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OCT. 2012 ISSUE

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- How to Catch X-rays
- Magellanic Mysteries
- Find the Outer Planets

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Photo Gallery

Image by
Stephen Mounioloux

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October 2012

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NASA / GSFC / SDO

On the cover: June's transit of Venus was a rare chance for exoplanet researchers to test their techniques.

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S&T TEST REPORT

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Robert Naeye
Spectrum

S&T's Award-Winning Authors

ARTICLES ABOUT SCIENCE rarely win high-profile journalism awards such as Pulitzer Prizes and National Magazine Awards. These honors often go to reporters and publications that cover business, politics, and society. Fortunately, however, scientific organizations have a deep appreciation for the importance of high-quality science journalism, and some of these groups give out awards on a regular basis.

If you've been reading my Spectrum columns for the past few years, you may recall that *S&T*'s senior contributing editor J. Kelly Beatty, along with contributing editors Jim Bell and Emily Lakdawalla, won prestigious awards for science popularization from the American Astronomical Society's Division for Planetary Sciences. Contributing editor Gary Seronik won the Simon Newcomb Award from the Royal Astronomical Society of Canada.

With this recent history, I'm very pleased to announce that the authors of two articles in our February 2011 issue (a special issued devoted to the Sun) have just earned 2012 Popular Writing Awards from the Solar Physics Division of the American Astronomical Society.

Daniel Baker (Director of the Laboratory for Atmospheric and Space Physics at the University of Colorado–Boulder) and James Green (Director of NASA's Planetary Science Division) won their award for the cover story of the issue, titled "The Perfect Solar Superstorm." This article describes how a repeat of 1859's extremely powerful solar storm could wreak havoc on economically advanced nations such as the U.S.

J. Kelly Smith, David L. Smith, and William L. Joyner won their award for the feature article "Solar Radio Astronomy." This story describes how interested amateurs can purchase and assemble inexpensive antenna/receiver kits to make scientifically important observations of the Sun at radio wavelengths.

Previously, science writer Kristina Grifantini won the 2010 Solar Physics Division Popular Writing Award for her cover story in the March 2009 *S&T* titled "Solar Impact."

It's a great honor for *S&T* to have our authors and articles recognized by leading scientific organizations. The *S&T* staff will continue to bring you stories written by top-notch scientists, science journalists, and amateurs to help keep you well informed about the latest and most important developments in astronomy.

Before closing, we have recently released an upgraded version of our *SkyWeek* app for Apple mobile devices. *SkyWeek Plus* sells for only $2.99. It provides an alert service to notify you of unexpected sky events such as powerful solar flares and bright novae. It also allows users to sync sky events with their electronic calendars.

Robert Naeye
Editor in Chief

Student Wins Big with Astronomy

In the February issue (page 8) you published a letter by our student, Laurent Joli-Coeur, in which he explained how he took a picture of a shadow cast by Jupiter. We thought you'd like to know that in May he won Best Project Award (which comes with a $10,000 cash prize) at the 2012 Canada-Wide Science Fair held in Charlottetown for that very project. His teachers are very proud of him!

Sonia Saumier
Collège Jean-de-Brébeuf
Montreal, Quebec

Comet Snuck on the Scene

I greatly enjoyed John Bortle's article on Comet Lovejoy (May issue, page 36). It truly was a spectacular comet. But despite Mr. Bortle's claim to the contrary, the comet was a visual daylight comet: Brian Day (NASA Lunar Science Institute) and I spotted it on December 16.825 (19:48 UT) just 19 hours 31 minutes after perihelion, when it was barely 4° from the Sun. We saw it through a stopped-down 16-inch Schmidt Cassegrain at 127× while observing from Foothill College Observatory in Los Altos Hills, California. It appeared to be about magnitude –1, with a small fan shape extending approximately 20 arcseconds. Sadly, we didn't have our cameras.

Rick Baldridge
Campbell, California

The Sound of Totality

In "The Quest for Totality" (July issue, page 36), Dean Regas quotes eclipse chaser Babak Tafreshi as experiencing nature's "sudden bizarre silence" during totality in Zambia in 2001. My experience of that eclipse was quite different: not only was everyone around me shouting and screaming, but a DC-3 vintage airplane used that exact moment to fly over our heads, adding the drone of its piston-driven propellers to the general excitement.

But I've known worse. During my very first total eclipse on February 26, 1979, viewed from Wolf Point, Montana, the town's sirens starting wailing at the exact moment totality began. And at the hybrid eclipse of April 8, 2005, which I watched from the deck of an old ship in the middle of the Pacific Ocean, the captain blew the ship's horn for the entire 29 seconds of totality. But we couldn't be mad at him: he had skillfully navigated our ship to sit right under the center of a hole in the otherwise overcast sky. We saw the corona and solar prominences in their full glory, too — horn blast notwithstanding.

Eli Maor
Morton Grove, Illinois

Will We Visit the Moon Again?

Forty-three years ago, on July 20, 1969, millions watched astronaut Neil Armstrong take his first historic step on lunar soil and proudly proclaim, "That's one small step for [a] man, one giant leap for mankind" (August issue, page 26). For one shining moment, it seemed that humanity took one giant leap into the future. So whatever happened to this American dream of exploring the universe? I look up at the Moon and wonder when we will go back. I look up at Mars and wonder whether we'll ever get there. Human exploration of the Moon, Mars, and beyond would restore national pride and bring purpose to our space program, and space exploration would be an incalculable investment in our future. The Apollo 11 lunar landing was an achievement that should still stir us to press on and chase the stars. Let us keep the dream alive and boldly step back into space.

Rick Schreiner
Norwalk, California

Venus's Atmosphere: Discoverer Debatable

We enjoyed Eli Maor's romp through the fascinating history of the 1761 transit of Venus (June issue, page 28), in which he mentions the great Russian scientist Mikhail V. Lomonosov's claim to the discovery of Venus's atmosphere. Lomonosov deduced the existence of an atmosphere from an analysis of various phenomena he observed from St. Petersburg. At the time, his argument appeared quite reasonable, but observations of the June 2004 transit strongly suggest that Lomonosov's aureole observations do not match the real thing.

After closely studying his original papers and observations, we think that the blurring he reported at first and fourth contacts was merely the manifestation of the black-drop effect, and the arc that he saw at second contact was nothing more than the appearance of a sliver of brilliant photosphere between the planet's black disk and the dark space beyond the solar limb. The third contact "blister" in particular was probably due to the same effect that causes Mars's polar caps to project over the planet's limb in a dark sky.

Though Lomonosov should not be credited with the discovery of Venus's atmosphere, he went beyond most astronomers of his era in actually investigating through observational evidence the physical nature of the other planets. See our recent *Journal of Astronomical History and Heritage* paper at **sites.williams.edu/transitofvenus2012**.

Jay M. Pasachoff
Williams College
Williamstown, Massachusetts
William Sheehan
Willmar, Minnesota

I disagree that Lomonosov's observations of the aureole can be dismissed. A comparison of Lomonosov's arc (the "blister") after the third contact with illustrations of the 1874 transit by Robert L. J. Ellery and Henry Chamberlain Russell — as well as with illustrations of the 2004 transit by Mario Frassati and images by Lorenzo Comolli — suggests that all the pictures show refraction by Venus's atmosphere. Other illustrations from Lomonosov's time also hint at refraction, albeit less conclusively. Lomonosov did not use the hair-thin brilliance at second contact as proof for Venus's atmosphere.

Critics also argue that Lomonosov's instruments were inadequate to observe such fine effects, but that argument was refuted during the recent 2012 transit. Using 18th-century Dollond two-lens achromat refractors similar to the one Lomonosov utilized and following his recipe for weak solar filters ("not-so-heavily smoked glass"), at least two U.S. observers saw the blister-like Lomonosov arc. This aureole appeared as either a full arc or an asymmetric partial one.

These observations, coupled with Lomonosov's own detailed description and the fact that he was the only one to give a correct physical explanation of the effect, put Lomonosov's claim to priority in the discovery of Venus's atmosphere on solid ground. Readers can decide for themselves by reading a translation of Lomonosov's original paper at **bit.ly/LannTc**.

Vladimir D. Shiltsev
Fermi National Accelerator Laboratory
Batavia, Illinois

For the Record

✷ *The illustration of Le Gentil in the June issue (page 31) was loosely based on a portrait of French mathematician Guillaume François Antoine, Marquis de l'Hospital. No known portrait of Le Gentil exists from his lifetime. Thanks to Robert van Gent (Utrecht University) for discovering the impostor.*

75, 50 & 25 Years Ago

Roger W. Sinnott

October 1937

Spotty Sun "[A]s 1938 approaches the number of sun-spots is rising to a novel maximum. Perhaps 1938 will top 1870, spottiest year in celestial annals. . . .

"Thus, this winter, northern lights should shimmer with more beauteous brilliance. Magnetic compasses should swirl crazily. Radio and long-distance phone service should suffer some disruption.

