white star that's attended by two gold, 9th-magnitude companions. One rests 26″ east-northeast of its primary and is a suspected variable star. The other sits southeast at four times that spacing, but it's not physically related to the other two stars. **Struve 2576** (Σ2576 or STF 2576) is a visual binary with an orbital period of 232 years. It shows two nearly matched gold stars, currently 3.0″ apart, with the slightly dimmer star south-southeast of the primary. Struve 2576's stars have the same proper motion (apparent motion on the celestial sphere) and distance (69 light-years) as 17 Cygni; therefore, they may have a common origin.

Let's end our sky tour on a happy note with **Vultus Irrisorie**, the Smiley Face, a binocular asterism fashioned by Alabama amateur Roseann Johnston on July 21, 2001. Although it dwells just beyond the Summer Triangle's northern border, this winsome face is simply too delightful to pass by. If you place Delta (δ) and Omicron[1] (o^1) Cygni in your field of view, the asterism will be between the two and a bit farther away from the Swan's body. Five stars form a north-south, mouth-stretching grin, while two stars closer to Delta are the eyes. The stars range from magnitude 5.6 to 7.6. Through most binoculars, the face will span about one quarter of the field. Many telescopes can't attain a low enough power to show an object as large as Vultus Irrisorie. Using an eyepiece with a 50° apparent field, you'll need a magnification of 25× or less to frame the group well.

Sadly, Roseann is no longer with us, but we can still see her smiling down from her perch in the sky, saying, "Have a nice night!" ✦



MIKE SCHUSTER

If you have trouble spotting the emission nebula Sh 2-88, try adding an O III filter to the eyepiece. The above image shows a 1° 56′ × 1° 28′ field of view as recorded in thirty 40-minute exposures through a 530-mm f/5 astrograph with an H-alpha filter.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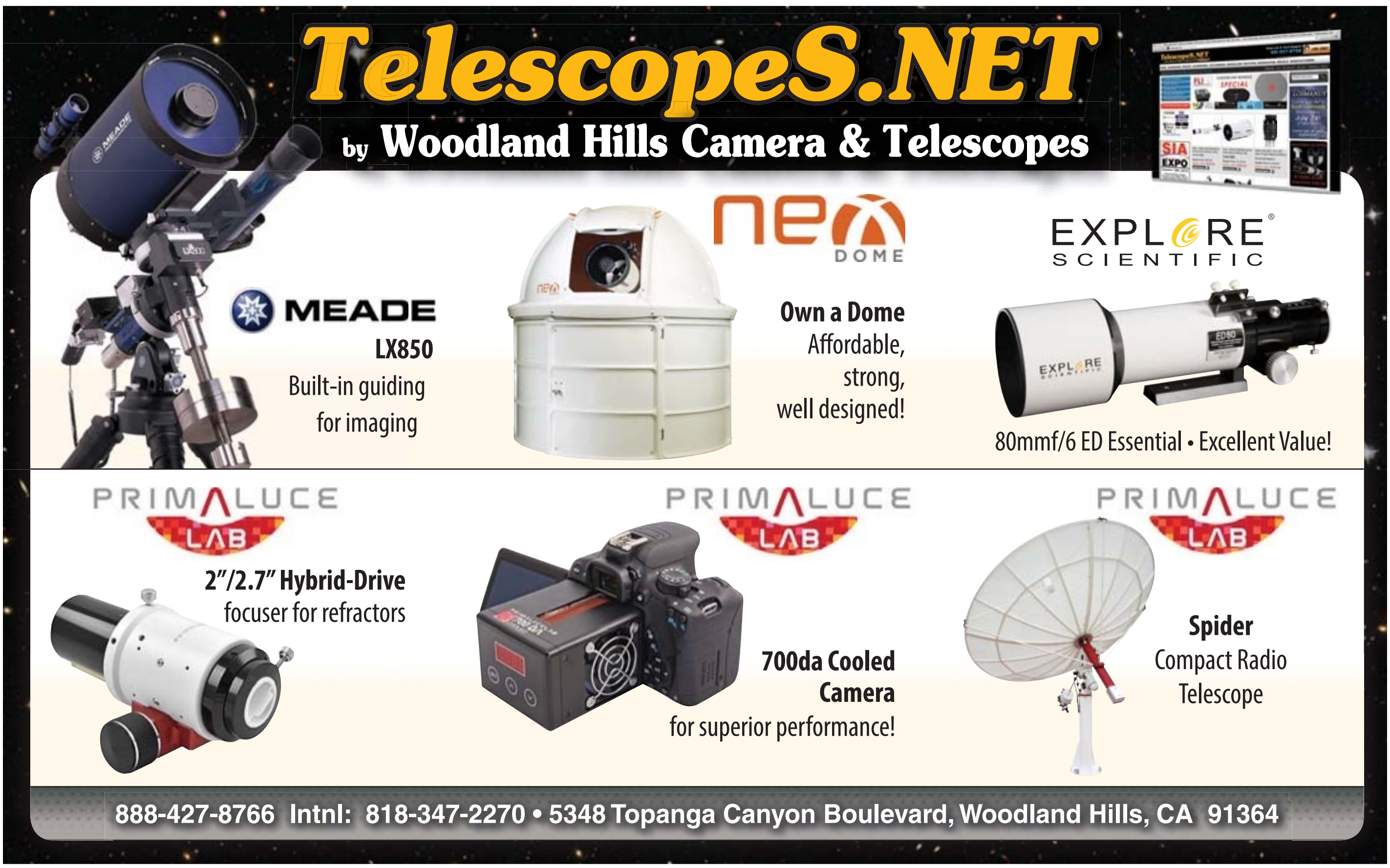
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 Alan Dyer

Nightscapes with

iOptron's iPANO AllView Pro mount makes a new form of astrophoto possible.

iOptron iPANO AllView Pro Camera Mount

U.S. price: $999
Available from iOptron.com and dealers worldwide.

If you frequent online galleries of astrophotos you've likely marveled at panoramic nightscapes showing the Milky Way sweeping from horizon to horizon above a starlit landscape. So how do photographers do it? The secret is to cover the complete scene with multiple frames shot to include generous overlap. In the past, I've shot night panoramas manually, using either a 14-mm ultra-wide or 15-mm fish-eye lens, with the camera turned to portrait orientation, and aimed about halfway up the sky. I shot eight frames equally spaced 45° apart to cover a full 360°.

That manual method certainly works. But the new iPANO AllView Pro mount permits photographers to take panoramas to a new level of quality and detail. With

The iPANO is designed to create high-resolution panoramas of night scenes, such as this nearly 360-degree horizon-to-zenith panorama of the May sky, complete with an aurora and the Milky Way, taken at the author's rural home. This is a massive mosaic of 44 images in 4 tiers of 11 segments, each a 30-second exposure with a 35-mm lens at f/2 and recorded at ISO 4000.

ALL PHOTOS BY THE AUTHOR

iOptron's iPANO

it, you can create "gigapixel" panoramas, made not only of several frames next to each other horizontally, but of two or more tiers of frames arranged above each other vertically. Panoramas can be created from images shot as a matrix of 2 to 5 rows, with perhaps 8 to 12 individual frames in each row.

Remarkably, today's stitching software can align and seamlessly blend even these complex multi-tier panoramas. The resulting image can be over 8,000 pixels high and tens of thousands of pixels wide, approaching one-half to one *billion* pixels — a gigapixel — in size.

Why go to that excess? The reason is detail. By dividing the scene into smaller segments, you can shoot with longer focal-length lenses, perhaps a 35-mm or 50-mm lens. That allows the final panorama to resolve more detail in the sky and ground in massive prints, virtual-reality simulations, or projection in the new generation of digital planetariums.

Longer lenses also suffer less from distortion and aberrations, especially at the edges of the frame where segments overlap. The result is a panoramic sky filled with consistently sharp stars, even in the overlapping areas.

However, shooting multiple tiers with consistent spacing and overlap, both horizontally and vertically, requires either a lot of fast but precise handwork — or an automated mount like the iPANO AllView. I found it worked amazingly well.

WHAT WE LIKE:

- Lightweight and portable
- Long battery life
- Self-contained control panel

WHAT WE DON'T LIKE:

- Included stitching software has problems with large files
- LCD screen not dimmable

Mechanical Setup

Let's be clear what the iPANO is . . . and is not. It's a motorized mount dedicated to taking panoramas and time-lapse sequences automatically. The iPANO is not an astronomical mount. It doesn't slew to astronomical objects, nor can the iPANO track the rotation of the sky from east to west. This is not a mount to be used with a telescope, nor for taking tracked "piggybacked" images. The

The mount includes multiple sliding brackets for adjusting the height and forward/backward position of the camera to minimize parallax shift. The "80mm" scale on the vertical adjustment is only for very tall cameras and requires that the horizontal plate be unbolted and moved down the fork arms. The fittings employ the Arca-Swiss style of dovetail plate, a common standard in the photo industry.

iPANO is specifically for creating panoramas of daytime landscapes and star-filled nightscapes.

As such, the iPANO comes with adjustable brackets and dovetail plates for mounting your camera and lens combination so that the camera turns around the nodal point of the lens — what iOptron calls the "No Parallax Point." This is located near the lens's iris diaphragm inside the lens. Turning the camera around this point, and not around its tripod socket hole, minimizes parallax shift from frame to frame, so stitching software can seamlessly blend images.

Eliminating parallax is critical when taking "virtual-reality" panoramas of indoor spaces, or outdoor scenes with lots of foreground detail. It's of less concern when shooting nightscapes where most subject matter lies at a great distance, if not at infinity. Nevertheless, the range of adjustments provided and instructions make it easy to position your camera for minimum parallax shift.

This mechanical adjustment is something you typically need set only once, varying it slightly only if you change lenses. But make sure you note the settings, as you have to disassemble the brackets to fit the iPANO back in its case.

Once you have the camera positioned, another largely "set once and forget" adjustment is telling the iPANO the field of view (FOV) of your lens. This is not done by inputting the lens focal length and sensor size, but rather by actually moving the camera to place the horizon at the top, then bottom, of the frame following the prompts on the onscreen menu.

The other key setting is determining the amount of overlap desired. The iPANO defaults to 30%. I found this worked well in most cases, but to be on the safe side with very wide, distortion-prone lenses, I'd suggest an overlap range of about 40 to 50%.

Electronic Setup

In my testing I concentrated only on taking long-exposure nightscapes and time-lapses, using exposures of 10 to 30 seconds and at high ISO speeds. However, the iPANO is equally at home shooting daytime or twilight scenes using short shutter speeds. It can also create high-dynamic-range (HDR) panoramas by firing the shutter multiple times at each segment while the camera varies the exposure.

By contrast, at night you are shooting a moving target — the starry sky. As such, it's best to keep exposures as short as possible, to minimize star trailing within a

The 7.9 lb (3.6 kg) iPANO head comes with a handy carrying case for taking it into the field. The package includes seven shutter release cables (in front) to connect it to a variety of Canon, Nikon, Olympus, and Sony cameras, as well as an RS-232 cable for computer control.

The rear LCD screen and scroll buttons provide access to all the functions needed to set up a complex panorama sequence. While the contrast can be adjusted, the screen's brightness is not dimmable. The author found it blindingly bright at night. A red gel taped over the screen proved essential.

frame (remember, the iPANO does not track the sky), and also frame-to-frame motion.

For long exposure nightscape panoramas, set your camera on Bulb and the iPANO's "Shutter Length" also to Bulb. Then set the iPANO's "Period/Exposure" to the desired length. The menu offers a choice of useful exposure times, up to a maximum of 60 seconds, as long as any nightscape might need. With this combination of settings the iPANO moves immediately after the shutter closes.

You can program in a "Pretrigger Delay," so that the shutter doesn't fire again as soon as the mount stops moving, but after a delay to allow for vibration to settle. However, the mount and iOptron's optional tripod proved very solid. I found a delay of just one second more than adequate.

In the Field

Many of the required settings can be programmed ahead of time and stored in what the iPANO calls a "Bank" — a collection of user settings. The iPANO can store up to six banks of settings for quick recall.

What you need to do in the field is level the unit (a top-mounted bubble level aids in this), then tell the iPANO where to start the panorama and where to end it. It's easy — you use the Up-Down and Left-Right buttons to slew the camera to frame the first segment that will form the lower left of the panorama, then press OK. The display then prompts you to slew the camera to the position that will form the upper right corner of the panorama. Press OK.

The iPANO then offers the option of slewing to all four corners and to the center of the calculated panorama, for you to check if that's what you really want. If it is, hit OK and the iPANO goes to the start position and triggers the first exposure.

In what order the iPANO takes the mosaic segments is up to you. For night-sky panoramas, I found it best to slew up, then across to the right, then down, to work across the turning sky from east to west (left to right in the Northern Hemisphere). The menu also offers a pattern suitable for scanning across the Southern Hemisphere sky from right to left.

Once you have start and end frames programmed, the iPANO's LCD display indicates how many segments it will require (based on how long your start and end frames are), and also how long it will take to shoot them (based on your exposure time and the number of frames required), which in turn are all based on your lens FOV and frame overlap. As the shoot progresses the screen displays how many segments have been taken so far.

I tested the iPANO using only its on-board control screen. Alternatively, a Windows computer running the free *iPANO Commander* software can operate the iPANO, through either an RS-232 serial connection or

The included *iPANO Commander* software allows control of the iPANO with a Windows computer. However, the program requires a monitor screen resolution of at least 1024 x 800 pixels. On the small Windows netbook the author uses in the field, the screen was cut off and is not resizable or scrollable, preventing access to key buttons.

via WiFi. For the latter, the iPANO sets up its own ad hoc WiFi network. The software worked well but needs a computer with a widescreen monitor to show the full set of buttons. My little netbook was inadequate.

Alternatively, iOptron also offers a control app for iPhone and iPad. While it and the Windows app did work, albeit with a few bugs, neither offered functions beyond what is offered by the on-board screen.

Stitching Frames

However you control the iPANO, what you end up with is anywhere from a handful to several dozen images per panorama. My workflow is to process all these files in *Adobe Camera Raw* (or *Adobe Lightroom*) with identical settings to make them all look as good as possible, including the application of Lens Correction to correct lens distortion and reduce vignetting.

Now, throw all these developed Raw files at *Adobe Photoshop* and its Photomerge function, or use *Adobe Lightroom*'s Panorama function, and you might have success. But chances are you won't, particularly not when stitching complex multi-tier panoramas.

Purchasers of an iPANO are eligible for a free copy of the Standard Edition of the stitching software *Panoweaver* (**easypano.com**). iPANO owners receive a code to unlock and register the trial copy. Unfortunately, even the registered program failed to export complex multi-panel panoramas at their maximum resolution.

Instead, I used *PTGui* (**ptgui.com**). It aligned and blended even iPANO's complex multi-tier mosaics quickly and perfectly, and offers a variety of map projections to turn the spherical sky into a flat image.

Motion-Control Time-Lapse

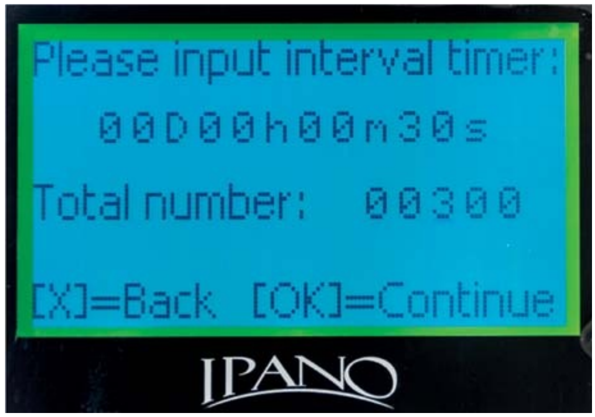
The iPANO can also function as a dual-axis "motion controller" for taking time-lapse movies where the camera moves incrementally between each frame, in both azimuth and altitude if desired.