"As advance notice of strange events to come, short-wave police-calls with a maximum range usually of a mere fifty miles are being readily heard across the Atlantic."

But 1937–38 was just a typical peak in the roughly 11-year sunspot cycle. That of 1957 is now the all-time big one.

October 1962

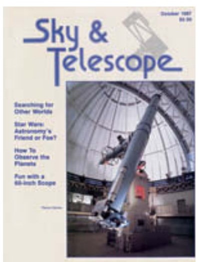
X-rays from Scorpius "Discovery of what apparently is an intense cosmic source of X-rays in the Scorpius region of the sky has been announced by Riccardo Giacconi, of American Science and Engineering, Inc., Cambridge, Massachusetts. X-ray sensors carried in an Aerobee rocket . . . were intended to measure fluorescence of the moon's surface under solar illumination. . . .

"As it turned out, the anticipated lunar X-ray flux could not be detected, even if present, because of interference from the Scorpius source, which was some 30 degrees west of the moon at that time."

The new source, Scorpius X-1, was later found to be a 12th-magnitude binary with a neutron star, the first X-ray emitter detected outside our solar system. Giacconi later won the Nobel Prize for launching X-ray astronomy.

October 1987

Hub of Our Galaxy "'The radio source Sagittarius A* defines the center of our galaxy,' said Don Backer (University of California, Berkeley) at the July meeting of the Astronomical Society of the Pacific. He and colleague Richard Sramek (NRAO) reached this conclusion by detecting no intrinsic motion of the source across our line of sight during observing runs with the Very Large Array between 1981 and 1986. These two astronomers also conclude that Sagittarius A* has a mass in excess of a few hundred Suns and an angular diameter smaller than Saturn's orbit. Thus, the radio emission is thought to be synchrotron radiation from matter being swallowed by a black hole."



The major update to Backer's assertion is the mass: stars found in tight orbits around Sgr A imply a central mass of more than 4 million Suns.*

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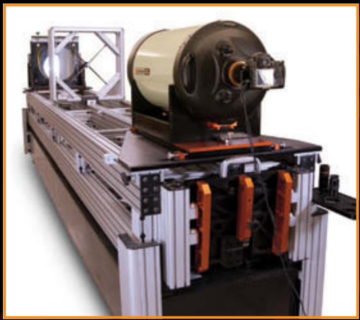

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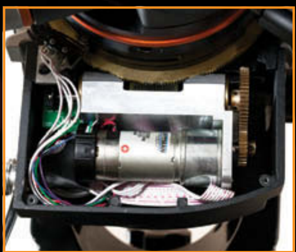
Telescopes, Eyepieces, Astrographs – Gregory Hallock Smith, Roger Ceragioli and Richard Berry



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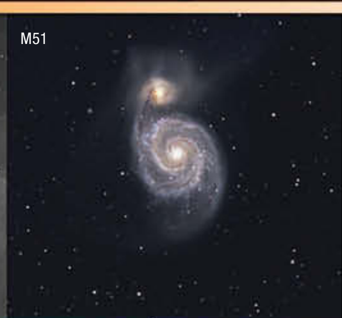
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The Moon


NGC 6946

Images by Andre Paquette with CGE Pro 1400 HD


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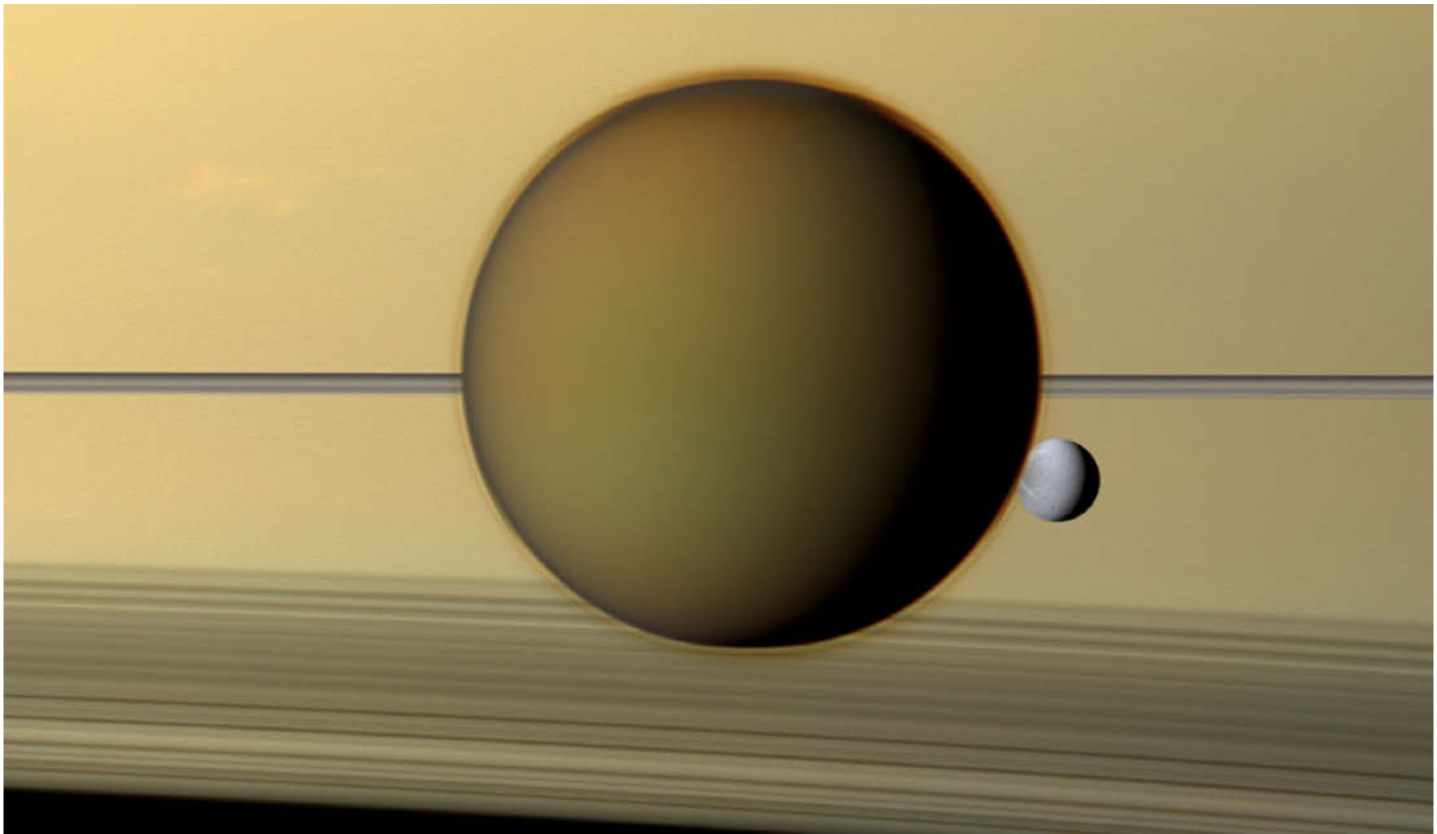
SOLAR SYSTEM | Titan's Lakes, Subsurface Ocean



Hazy Titan poses with Dione in front of Saturn's rings in this Cassini composite image taken on May 21, 2011. New research suggests Titan has methane lakes at its equator and a subsurface ocean.

NASA / JPL-CALTECH / SPACE SCIENCE INSTITUTE

Two different analyses of data from NASA's Cassini spacecraft argue once again that Saturn's largest moon is the solar system's most intriguing satellite.

The first study, presented by Caitlin Griffith (University of Arizona) and her colleagues in the June 14th *Nature*, used infrared images taken by Cassini to discover potential liquid methane (CH_4) lakes around Titan's equatorial region. Before now, the only hydrocarbon lakes observed have been in clusters at the moon's poles. These include the southern hemisphere's 6,000-square-mile (15,000-square-kilometer) Ontario Lacus. In 2005 the Huygens lander went splat on a methane-moistened dune at latitude 10° south, but theorists suspected that any tropical methane should be quickly whisked from the equator's dune fields to the cooler poles and dumped into the reservoirs there.

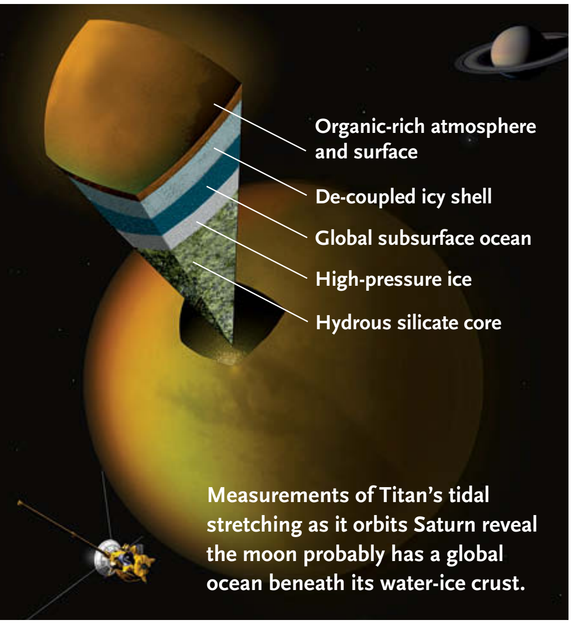
The new features appear in views taken at several infrared wavelengths during close flybys from 2004 to 2008. One oval, about 40 miles long, lies about 500 miles from the Huygens landing site and is too dark in infrared to be anything but liquid.

Other features are brighter and might be patches dampened by liquid methane a few inches deep. One of these patches actually lies within a dune field, reminiscent of an oasis on Earth.

The tropical lakes have only deepened the mystery of where and how Titan generates its methane. Hydrocarbons haven't rained down from the sky in enough volume to supply it, and although sunlight easily transforms methane into other compounds, methane is still the atmosphere's second most abundant constituent (after nitrogen). Researchers estimate that Titan needs to generate some 50 million tons of methane each year to keep its atmosphere enriched at present-day levels. Geological activity might help solve the enigma.

Methane lakes aren't the only thing lying beneath Titan's smog. Tidal flexing detected in the moon's crust suggests that the ice surface may conceal a global ocean, Luciano Iess (Sapienza University of Rome, Italy) and his colleagues reported online June 28th in *Science*. Planetary scientists have predicted a subsurface ocean since the 1970s, but the new results set

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



Measurements of Titan's tidal stretching as it orbits Saturn reveal the moon probably has a global ocean beneath its water-ice crust.

A. TAVANI

Titan firmly with Europa, Ganymede, and Callisto as moons with subterranean seas.

The researchers reached their conclusion after they carefully tracked Cassini's position during six close flybys of Titan from 2006 to 2011 and detected subtle Doppler shifts in the radio transmitter's signal. From these variations, the team deduced incredibly tiny changes in the spacecraft's line-of-sight velocity — as small as 75 microns per second (0.00017 mile per hour) — allowing them to map the moon's gravitational field and determine how Titan's shape changed during its 16-day orbit around Saturn. The team found that the moon's icy surface bulges outward by as much as 30 feet during its orbit. When the team did a second analysis that included data from other spacecraft encounters as well as astronomical observations, the results matched.

The only reasonable explanation is that the giant moon has a liquid water ocean inside, says geophysicist Julie Castillo-Rogez (Jet Propulsion Laboratory). This ocean lies anywhere from 30 to 60 miles down. The added squishiness in the moon's interior lets the icy crust deform.

What's still unknown is what lies beneath this subsurface ocean. Most speculations envision either a core composed of hydrated rock overlain by a mantle of high-density water ice, or a mishmash of rock and ice that never segregated into discrete layers.

■ **J. KELLY BEATTY**

MISSIONS

Nonprofit Group to Build Spacecraft

A private nonprofit group led by former astronauts, spacecraft designers, and asteroid specialists has proposed a spacecraft to find a half million asteroids in Earth-crossing orbits and provide advance warning of impact threats.

The B612 Foundation (named after the asteroid featured in Antoine de Saint-Exupéry's 1943 novella *The Little Prince*) is the second high-profile group of space entrepreneurs to announce asteroid-tracking plans (August issue, page 18). But unlike Planetary Resources' mining scheme, B612's objective is to find and track near-Earth objects (NEOs) that may pose a threat to our planet.

The proposed spacecraft, named Sentinel, could be launched as early as 2017 and will follow an elliptical, low-inclination orbit roughly at Venus's distance from the Sun. About the size of a small school bus, the spacecraft will have a 20-inch (0.5-meter) telescope and a single detector array recording infrared light from 5 to 10.4 microns, a range in which NEOs stick out like sore thumbs. That's because the asteroids heat up as they near the Sun, allowing the team to make reliable diameter estimates and easily track the objects regardless of how dark their surfaces might be in visible light.

The scope's big field of view, 5½° by 2°, will allow it to cover the entire sky every 26 days. Moreover, Sentinel will circle the Sun in about 7 months, "lapping" Earth every 2.2 years and permitting relatively rapid all-sky coverage. With multiple looks in each field of view, the team can follow newly discovered asteroids for up to three months, gaining data crucial to determining accurate orbits.

Sentinel is not equipped to determine the NEOs' chemical compositions from the infrared light emitted. That will require follow-up work by other groups, perhaps including Planetary Resources.

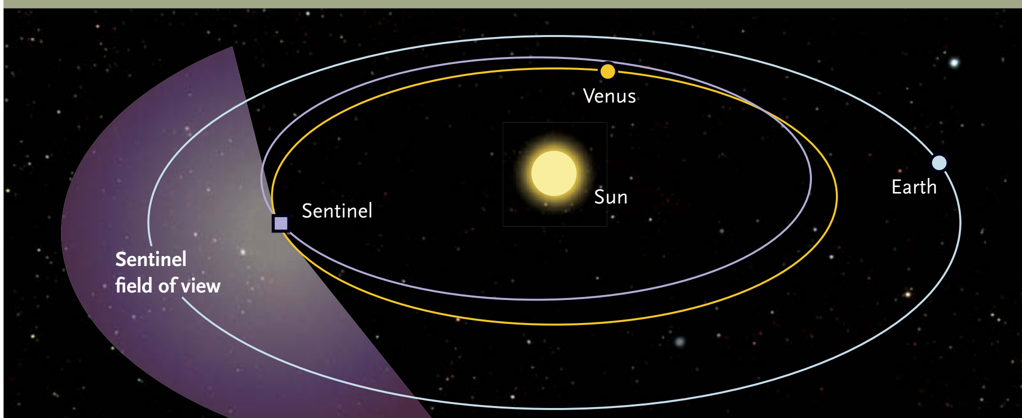
The B612 team estimates that Sentinel will sweep up 90% of NEOs with diameters of at least 460 feet (140 meters) over its planned 5½-year mission.

While Sentinel stands to become the first privately funded interplanetary mission, the B612 Foundation will have some government partners. Thanks to a Space Act Agreement signed this past June, NASA has agreed to provide experts to review plans for Sentinel and its mission and use its team of dynamicists to provide asteroid orbit calculations and threat assessment. Spacecraft tracking and communication will also use the agency's Deep Space Network.

The B612 team hopes that, if dangerous NEOs are detected early enough, scientists can find ways to alter their orbits enough to avoid a Tunguska- or extinction-level event (*S&T:* December 2010, page 22).

B612 cofounder and former astronaut Ed Lu says Sentinel itself will cost a few hundred million dollars to build, and they'll need about that much again to pay for the planned SpaceX Falcon 9 launch vehicle and mission operations. Fundraising is underway.

■ **J. KELLY BEATTY**



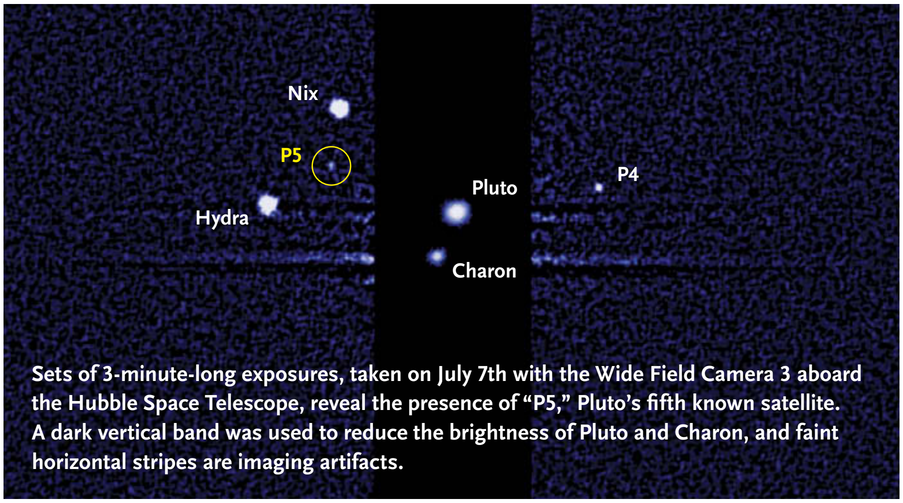
If private funding can be found, the B612 Foundation plans to launch its Sentinel spacecraft in 2017 to scan for near-Earth asteroids from a Venus-like orbit around the Sun.

S&T: LEAH TISCIONE, SOURCE: B612 FOUNDATION / BALL AEROSPACE

KUIPER BELT | Pluto Sports Fifth Moon in Step with Other Four

The logistics of the 2015 Pluto flyby by NASA's New Horizons spacecraft just became more complicated: the dwarf planet turns out to have a fifth moon.