To create such a sequence you choose Time-Lapse Photography from the main menu. In this case, using the combination of settings I used for panoramas, I found that the mount tended to move in a quick shudder just as the shutter was closing. While this didn't seem to blur images, I preferred to add a delay between shutter closing and the move. To do this, I set the exposure on the camera, and then set the iPANO's Shutter Length to 0.1 second, and the Period/Exposure to the next increment longer than the camera's exposure time.

In the time-lapse menu, setting the "Interval Timer" to any length equal to or shorter than the Period/Exposure time ensures images are taken as quickly as possible, usually desirable for time-lapses at night.

The other required setting is the "Total Number" of frames you wish to shoot (300 is typical for many time-lapse sequences), or the amount of motion, in degrees, you want between each frame (no more than 0.15° per move ensures a smooth final movie).

For video sequences captured with the iPANO mount:
https://is.gd/ulKnNL/ipano



The screen for programming a time-lapse sequence asks for the interval between shutter firings and the number of frames you want it to take.

It would be useful if the iPANO screen then calculated and displayed the angular sweep of your sequence and how long it will take to shoot. As it is, you are left to figure out these key factors on your own.

Unlike many dedicated motion controllers, the iPANO offers no exposure ramping, nor speed ramping (see *S&T:* November 2015, p. 63). The former makes day-to-night sequences feasible, while the latter brings the camera's motion up to speed at the start of a sequence, then ramps it down gradually to a stop at the end.

Nevertheless, the time-lapse mode worked very reliably and provides owners with a dual-axis motion controller for a price comparable to other units on the market, with the bonus of panorama functions! The iPANO also has an advantage in including a convenient built-in lithium battery (most other time-lapse controllers require an outboard 12-volt battery).

The internal battery lasted for many nights of shooting, even after several multi-hour time-lapses. The downside is that recharging the internal battery must be done with the included 8.4-volt/2-amp AC adapter. (Don't lose it!) The manual specifically warns against using a standard 12-volt charger or car lighter adapter.

In all, with a price of $999 the iPANO is no small investment in a specialized piece of gear. However, it performs its panorama and time-lapse functions very well, in a lightweight and self-contained package that is easy to carry to backcountry sites. Think breathtaking gigapans of the Milky Way over Delicate Arch in Utah! ✦

*Contributing Editor **Alan Dyer** is author of the eBook* How to Photograph & Process Nightscapes and TimeLapses, *available at **amazingsky.com/nightscapesbook.html**.*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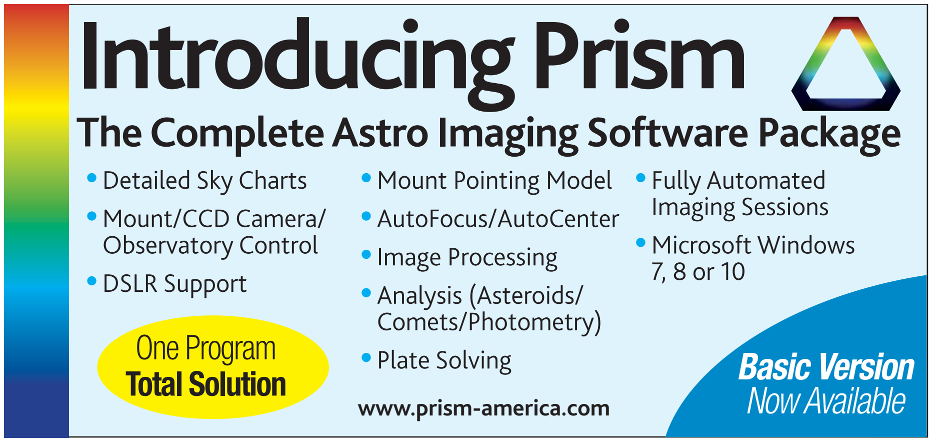
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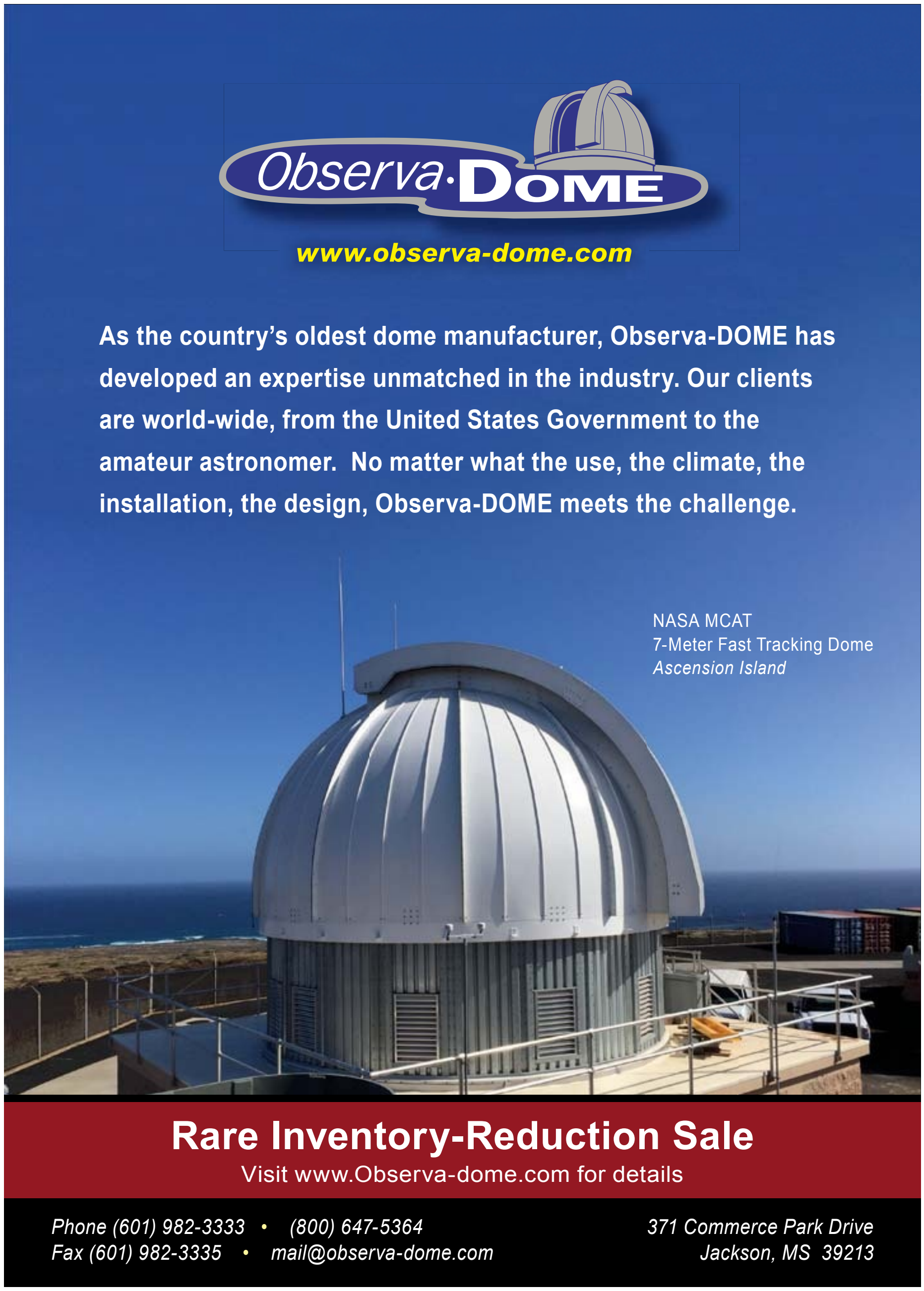
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New Product Showcase

▶ **SMARTPHONE POINTER** CosmoStory rolls out the Cosmo Laser ($25), a laser finder for your smartphone. The device consists of a 5-milliwatt green laser pointer paired with a universal smartphone ¼-20 threaded bracket. Simply add your smartphone with your favorite planetarium app and a standard photo tripod, and you'll be able to identify virtually any object centered in your smartphone screen. The Cosmo Laser's mounting bracket includes a safety lock position, which hides the ON button to prevent involuntary activation.

CosmoStory
cosmostory.com

▲ **TABLETOP TELESCOPE** Orion Telescopes & Binoculars announces the Orion FunScope Astro Dazzle 4.5″ Reflector Telescope ($179.99). This 114-mm f/4.4 Newtonian reflector features a plate glass parabolic primary mirror in an eye-catching tube. Its rack-and-pinion focuser accepts 1¼-inch eyepieces and includes a pair of 25- and 10-mm Kellners that yield 20 and 50×, respectively. Its single-arm altazimuth mount produces smooth motion in both axes, and, combined with the EZ-Finder II red-dot sight, makes aiming the scope quick and easy. The telescope comes with a quick-collimation cap, a copy of MoonMap 260, and a free download of Orion's *Starry Night Special Edition* software.

Orion Telescopes & Binoculars
89 Hangar Way, Watsonville, CA 95076
800-447-1001; oriontelescopes.com

ASTRONOMY GLASSWARE
UncommonGreen now produces a series of etched glassware. The Constellation Glassware series features pints ($16), rocks ($14), and stemless wine glasses ($15) etched with the classical constellations of the Northern Hemisphere's Winter or Summer skies. Each is meticulously engraved with the familiar lines and names of the constellations, and are designed to never wear off. Free shipping on orders of $75 or more.

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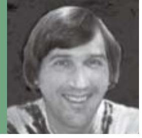
New Product Showcase is a reader service featuring innovative equipment and software of interest to amateur astronomers. The descriptions are based largely on information supplied by the manufacturers or distributors. *Sky & Telescope* assumes no responsibility for the accuracy of vendors' statements.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

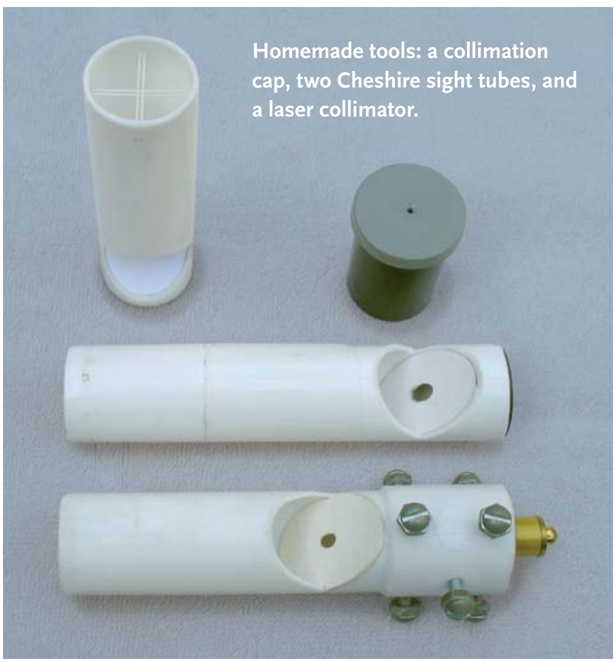


Contemplating Collimators

Make high-precision tools from plastic piping and underwear.

If you own a Newtonian telescope, you need a collimator. It can be as simple as a focuser plug with a hole in the center, or as complex as a combination Cheshire sight tube with crosshairs and an angled reflecting plate. It might even be a laser mounted so its beam shines precisely down the optical axis of the scope. Most people think precision tools like the latter two need to be manufactured under exacting standards in machine shops with CNC milling machines accurate down to the gnat's whisker, but that's not so. You can make a perfectly good collimator in your home shop with little more than a saw and a hand drill. Here's how:

Start with a 1¼-inch tube. If you're making a simple collimation cap, cut the bottom off an old 35mm film can, drill a ⅛″ hole in the middle of the lid, and you're done. If you're going for a Cheshire or a laser collimator, buy a plastic drainpipe from the plumbing section of your local hardware store. Make sure you get the 1¼″ outside-diameter pipe, not the 1½″. You might find chrome ones, too, but they're a pain in the patootie to work with. Get the plastic kind.



Homemade tools: a collimation cap, two Cheshire sight tubes, and a laser collimator.

JERRY OLTION (2)

Lining up the laser is the most finicky part, but with a V-shaped notch and a little patience it's not all that difficult.

When making a laser collimator, find a small laser that will fit inside the pipe, and cut the pipe so there's enough length for the laser and three or four inches more.

To make a Cheshire eyepiece, cut the pipe to the same f/ratio as your scope. (For an f/5 scope, make your tube 5× as long as it is wide.) If you do that, you'll be able to see your entire primary in the secondary and also center the secondary perfectly inside the Cheshire's outermost circle. Don't obsess about the length, though; it'll work fine if you're off a bit.

Both the Cheshire and the laser need a 90° notch in the tube, extending only halfway through. Again, don't obsess about getting a perfect 90°. Anything close will do. For the Cheshire, cut the notch close to the eyepiece end. For a laser, leave room for the laser module.

Cut a white cardboard oval to fit inside the tube along the eyepiece/laser side of the notch. A business card will work perfectly. Make it 1.4 times as long as it is wide and nibble away at the edges until it fits snug all the way around. Then use a sharp knife or a hole punch to nibble out another small oval at the center of the big oval. Make it about ¼″ wide and ⅜″ long. Get this as centered as you can, then glue the oval into place.

For the combination Cheshire sight tube, put a cap on the eyepiece end with a ⅛″ hole in the center of it. Put crosshairs at the other end.

Yeah, crosshairs. Crosshairs are easy! Don't mess with wires or string; those always sag. Instead, pull a piece of elastic out of the band of a pair of old underwear. You'll have to unwind the thread covering, but you'll wind up with a nice even piece of stretchy rubber. Drill some holes or cut some notches in the end of the pipe (do make sure these are as accurate as you can get them), run the elastic through the holes or over the notches, tug it tight, and glue it in place. You can get fancy and make double crosshairs if you prefer, or just make a simple X.

When the glue dries, shave off the elastic that sticks out so the outside of the tube is smooth enough to fit into the focuser. If you're making a Cheshire sight tube, you're done.

A laser collimator doesn't need crosshairs, so you just need to drill the holes for your laser mounting screws. Cut threads if you've got a tap; otherwise just drill tight holes and force the issue. Add an extra screw over the laser's on button.

Centering the laser is the only finicky part. Get it to shine through the center hole in the angled disk, then rotate the collimator in a V-shaped notch while watching the laser beam draw a circle on the wall. Adjust the laser's angle until the beam stays put.

You're done! Now line up your mirrors and get out under the stars. ✦

__Jerry Oltion__ often hears people say "culminate" when they mean "collimate." Remember: collimation culminates in co-linear optics. Contact Jerry at ***j.oltion@sff.net***.

JERRY OLTION

Elastic crosshairs are easy. Stretch them a little and glue them in place. Unlike wire or string, they'll stay straight even if bumped.

Planetary Processing

This freeware takes the drudgery out of stacking planetary videos.

Emil Kraaikamp The long-established technique of lucky imaging is unquestionably the best and easiest way to record high-resolution photos of the Sun, Moon, and planets. Using high-speed digital cameras, amateurs record thousands of video frames of their chosen target in short, multi-gigabyte files, which are later sorted to select the sharpest frames to combine into a final, detailed result.

The problem then becomes working through all the data — it's easy to accumulate several dozen to more than 100 gigabytes of video files in one evening! Distilling these files is a time-consuming process. The most popular program, *RegiStax 6*, can't batch-process these files well, so users have to process each video individually.

This led me to write *Autostakkert!* (**autostakkert.com**), a program whose primary function is to stack the best parts of video frames with only a few mouse clicks, permitting you to concentrate on processing your images. Here's how it works.

Determining Image Quality

Begin by opening the files you'd like to process by clicking the **1) Open** button and navigating to the folder where your files reside, or simply drag and drop them into the program. The first frame of the first file will then be displayed in the frame view window.