Announced July 10th by the IAU's Central Bureau for Astronomical Telegrams, P5 — officially S/2012 (134340) 1 — gleams at magnitude 27, which puts its diameter somewhere between 6 and 15 miles (10 and 25 kilometers), depending on the moonlet's surface reflectivity. The orbit is still somewhat uncertain, but P5 appears to circle in the same plane as Pluto's other satellites at roughly 26,000 miles out. That puts the body nearer to Pluto than Nix, Hydra, and the not-yet-named P4 (*S&T*: October 2011, page 12), though not nearly as close as Charon.



Sets of 3-minute-long exposures, taken on July 7th with the Wide Field Camera 3 aboard the Hubble Space Telescope, reveal the presence of "P5," Pluto's fifth known satellite. A dark vertical band was used to reduce the brightness of Pluto and Charon, and faint horizontal stripes are imaging artifacts.

M. SHOWALTER ET AL. / NASA / STSCI

Led by long-time Pluto-watcher Mark Showalter (SETI Institute), the nine-member discovery team took advantage of Pluto's opposition on June 29th to take 14 sets of images from June 26th to July 9th with Hubble's Wide Field Camera 3. At 31¼ astronomical units (2.9 billion miles) away, Pluto and P5 were 1″ apart and the moonlet was 100,000 times fainter than the dwarf planet. "I continue to be amazed at what Hubble can do with fine-tuned observations," Showalter says.

All five moons probably formed from debris tossed out when a renegade object struck Pluto long ago. Collisions in this distant region of the solar system are typically so slow that most of the resulting fragments couldn't have reached escape velocity, which is a bit under 1 mile per second for Pluto. Ballistically speaking, the stuff should just have fallen back onto Pluto, so tidal interactions among the large chunks must have allowed what became Charon and the other moons to remain in orbit around Pluto's equator.

Astronomers are carrying out this careful census of Pluto's extended family because small objects and rings might pose a danger to New Horizons as it zooms through the system at 32,000 miles per hour on July 14, 2015. Plans now call for the spacecraft to pass well inside Charon's orbit, at a point about 6,000 miles from Pluto.

■ **J. KELLY BEATTY**

DARK MATTER | Invisible Thread Revealed

For the first time, astronomers have detected an individual dark-matter filament between galaxy clusters, Jörg Dietrich (University Observatory Munich, Germany) and his colleagues reported in the July 12th *Nature*. Although scientists have detected hints of dark matter's network before and shown that the cosmic web's intersections closely align with the positions where galaxies bunch into clusters (April issue, page 12), the dark-matter strands that theoretically link clusters have remained undetected until now.

Dietrich's team looked at the Abell 222/223 supercluster system, a gigantic group of galaxies roughly 3 billion light-years away in the constellation Cetus. Combining observations of the system by the National Astronomical Observatory of Japan's 8.2-meter Subaru Telescope in Hawaii and the European XMM-Newton space telescope, the team detected a filament connecting the supercluster's two main components as it weakly lensed distant galaxies' light. The only visible material was a hot, wispy gas tail between the clusters, but the team calculated that this cloud accounted for at most 9% of the mass in the area. The remainder, says Dietrich, is dark matter.

The cosmic web's individual strands are difficult to detect not only because dark matter is invisible, but also because it's so diffuse. The filaments are roughly pole-like in shape, and most are oriented vertically from our perspective, so we look through their sides instead of along their lengths. But the strand connecting Abell 222 and Abell 223 happens to be pointing roughly along our line of sight, so we look straight down the barrel. This orientation puts more material between us and the light sources beyond the clusters, which enhances the gravitational lensing effect and makes the dark matter detectable.

Such specific orientations are rare, which might explain why the filaments have gone undetected until now. But Dietrich has high hopes that similar discoveries lie just around the corner as data from the Sloan Digital Sky Survey and the upcoming Dark Energy Survey expand the catalogs of galaxy clusters. "We are in a great age of observational cosmology," he says.

■ **STEPHEN P. CRAFT**

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SOLAR SCIENCE | Waves Might Heat Sun's Atmosphere

Two new studies in the *Astrophysical Journal* suggest a possible solution to the mystery of why the solar corona is 100 times hotter than the chromosphere below it. Perhaps more convincingly, the solution — *Alfvénic waves* — might also explain how the fastest particles in the solar wind attain such high speeds.

Alfvénic waves are oscillations that move along magnetic field lines like vibrations in a plucked string. Scientists first suggested them as a driving force behind both the corona's heat and the acceleration of the fast solar wind in the 1940s, but they weren't observed in the corona until 2007, when a team including Scott McIntosh (National Center for Atmospheric Research) caught sight of them. Last year, McIntosh and his colleagues discovered that these waves permeate the corona.

Now, two independent teams have cemented the key role these magnetic vibrations play on the Sun. The teams used the Extreme Ultraviolet Imaging Spectrometer on Japan's Hinode spacecraft to observe a hole in the corona over the Sun's south pole. In coronal holes the Sun's magnetic field lines stream out straight, instead of curving back down again in big loops. The particles that make up the fast solar wind whiz forth from these regions, zooming through space at 800 kilometers per second (2 million miles per hour).

The teams observed spectral-line broadening in the corona's hot, ionized gas to measure how much energy the Alfvénic waves carry at different heights. Determining the lines' widths allows astronomers to detect the waves, because the waves slosh the corona's ions back and forth along the line of sight at a velocity that depends on the waves' energy.

Both teams, a trio made up of Michael Hahn (Columbia University) and his colleagues, the other a duo comprising Alessandro Bemporad and Lucia Abbo (National Institute of Astrophysics, Italy), found that the Alfvénic wave energy dropped off rapidly within the lowest quarter or so of the solar atmosphere. The drop suggests that the energy is somehow being dumped into the corona's lowest region, where temperatures already reach 1 million kelvin. This energy is then conducted by particle motion throughout the corona. Hahn's team also calculated that the energy dissipated could provide up to 70% of that needed to heat the polar coronal hole and accelerate the fast solar wind. (The lower limit is still zero.)

Coronal holes are cooler than other parts of the Sun, and magnetic waves appear to deposit more energy in the cooler regions than in the atmosphere's warmer parts. How much Alfvénic waves could contribute to the corona's temperature overall — or even how their energy is deposited in the first place — is unclear.

McIntosh says he's excited that people are probing this enigmatic energy source in the Sun's atmosphere. But while he's convinced the waves have an impact, he's not so sure they're needed to heat the material in the coronal holes. Jets shooting up from the chromosphere might do that just fine. Riding these jets, the waves could then accelerate the jet-heated ions and send them rocketing into space.

Other researchers vote instead for energy bursts released when magnetic field lines snap into new configurations or even "magnetic tornadoes" channeling energy up from below.

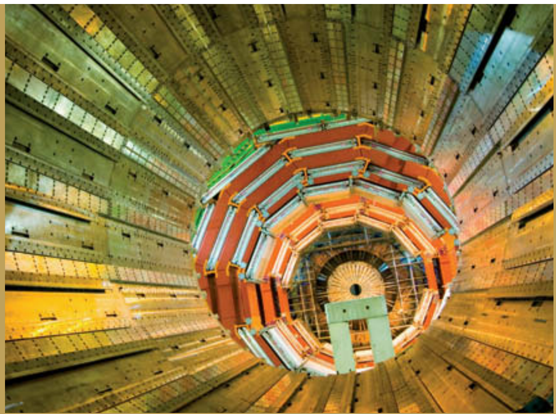
■ **CAMILLE M. CARLISLE**

PARTICLES | Higgs Hype Merited

On July 4th physicists using the proton-smashing Large Hadron Collider near Geneva, Switzerland, announced their discovery of a "Higgs-like particle." Just as the photon is the particle associated with an electromagnetic field, the Higgs boson is the particle associated with the Higgs field, the theoretical field that permeates space and imparts mass to particles depending on how strongly they interact with it.

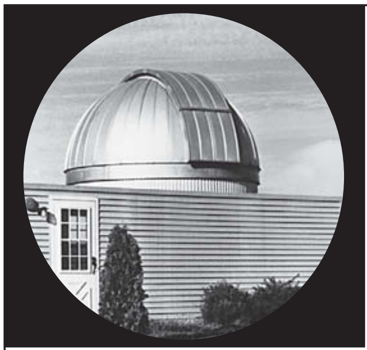
The LHC announcement wasn't a surprise: it was the culmination of several years of hints and upholds the wonderfully successful Standard Model of particle physics. Physicists first predicted the Higgs boson in the early 1960s, and its detection is yet another demonstration of the predictive power of science. By upholding current theories, the detection gives physicists confidence they're heading in the right direction in their quest to understand the universe.

The LHC results put the Higgs-like particle at about 125 billion electron volts, 133 times more massive than a proton. According to the LHC team, there's only about 1 chance in 3 million that the signals detected are a statistical fluke, assuming there are no systematic errors. (Systematic errors are what led to the recent faster-than-light neutrino result: a faulty yardstick ruins even careful measurements.) The work used two experiments at the LHC, including the Compact Muon Solenoid (shown here), which detects protons smashed together with energies of up to 8 trillion electron volts.