The first action *Autostakkert!* (now on version 2) needs to perform is an evaluation of the quality of your video frames. To do this, it needs to stabilize the individual frames (correcting tracking errors) before it performs alignments on a finer scale.

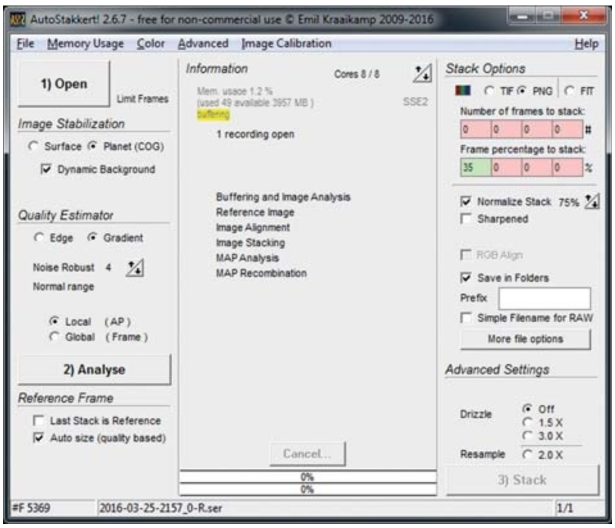
The software does this in one of two ways. For planetary recordings, the Planet (COG) mode is implemented, centering the largest bright group of pixels (the target planet) in each frame. By default, it automatically determines the threshold that separates the bright pixels from the background. You can often significantly speed up the process by making sure the width and height — in the frame view — are set as small as possible, encompassing only the subject.

In Planet (COG) mode, the target will be centered by default. You can change this composition and move the planet around the field by holding the Shift + left mouse button while dragging the planet around the frame. This is most useful when offsetting Jupiter or Saturn to include their largest moons in the field of view. Planet (COG) mode ensures the planet is also aligned from one recording to the next, making post-processing much easier, particularly if you're combining monochrome videos shot through color filters into a color image, or assembling a time-lapse animation.

The other option for the stabilization of individual frames is Surface stabilization, which is best used on

with Autostakkert! 2

close-ups of the Sun and Moon. Surface allows you to choose and track one particular feature throughout the video. Use Ctrl and click in the frame view to place an alignment anchor on a prominent feature such as a sunspot or a high-contrast area on the Moon. You can also resize the alignment anchor by typing 1 to 9 on the



CONTROL PANEL The program's main user interface is a sub-window that appears alongside the frame view window. Key actions are located along the left and right sides, while the center column displays the progress of actions in process.

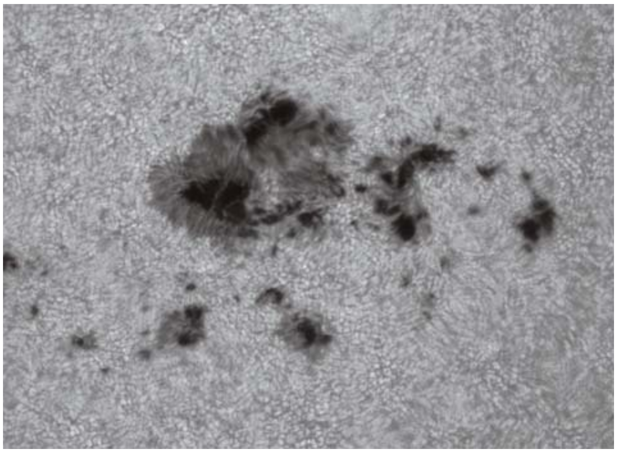
STACKED Stacking planetary videos is often a time-consuming process, but it doesn't have to be. *Autostakkert!* is a time-saving program that lets you batch-process many videos to produce high-resolution images of the Sun, Moon, and planets, like the detailed results above. All photos courtesy of the author.

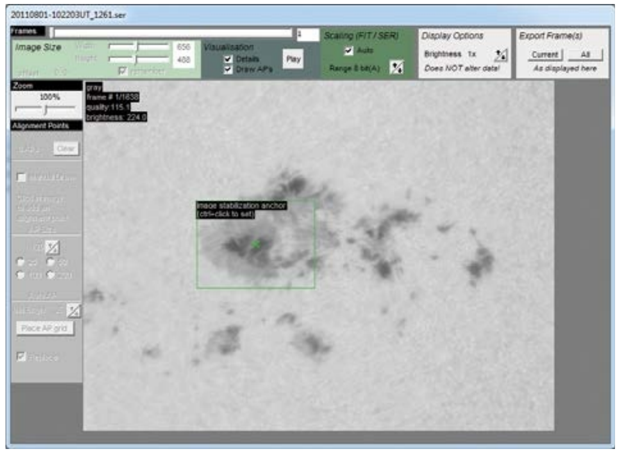
keyboard, which is especially useful when you want to track on a very small feature. The smaller the alignment anchor, the faster the surface stabilization runs.

The next step is to determine which of the two available Quality Estimator functions should be used to evaluate the frames in your recordings. The Edge quality estimator is based on edge detection in images, which works best for the smallest planets, particularly Mercury and Venus. Edge is designed to examine the sharp, sunlit limb of your target, so you'll want to uncheck the selections around the planet that are near its shadow side.

The other option is the Gradient estimator. As the name implies, it detects gradients on your target at a scale that is determined by the "Noise Robust" levels in the image. Typically, 4 is a good starting point, but for noisy images or videos shot at very high focal ratios, you might achieve a better result by increasing this setting to 6.

Gradient has another option that determines whether the frame quality will be estimated around each alignment point, called Local (AP), or by examining each frame in its entirety, called Global (Frame). Best results are most often achieved using the Local estimator, because it allows





BOILING ATMOSPHERE ***Left*****: This single frame of a white-light solar recording shows "seeing cells" distorting some areas of the image much more than others.** ***AutoStakkert!*** **extracts only the sharpest areas in each frame.** ***Right*****: A high-contrast area is chosen as an anchor point to roughly align the video.**

the software to select the best areas of each frame. The Global setting is useful when the background is changing in brightness, which can happen during daytime imaging with changing transparency. The Global setting ensures that each alignment point uses the exact same set of frames for stacking, thereby avoiding brightness inconsistencies in your final stacked image.

After selecting the Quality Estimator, it is time to click the **2) Analyse** button, which will start the quality estimation of all frames and, in the case of a surface recording, will also perform the surface stabilization. Image stabilization is a crucial stage in processing the recording, so when it's complete, you should check how well this was executed automatically. Go to the frame view window and drag the Frames slider around to ensure that each frame is coarsely aligned and only small movements are still visible. If there are large movements visible after surface stabilization, try placing the alignment anchor on a different feature and rerun the analysis stage.

When image analysis is completed successfully, the label of the Frames slider turns green and the frame view window shows all the frames sorted by their average quality, from best to worst. The main window will also show a Quality Graph, indicating the frame quality over time (as a gray line) and the distribution of the sorted frame qualities (green line), scaled from their best (top left) to worst (bottom right) values. By clicking on the Frames label, you can switch between browsing through the quality sorted or unsorted frames.

The Quality Graph will give you an indication of how many frames you might want to stack; typically anything below the horizontal 50% quality line (halfway up the image) can be ignored. By pressing Ctrl and right clicking in the quality graph at the point where the majority of frames are below the 50% line, you can automatically set the corresponding percentage of frames you want to stack. However, this quality graph only gives a rough indication, and it's advised to check the frames by eye as well, as this gives a better indication of what your frames really look like and how many of them you might want to stack for your recording.

Alignment Points

Now that the quality evaluation is complete, it's almost time to stack your videos. *AutoStakkert!* allows you to make multiple image stacks from the same video simultaneously, using both fixed numbers of frames and/or frame percentage numbers (e.g., you can ask it to always stack 50% of all the frames). This is particularly handy when you are not sure how many frames you should stack. This percentage number strongly depends on the imaging conditions (most importantly, the seeing). A good rule of thumb in planetary imaging is to use about 50% of the frames; use more when the seeing is very good and fewer when the seeing is poor. When you have a very bright subject, such as the Moon or Sun, fewer frames are often preferred.

To correct for fine-scale movements caused by seeing distortions, the best results are produced by using multiple alignment points (APs). These APs define regions of the images the program will analyze and track to compensate for seeing distortions. Each of these APs uses a local quality estimation to build up a unique subset of the best frames for that area, allowing the software to build a map of the image as it would appear without gross distortions.

The APs are typically placed with quite a bit of overlap, allowing the program to discard the bad ones. When the contrast is inadequate for a particular AP to track, the resulting blurry stack from that particular AP is ignored and replaced by the data from an adjacent AP.

Determining where and how many APs should be used isn't easy. You can get very good results with the Place AP grid button, which places APs automatically in a grid-like structure. However, manual placement of APs can often produce notably better results. You can add APs manually by left clicking on your image, and remove APs by right clicking on them. The mouse scroll wheel can be used to change the size of an AP before placement, or by clicking the up and down arrows in the Alignment Points section of the frames window. The best locations for APs are those areas of high contrast in at least two perpendicular directions, providing the program with distinguishable features it can lock onto. Some good areas to place smaller APs are where the rings of Saturn meet the planet, the polar caps of Mars, or the shadows of Jupiter's moons on the planet itself.

Use large APs for areas that contain less contrast; a good example is a large area of lunar maria with few craters. Avoid linear features that may only be tracked well in one direction. For example, when a small AP is placed on top of the edge of the solar disk, details within the disk can suffer if that "line" is tracked inadequately in just one direction. In those cases it's better to use a larger AP, or move it towards the center of the disk, allowing only 10% of black space visible for each AP. You can mix and match different-sized APs, and they can also be placed on top of each other. Always try to cover your entire subject with APs.

Once the APs have been selected, press the **3) Stack** button to generate your stacked results. Check the Save in Folders option, especially if you chose to use several different frame totals in your stacks. A new folder is created for each stack size (or quality percentage), organizing your output nicely. Once completed, you can then import each image into your preferred image-processing program to sharpen the results.

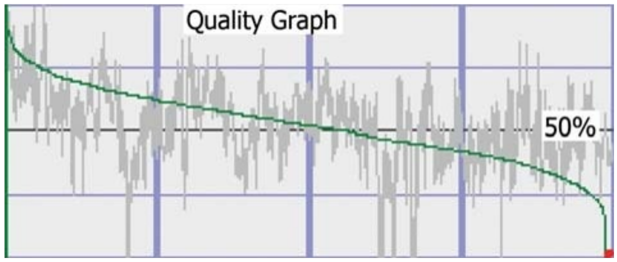
Advanced Features

Autostakkert! includes a few additional features that can help you get the best results from your recordings. They can perhaps even open up more possibilities in your choice of targets.

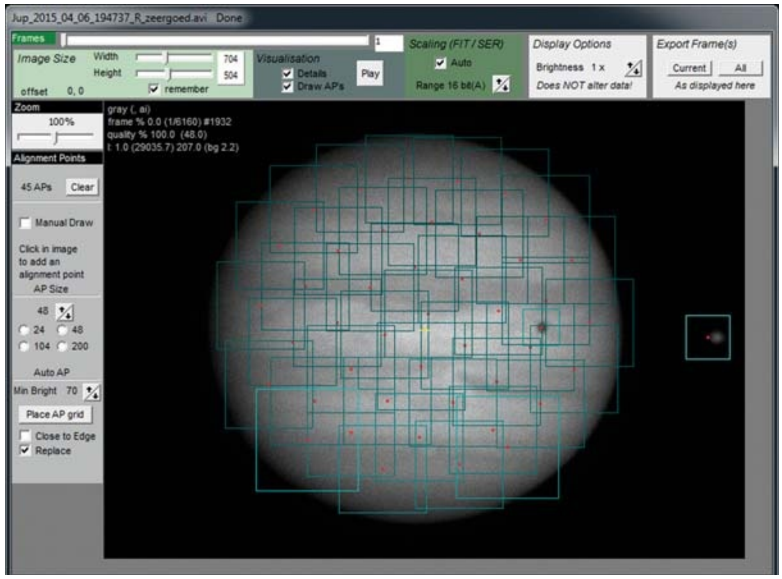
For most planetary imaging, image calibration isn't as necessary as it is for deep-sky photography, but the software includes the option to create and apply both dark and flat fields, which are especially useful for calibrating your lunar or solar recordings.

Normalize Stack is a helpful option only available for planetary recordings. It sets the brightness of the image stack to a fixed percentage and compensates for brighter than normal backgrounds from imaging in twilight (or even daylight). Turning this option on greatly simplifies post-processing, particularly if you're processing many recordings with gradually changing brightness levels. This option also helps maintain a consistent brightness between images when creating animations.

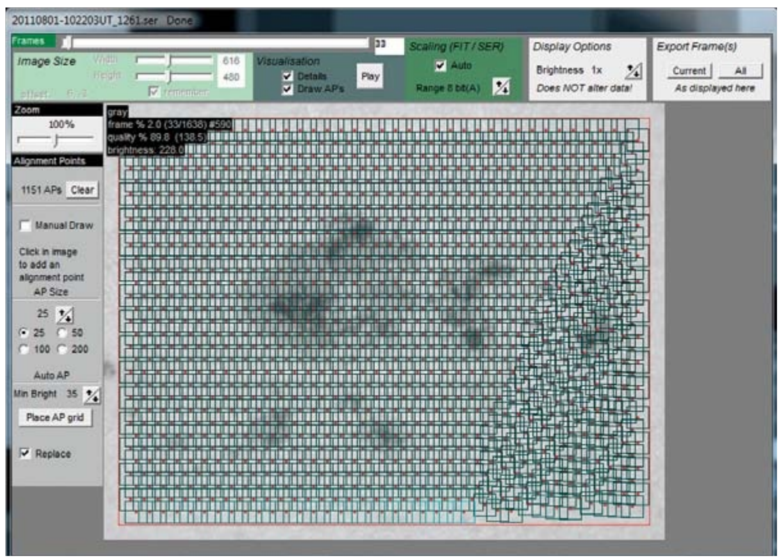
As most planetary images taken with amateur telescopes are relatively small, the program includes two options to deal with them. Drizzle and Resample are