SCIENCE AND TECHNOLOGY FACILITIES COUNCIL

The work might also lead to new physics. Some theories predict more than one type of Higgs particle, so as the LHC cranks up the energy of its collisions it might bust open entirely new particles — perhaps particles responsible for dark matter or something completely unexpected. ✦

■ **ROBERT NAEYE**



Lagoon Nebula Region in Hα
ProLine PL16803 | John Gleason

It All Started with Mariner 2

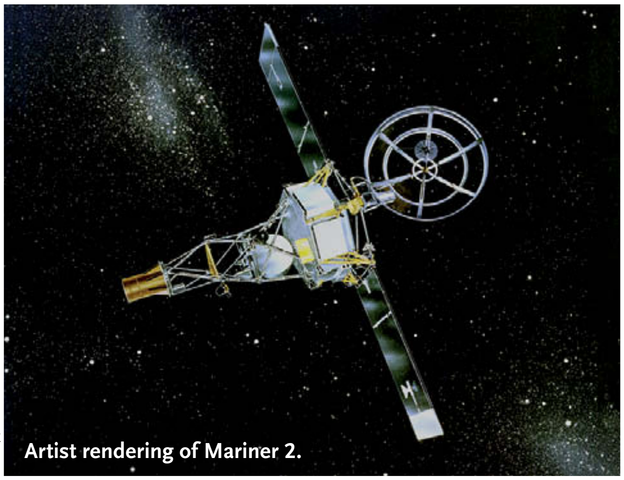
Fifty years ago this August, with the launch of Mariner 2 toward Venus, something profoundly new appeared around the Sun.

THE PLANETS in our solar system began coalescing 4.6 billion years ago from the whirling disk of debris cooling around the infant Sun. As they gained in mass, they invited a cosmic barrage of ice, rock, and metal that tapered and swelled in waves until the great accretion was complete a few hundred million years later.

On Earth, as the impact blasts died down, the surface and atmosphere cooled. Lava and steam gave way to rock and rain. Organic molecules began to complexify, and then, wonder of wonders, started to reproduce themselves. This unleashed 4 billion years of biospheric activity. Very recently, all of this evolving finally produced an inquisitive species that looked, with wonder and calculation, to the skies, becoming aware of those other sibling worlds born of the same pre-solar cloud. Curiosity and imagination begat technology. Earth's deep gravitational well became a solvable problem. We were no longer stuck here.

Fifty years ago, on August 27, 1962, our planet's accretion began a curious reversal. Earth started hurling pieces of matter back out into the wider solar system from which, long ago, everything once fell. Our fragile, instrument-laden metallic bugs began to cross the interplanetary void, seeking perspective on our origins and place.

The first of these probes to reach its target was NASA's Mariner 2 to Venus. With an audacious flyby on December 14, 1962, humanity began to gather the missing pages of our origin story, scattered throughout the solar system among the ancient surfaces and alien clouds of our brethren worlds.



NASA / JPL

Artist rendering of Mariner 2.

Mariner 2 showed that Venus's mysterious microwave brightness was, as some had proposed, coming from the surface and not the upper atmosphere. This told us that our "twin planet" was too hot for surface water and our kind of life. And it posed a puzzle about climate evolution: how could two such nearby and similar worlds evolve such different surface environments?

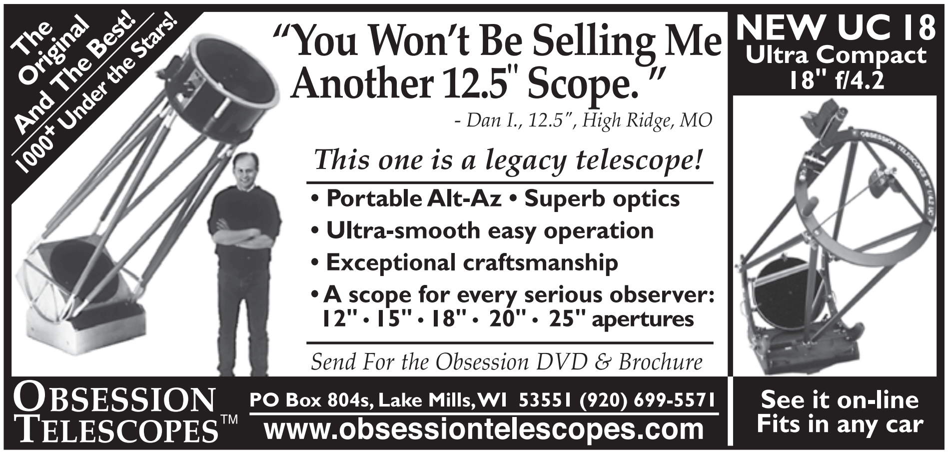
In the ensuing 50 years we've sent spacecraft to all of the terrestrial and giant planets, and New Horizons is approaching the ice-dwarf planets that ring our solar system. We have also confirmed that our planetary system is not a freak of nature.

In this same time span, Earth's human population has more than doubled and atmospheric carbon dioxide has increased by nearly 25%. Some say we've entered a new geological era, the "anthropocene," in which human activity dominates changes occurring on our planet. If we're not running this place already, sooner or later we will be if present trends continue. But do we really know what we're doing? Nobody gave us an operating manual. We had better figure out how planets work.

In the next 50 years we'll learn a lot more by continuing to explore our local planets and characterizing the variety of planets around other stars. The next generation of Venus missions will follow the trail blazed by Mariner 2. They will search for the secrets of ancient climate change by looking under the hood at the engine of another Earthlike planet.

"Human history becomes more and more a race between education and catastrophe," wrote H. G. Wells nearly a century ago. The legacy of Mariner 2 and its successors is a crash course in comparative planetology that may help us win that race. ✦

David Grinspoon *was recently appointed to be the first Chair of Astrobiology at the Library of Congress. Follow him on* ***Twitter@DrFunkySpoon****.*



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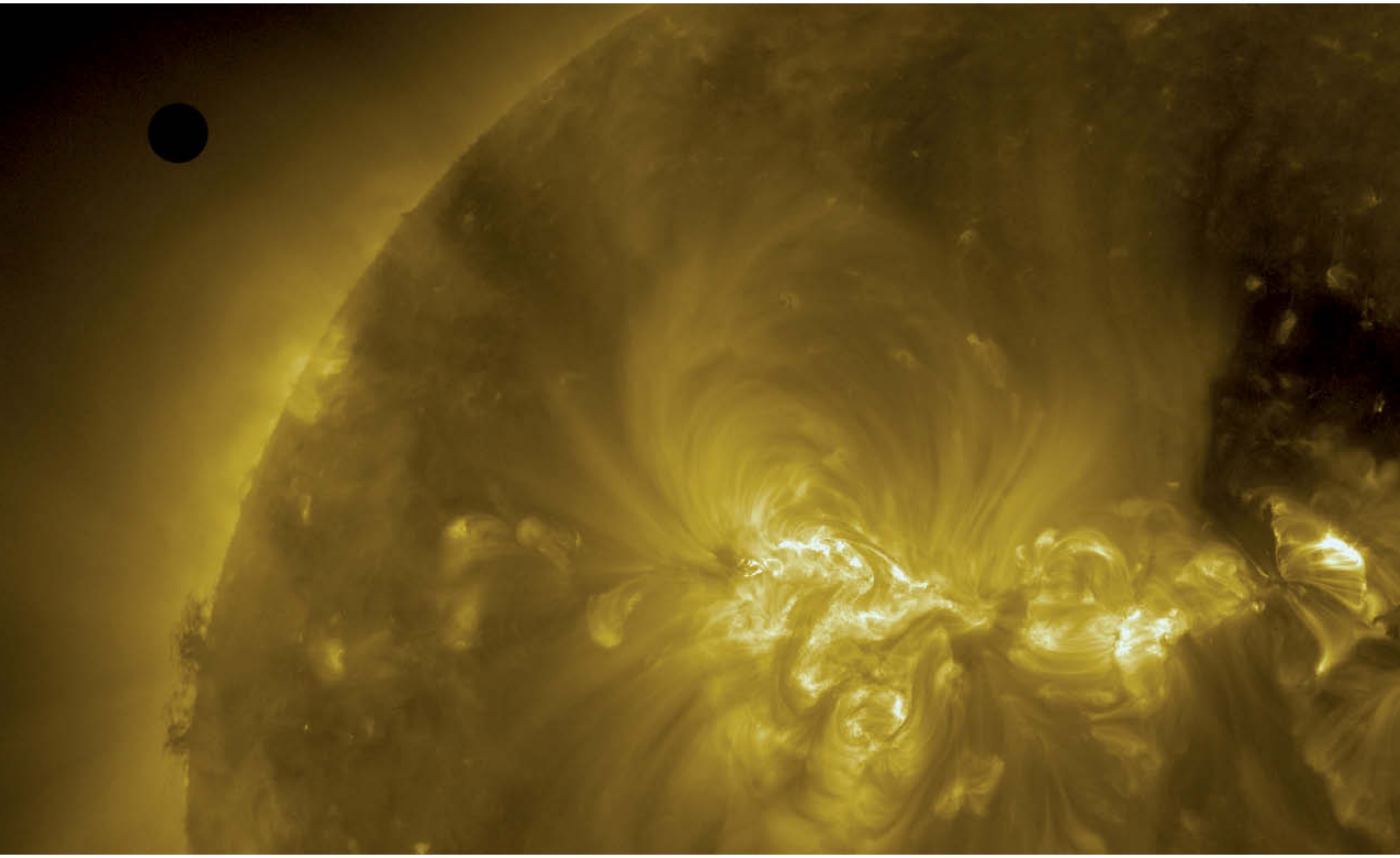
Background image taken by Michel Lefevre, winner of the 2011 ATIK Imaging Competition.