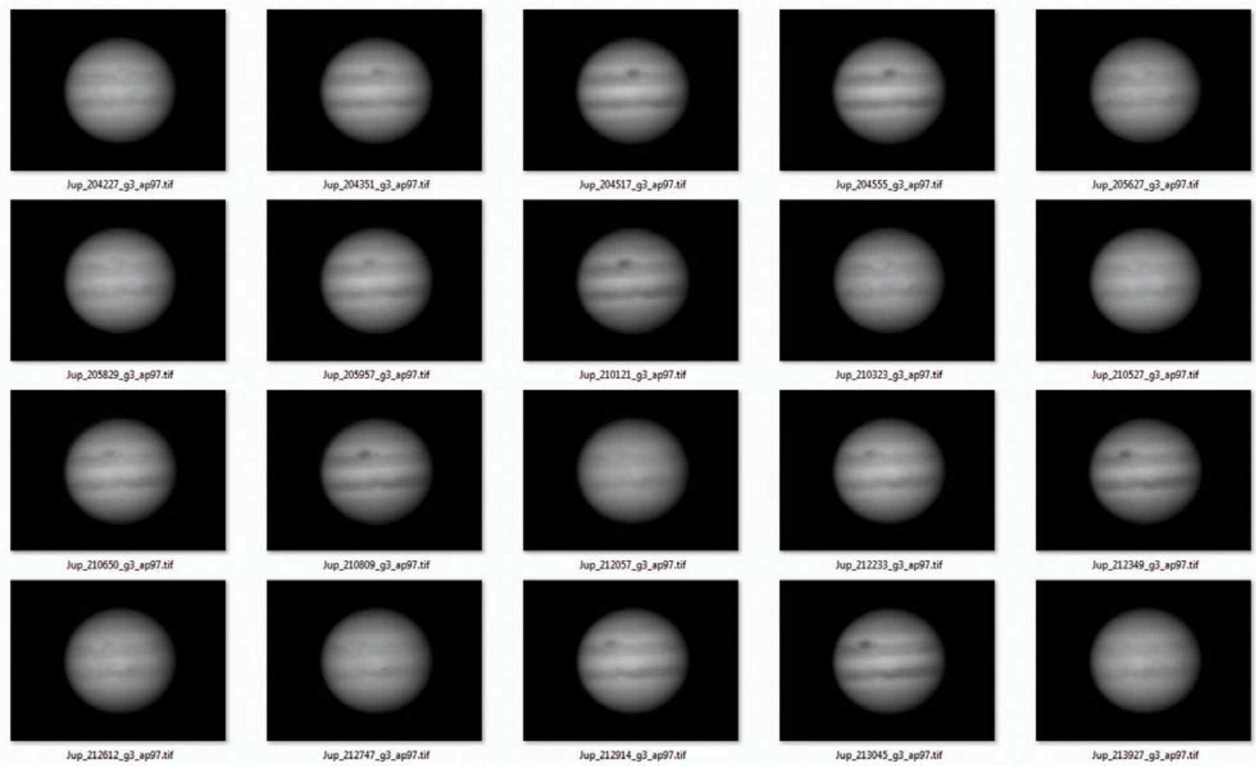
QUALITY ASSESSMENT After analyzing the first video, *AutoStakkert!* produces a quality graph. The gray lines show the quality of the unsorted frames, and the green line displays the distribution of the quality sorted frames.



MULTI-POINT ALIGNMENT Setting alignment points in your video can be performed manually, or you can click the Place AP grid button to allow *Autostakkert!* to choose alignment points automatically.



STACK OPTIONS The program allows you to generate multiple stacks from the same video. Type in the number of frames (or percentage of frames) in the pink boxes, and they'll turn green when active. Be sure to check the Save in Folders box to keep the output files organized.



FINAL OUTPUT Upon completion, *Autostakkert!* produces a folder for each of the stack options you chose, ready to be imported into your favorite planetary processing software for sharpening, deconvolution, or any additional processing you choose.

output options in the program to upscale your images. Resample enlarges the image using a bicubic interpolation algorithm. Drizzle, on the other hand, is a technique developed for the Hubble Space Telescope that takes undersampled data and improves the resolution of your final image. Both drizzling and resampling are performed during the stacking process, allowing sub-pixel alignment accuracy.

DEEP-SKY STACKING *Autostakkert!* can also stack deep-sky images to take advantage of the superior resolution afforded by short exposures. This detailed photo of edge-on spiral galaxy NGC 891 was recorded with a 16-inch f/5 Newtonian reflector and Point Grey Research Blackfly IMX249 camera and color filters. A total of 3,300 one-second exposures were stacked to produce the luminance image, while 100 four-second exposures were stacked for each of the red, green, and blue images.

When processing raw color recordings taken with color cameras, *AutoStakkert!* performs on the fly "drizzle debayering" (*S&T*: May 2014, p. 72). This technique doesn't perform debayering per frame, but instead relies on small movements in the recording to fill in the missing information between the pixels of the Bayer filter. This results in more details than the interpolation of regular debayering methods and produces a final image stack that is comparable to images shot with the tri-color method.

Finally, *Autostakkert!* isn't limited to processing planetary images. I've had excellent results shooting deep-sky objects with the lucky imaging technique that resolve extremely small-scale features in bright galaxies and planetary nebulae. This requires a fast telescope with plenty of aperture, as well as a high-sensitivity camera. Fortunately, both are readily available today.

This tutorial should allow you to get the most out of your planetary videos, without having to shepherd each one through the program individually. This should free up your valuable time to explore additional post-processing techniques. I continue to improve *Autostakkert!*, so if you have any reasonable suggestions on advancing the software, email me at **ekraaikamp@gmail.com**. ✦

Emil Kraaikamp *shoots the night sky from his favorite observing location in the Dutch province of Ruinerwold.*

J. Kelly Beatty

Gallery

▸ ENSHROUDED DIAMONDS

Jeffrey O. Johnson

NGC 6820 is a diffuse nebula in Vulpecula that glows brightly thanks to the energizing radiation from the cluster of young stars (NGC 6823) near its center.
Details: *Takahashi FS-60C apochromatic refractor and QSI 540wsg CCD camera used with Astrodon Hα and Gen2 RGB filters. Total exposure: 3¾ hours.*

▾ MERCURY'S DAY IN THE SUN

Dan Dill

Mercury's tiny black silhouette (lower left of center) slides across the Sun's face on May 9, 2016. Patchy clouds and a sizable sunspot group add to the event's drama.
Details: *Canon EOS 5D Mark III CCD camera with 400-mm lens and 1.4× extender. Exposure: 1⁄60 second.*

▼ ICONIC NEBULAE IN CYGNUS

Michael de Nigris

The North America (NGC 7000) and Pelican nebulae are clouds of ionized hydrogen roughly 1,500 light-years away that bear remarkable resemblances to their namesakes.

Details: *Celestron EdgeHD 11 Schmidt-Cassegrain telescope, Atik monochrome CCD camera, and hydrogen-alpha filter. Total exposure: 6 hours.*

► IN THE WHALE'S TALE

Tom Harrison

Discovered by William Herschel in 1785, NGC 210 is an 11th-magnitude barred spiral galaxy in Cetus. Its nearly disconnected arms might be evolving into a ring structure.

Details: *RC Optical Systems 12.5-inch Ritchey-Chrétien astrograph and SBIG STL-6303E CCD camera with Astrodon Gen2 LRGB filters. Total exposure: 22.3 hours.*

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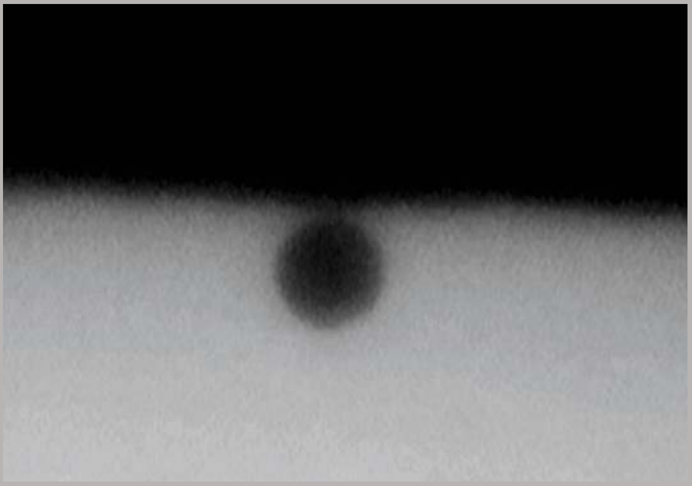
▲ GLOWING GLOBULE

Harel Boren & Lukas Demetz

A favorite with astrophotographers, the Bubble Nebula (NGC 7635) in Cassiopeia is a large blob of hydrogen gas ionized and forced outward by a hot, massive 9th-magnitude star near its center. William Herschel first spotted it in 1787, and it's observable visually with a moderately large aperture.
Details: *14½-inch Newtonian reflector, SBIG STF-8300M CCD camera, and Baader LRGB filters. Total exposure: 24.7 hours.*



► GETTING THE DROP ON MERCURY

Ralf Vandebergh

During May 9th's transit, amateur and professional observers alike watched intently for the *black drop effect,* captured here at 2nd contact (11:15 Universal Time), as Mercury's silhouette remained "connected" to the Sun's outermost edge. The effect seems illusory, but it's real (*S&T:* Oct. 2012, p. 20).
Details: *6-inch refractor, Sony DCR-TRV740 video camera, and green and double-polarizing filters. Exposure: 1⁄30 second.*

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

▶ **TRANSIT IN A NEW LIGHT**

Howard Eskildsen

Mercury's 7½-hour-long transit tested the patience of observers. This sequence, from 11:15:23 to 18:38:30 UT, shows the Sun as it appears at a wavelength of 393.4 nm (the Ca-K line).

Details: *Orion ED80 apochromatic refractor, Lunt B600 filter module, and DMK 21AU04.AS video camera. Colorized stack of sixteen 12-second images.*

▼ **CLASSIC SPIRAL**

John Vermette

Staring at us face-on from 21 million light-years away in Ursa Major, the Pinwheel Galaxy (M101) nearly matches the full Moon's apparent size.

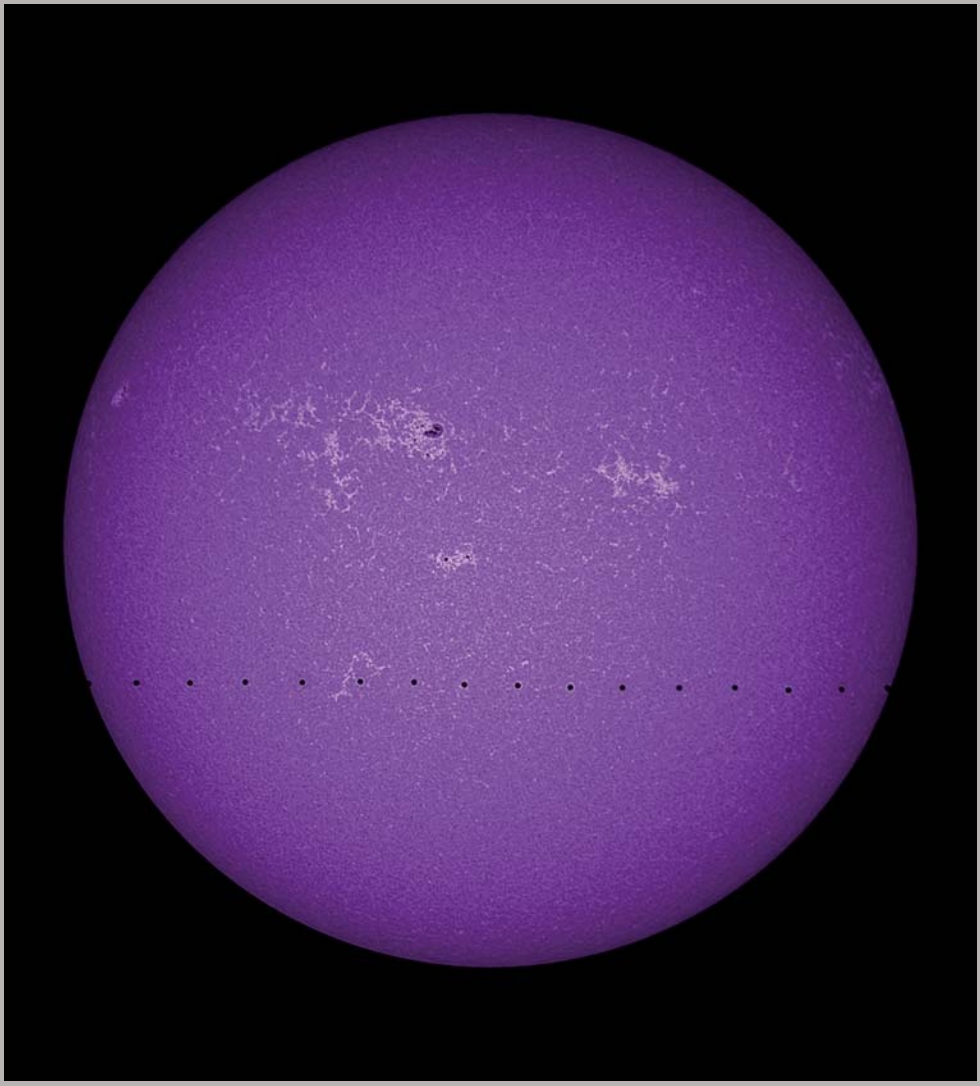
Details: *Hyperion 12.5-inch astrograph, SBIG STL-11000M CCD camera, and LRGB filters. Total exposure: 5.3 hours.*

▼▶ **BRIGHT AND EASY**

Bob and Janice Fera

A treat when spotted in even small telescopes, Messier 81 (Bode's Galaxy) is a 7th-magnitude gem in Ursa Major. The supermassive black hole in its core has a mass of 70 million Suns.

Details: *PlaneWave CDK17 astrograph and Apogee AltaU16M CCD camera used with Astrodon LRGB filters. Total exposure: 12.7 hours.*



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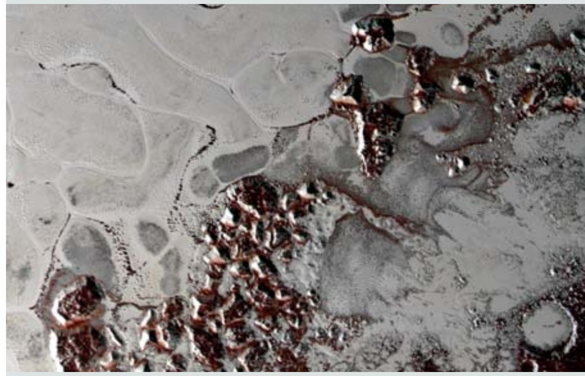

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A Tale of Two Books

First read decades ago, a pair of works still hold magic for an astrophysicist.

More than anything else, two books have shaped the arc of my astronomical life: *Starlight Nights* and *Norton's Star Atlas*.

Leslie Peltier's *Starlight Nights*, which I bought in 1965 when it was first published, showed a 15-year-old budding astronomer how much one could do with a simple telescope and a willingness to persist. I had already read biographies of the greats — Galileo, Brahe, Kepler. The life of George Ellery Hale, including his heroic efforts to build ever bigger telescopes, was fascinating. But all these lives were full of stress and turmoil.

Peltier's story was far more appealing to a teenager bitten by the stargazing bug. Look at the stars as often as you can. Never lose the sense of wonder and wonderful things will happen. Observing variable stars became my passion, and my career path was set.

More than 50 years later, I still reread it occasionally. That it is still available suggests that many others are reading it as well.

Norton's, first published in 1910, has had a long run and is still going; its 20th edition came out in 2003. I bought my copy of the 16th edition in 1975, when I was halfway through my graduate career in astronomy at Harvard. Somehow at that time I sensed that I needed to reconnect with the night sky. *Norton's* did the trick. To this day I believe that the hand-drawn pages in my edition are among the most beautiful star charts ever produced.

S&T: EDITORS' DOODLES MADE DURING MEETINGS; NORTON'S STAR ATLAS

Each chart has a sensibly large piece of sky on it, with stars to 6th magnitude. The map projection is close to the naked-eye sky, with star sizes that make it easy to navigate. But there is enough detail to locate with a small telescope most of the celestial sights it contains, and the pale-green Milky Way is perfect.

Early in my ownership, the individual chart pages began to fall out of my copy. So much the better: I only had to carry the relevant chart to the telescope.

My *Norton's*, and I suspect many other people's, is something more, however — a personal record of a lifetime of looking at the night sky. The heavy, slightly cream-colored pages beg for annotation with a soft pencil. Over more than five decades they have become crowded with predicted tracks for comets, the odd nova, and dates next to clusters and nebulae indicating the first time I found them. Mercury is there too. Uranus, Neptune, and bright asteroids are there many times. One page even went to Mali with me on a visit a few years ago so that I could try to locate the Magellanic Clouds.

I used soft pencils so I could later erase the marks. But I never did. Each sheet contains a piece of my astronomical life, my personal testament to how much can be done with a simple telescope, a willingness to persist, and a love of the night sky.

The spirits of Messrs. Peltier and Norton still have me in their grip. ✦

John Mariska, a research professor in physics at George Mason University, spent 34 years as an astrophysicist at the Naval Research Laboratory in Washington, DC. He still uses the telescopes he built as a teen growing up in Colorado.