A Glorious Transit of Venus

JAY M. PASACHOFF

Millions of people saw **June's transit of Venus**, but for research astronomers, it was a golden opportunity to advance science.



NASA / GODDARD SPACE FLIGHT CENTER / SDO

The most extraordinary predictable astronomical events of this new millennium — the 2004 and 2012 transits of Venus — have come and gone. Even total solar eclipses, commonly thought of as rare, can be seen somewhere in the world every 16 months or so. But transits of Venus now come in 8-year pairs with a gap of either 105½ or 121½ years before the next pair. So only the youngest of today's children might see the next pair of transits, in 2117 and 2125.

A coterie of scientists around the world endeavored to use ground- and space-based resources to make the most complete record possible of the 2012 transit across much of the spectrum. Public education programs and published articles brought tens of millions of people out to see the event across North America and around the world. My colleagues and I were particularly eager to use this rare transit opportunity both to study Venus's atmosphere and to help astronomers who want to hone their techniques for characterizing transiting extrasolar planets.

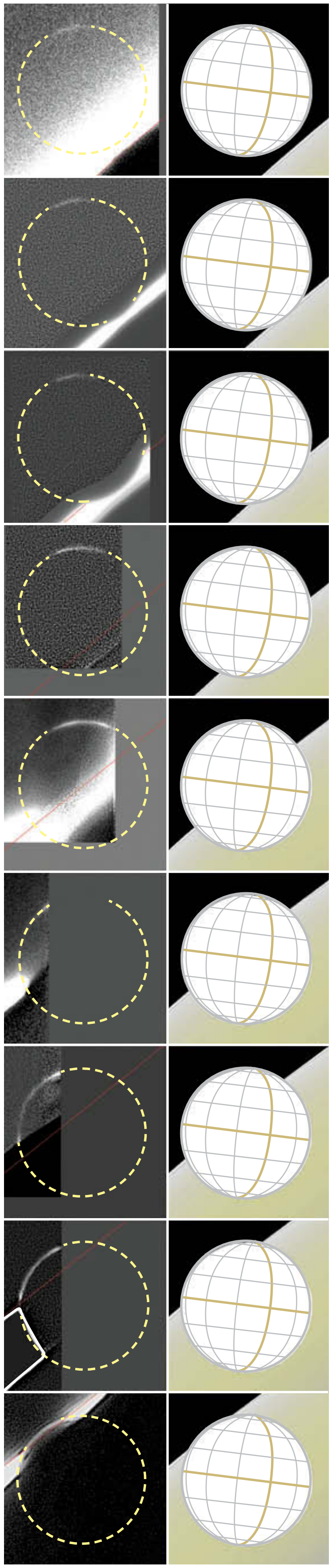
The 2004 Transit of Venus

When the 2004 transit of Venus came around, no human alive had ever seen such an event. However, the Galápagos tortoise Harriet, who died in an Australian zoo in 2006, was reportedly collected by Charles Darwin in 1835 — so she could have seen the 19th-century transits.

In the run-up to the 2004 transit, Brad Schaefer (Louisiana State University) realized that most of the published explanations of the so-called *black-drop effect,* widely attributed to Venus's atmosphere, were incorrect. This effect refers to the extended black link that connects Venus's silhouette when it's fully onto the Sun's disk with the black sky outside the Sun. For a minute or so at second and third contacts, this black drop had prevented observers from accurately measuring the exact contact times. Since Edmond Halley in 1716 had worked out a method of using accurate timing of a transit of Venus to triangulate the Earth-Sun distance, the black-drop effect frustrated human measurements of the size and scale of our solar system (June issue, page 28).

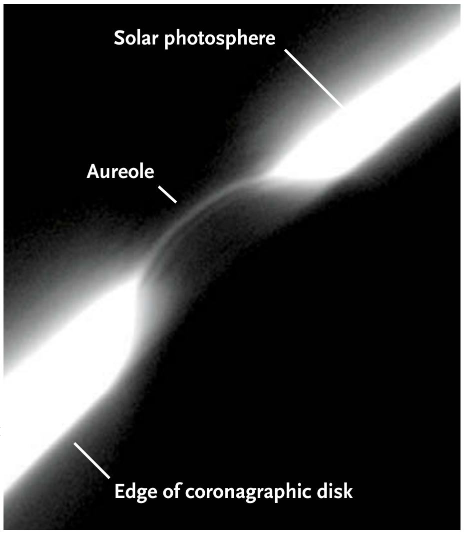
After hearing Schaefer present his paper, I recruited Glenn Schneider (University of Arizona) to reprocess and analyze archival Sun images during the 1999 transit of Mercury that we obtained from NASA's Transition Region and Coronal Explorer (TRACE) spacecraft. Since Mercury has essentially no atmosphere of any significance, and TRACE observed from

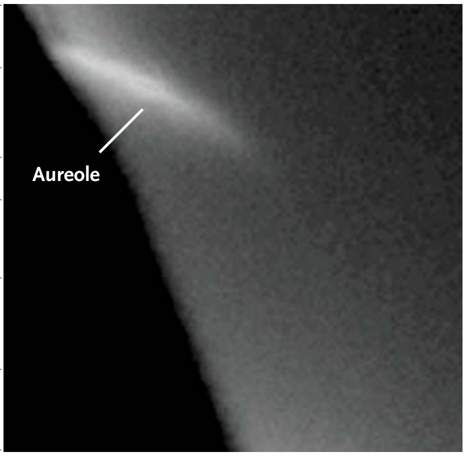
LET THE TRANSIT BEGIN! **NASA's Solar Dynamics Observatory, observing the Sun in ultraviolet light at a wavelength of 17.1 nanometers, caught the silhouette of Venus in front of the corona many minutes before the transit officially began at first contact.**



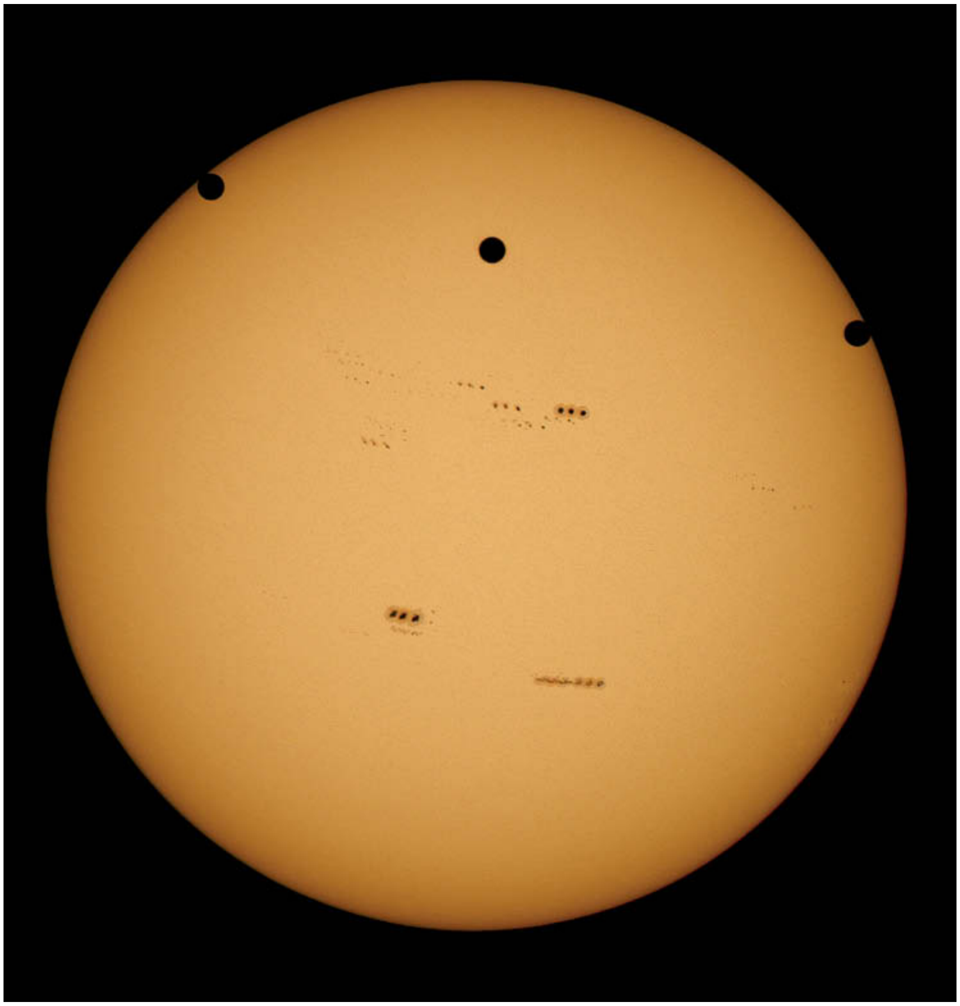
AUREOLE EVOLUTION **This sequence of nine composite images taken by the coronagraph on Haleakalā shows how Venus's atmospheric arc (aureole) changed from just before first contact to moments before second contact. Next to each image is a model of Venus's actual geometry relative to the solar limb at that point in time. Each image is a combination of up to 10 individual 0.5-millisecond frames taken during moments of good seeing. Venus's disk is 57.8 arcseconds (80 pixels) across.**

J. PASACHOFF / G. SCHNEIDER / B. BABCOCK / M. LU / T. WIDEMANN / P. TANGA / WILLIAMS COLLEGE TRANSIT OF VENUS EXPEDITION





J. PASACHOFF / G. SCHNEIDER / B. BABCOCK / M. LU / T. WIDEMANN / P. TANGA / WILLIAMS TOV EXP. (2)



R. DANTOWITZ (CLAY CENTER) / J. PASACHOFF / WILLIAMS COLLEGE TOV EXPEDITION / ET AL.

DIFFERENT VIEWS OF THE TRANSIT **With the coronagraph on Haleakalā and a CCD camera shooting at about 7 frames per second, the Williams College team used "lucky imaging" techniques to combine many short exposures during moments of good seeing. The resulting images captured Venus's aureole 1 minute before second contact (*top left*) and about 3 minutes after third contact (*above left*). Ron Dantowitz assembled this composite image (*above right*) based on three images taken with his 4-inch Takahashi refractor on Haleakalā. The Sun's slow rotation during the 6 hours from second to third contact is readily apparent in the repeated sunspots.**

above Earth's atmosphere, the fact that the transit of Mercury showed a black-drop-like effect proved that no atmosphere was needed to provide such a distortion. We also showed that solar limb darkening is an important contributor. The hot ball of gas we know as our Sun appears to have an "edge" because our line of sight changes from opaque to transparent over a very small angle. The Sun dims drastically over that tiny interval, interacting with optical limitations on telescopes that are imaging a dark disk to create the black-drop effect.

Since we wanted to see black drops at ingress and egress, our group observed the 2004 transit of Venus from Greece, where the entire event was visible. We also worked with scientists on the TRACE team. Some 15 minutes before second contact, when Venus was not even halfway onto the Sun, a thin, bright arc (known as an *aureole*) appeared on Venus's trailing limb. It was sunlight refracting through Venus's upper atmosphere! We saw the aureole brighten as Venus approached second contact, corresponding to more of this upper atmospheric layer (the *mesosphere*) bending sunlight toward Earth. We noted how the brightness varied along this arc. Such an aureole had been drawn by Australian observers during the 1874 transit, though few 21st-century astronomers had expected it to appear so prominently.

Working with scientists in France, we studied 2004 transit observations to pin down the aureole's relation with Venus's latitudinal winds, and we satisfactorily matched models of mesospheric aerosols. These studies also helped us decide what types of spectral observations we should make during the 2012 transit.

Planning for 2012

Schneider and I decided to focus our 2012 observations on studying how Venus's aureole changes over time. Again wanting a location where the entire transit would be visible, I chose the University of Hawaii's solar observatory on Haleakalā, a 10,000-foot volcano that towers over the east end of Maui (we observed the 2006 transit of Mercury from this site). The National Solar Observatory also granted us time on its Dunn Solar Telescope at Sacramento Peak in New Mexico, where staff astronomer Kevin Reardon operates a state-of-the-art spectrograph.

But our group was just one of many teams who planned to glean new science from the transit. Scientists at the Kitt Peak National Observatory in Arizona observed the transit with all three solar telescopes, doing spectroscopy and imaging. We also worked with scientists using the Big Bear Solar Observatory's New Solar Telescope in California to study the aureole and the development of the black-drop effect.

At a 2011 meeting of solar astronomers, I asked the key scientists of several spacecraft instruments if they could make extensive and improved transit-of-Venus observations. I am grateful that all of these scientists were receptive, including those working on NASA's Solar Dynamics Observatory, a successor to TRACE. For example, Phil Scherrer (Stanford University), who runs SDO's Helioseismic Magnetic Imager, enthusiastically agreed to modify the usual observing program to optimize transit observations. Unfortunately, the European Space Agency's Solar and Heliospheric Observatory (SOHO) would not be in a position from where Venus would transit the Sun.

Several of my colleagues also attended a 2011 planetary science conference and met with the chief scientists of ESA's Venus Express orbiter. These researchers realized that merging transit observations with their up-close spacecraft observations could provide new science. Each time Venus Express looks at a sunrise or sunset, it looks from a different position above Venus's atmosphere, which itself is constantly changing. By providing observations at one instant of an entire arc of Venus's mesosphere as it refracts sunlight toward Earth, we could help refine the spacecraft's observations and calibrations.

Thomas Widemann (l'Observatoire de Paris-Meudon, France) and Paolo Tanga (l'Observatoire de la Côte d'Azur, France) assembled an international collaboration called the Venus Twilight Experiment to monitor the transit. Widemann and Tanga built a set of nine identical coronagraphs — refractors with 4-inch lenses and occulting disks that could blot out the Sun's blazingly bright photosphere to better reveal the aureole. Two of these coronagraphs were stationed at the highest altitudes; we used one of them on Haleakalā, and another team observed from a 9,000-foot site in the Tian Shan mountains of Kazakhstan. These coronagraphs had filters that passed only blue light.

The other seven coronagraphs were stationed on the Japanese island of Hokkaido; on the island of Nuku Hiva in the Marquesas Islands; at the solar observatory at Udaipur, India; on Mt. Isa in Queensland, Australia; on Svalbard, an Arctic island governed by Norway; and at Lowell Observatory in Arizona, the last with a pair. Tanga used one of the Lowell instruments for CCD imaging, and historian of science (and *S&T* contributing editor) William Sheehan looked through the other to find out if he could see the aureole with his own eyes. The coronagraphs had different filters so we could investigate how aerosol droplets in Venus's upper cloud decks absorb light at different wavelengths. Coronagraphs and other solar telescopes in Mongolia, Slovakia, and China were also part of our network.

EMIL IVANOV

TRANSIT OVER THE BLACK SEA **Astrophotographers also had a field day with the transit. This sunrise image from Bulgaria shows Venus halfway across the Sun's disk.**

What We Saw

Besides Glenn and me, our Williams College Transit of Venus Expedition included my Williams colleague Bryce Babcock and undergraduate student Muzhou Lu. Team members arrived on Maui during the week before the transit.

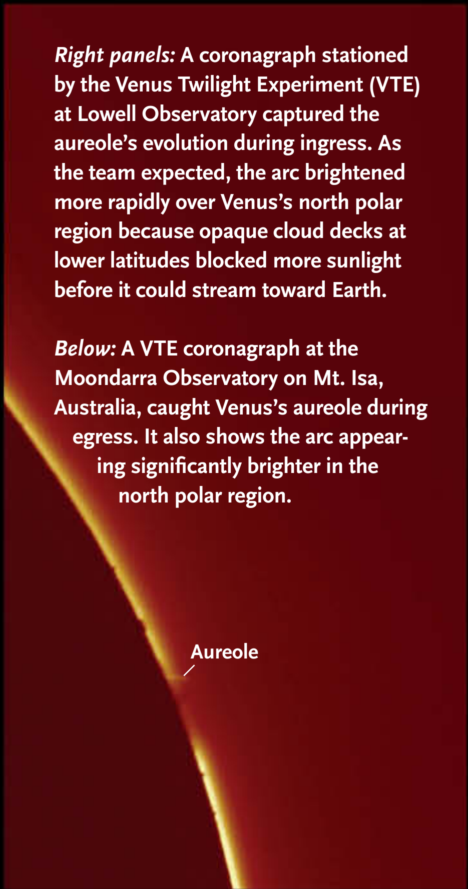
RAISHA FRIEDMAN / WILLIAMS COLLEGE TRANSIT OF VENUS EXP.

SUCCESS FROM HALEAKALĀ **From left to right: John Beattie, Michael Gill, Aram Friedman (front), author Jay Pasachoff (in back, wearing a lei), Glenn Schneider (back), Joel Moskowitz (front), Robert Lucas, Muzhou Lu, and Bryce Babcock are all smiles after successful ingress observations.**

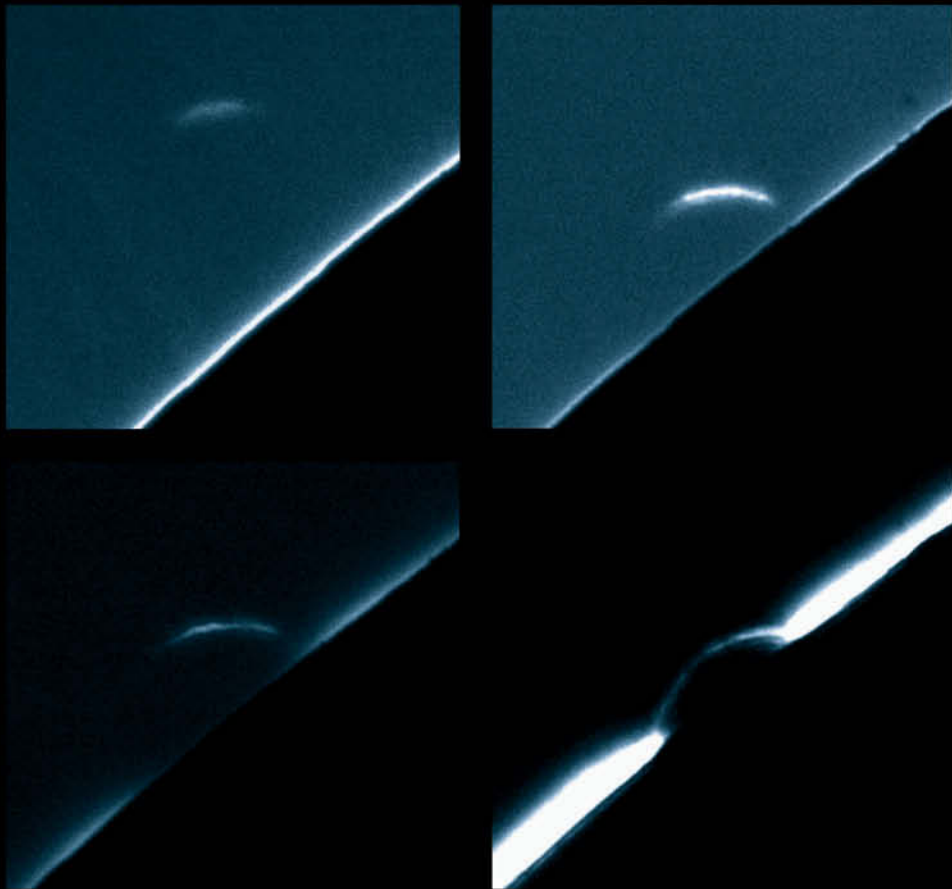
FROM AROUND THE WORLD

Right panels: A coronagraph stationed by the Venus Twilight Experiment (VTE) at Lowell Observatory captured the aureole's evolution during ingress. As the team expected, the arc brightened more rapidly over Venus's north polar region because opaque cloud decks at lower latitudes blocked more sunlight before it could stream toward Earth.

Below: A VTE coronagraph at the Moondarra Observatory on Mt. Isa, Australia, caught Venus's aureole during egress. It also shows the arc appearing significantly brighter in the north polar region.

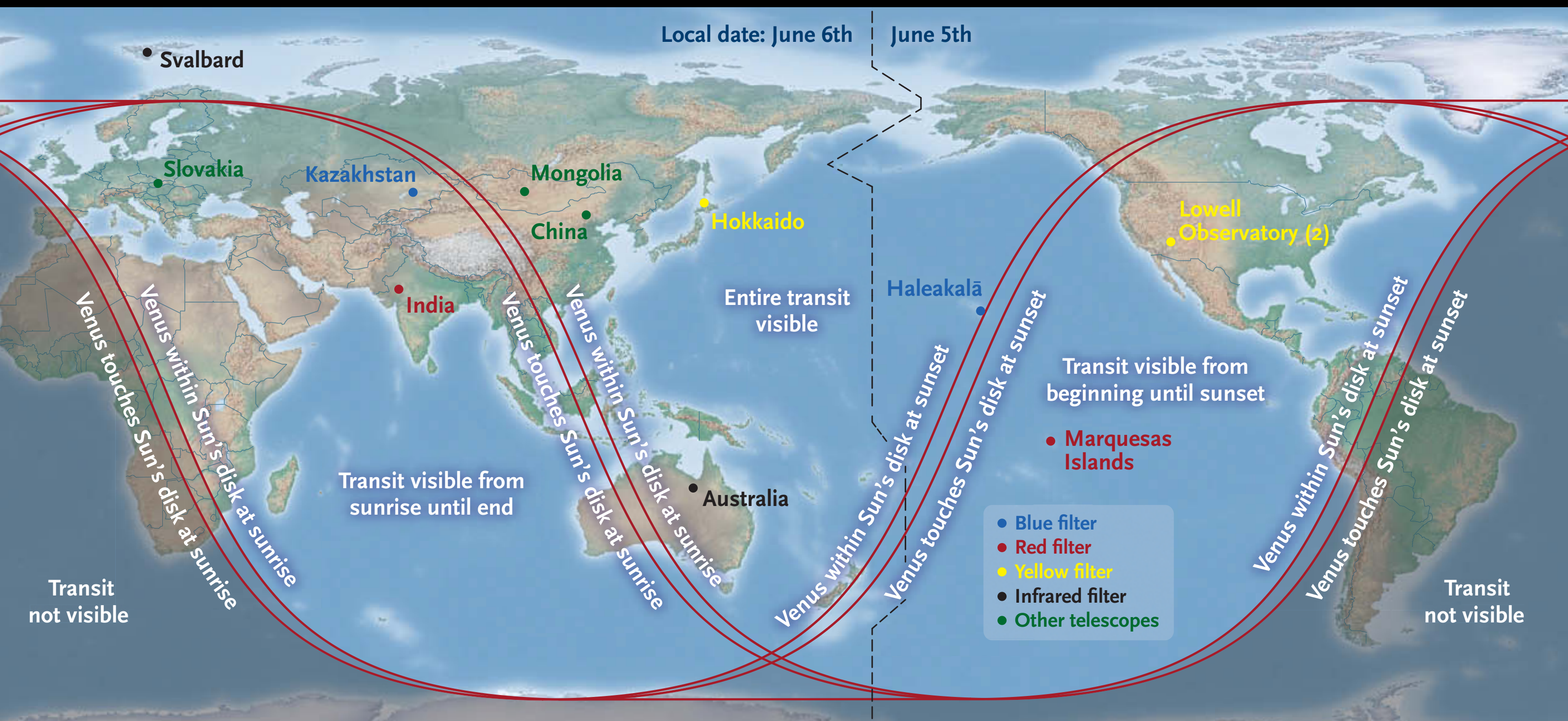


F. BRAGA-RIBAS (OBS. DE PARIS/LESIA) / L. FULMAN (MOONDARRA OBS.) / P. TANGA / T. WIDEMANN / VENUS TWILIGHT EXPERIMENT



P. TANGA / T. WIDEMANN / VTE (4)

TELESCOPE LOCATIONS



The dots on this map show the locations of the nine coronagraphs built in France specifically for June's transit of Venus as part of the Venus Twilight Experiment. Other telescopes in the network were stationed in Slovakia, Mongolia, and China. MICHAEL ZEILER / ECLIPSE-MAPS.COM

We worked with University of Hawaii scientists on the use of two telescopes inside the Mees Solar Observatory dome. We set up our coronagraph and various cameras and telescopes outside a nearby dome, to shield them from the wind as much as possible. We borrowed a sturdy Paramount ME German equatorial mount to provide some hope that we could keep the telescopes properly pointed in case of strong winds. We also used "lucky imaging," taking many very short images and selecting and aligning only the best shots.

Ron Dantowitz of the Clay Center Observatory in Brookline, Massachusetts, joined us with his 4-inch Takahashi refractor and a high-quality RED Epic digital camera. Rob Ratkowski of the Haleakalā Amateur Astronomers was very helpful in providing liaisons, telescopes, mounts, and other assistance. We also had a variety of Nikon cameras and lenses, the longest being a 600-mm lens with a 2× doubler borrowed from the National Geographic Society, which provided most of the funding for our expedition. Various organizations and individuals provided additional technical support.

We were very happy to be at 10,000 feet, where humans can still work well and think clearly, in stark contrast to the 13,800-foot summit of Mauna Kea on the Big Island of Hawaii, where some observers went. Though less well known as an astronomical site than Mauna Kea, Haleakalā is the home of a major U.S. Air Force telescope for tracking satellites, the prototype Pan-STARRS telescope, the 2-meter Faulkes North Telescope for the Las Cumbres Observatory Global Telescope Network (see page 36), and numerous other professional and amateur facilities. A collaboration of 22 institutions plans to build the Advanced Technology Solar Telescope on Haleakalā.

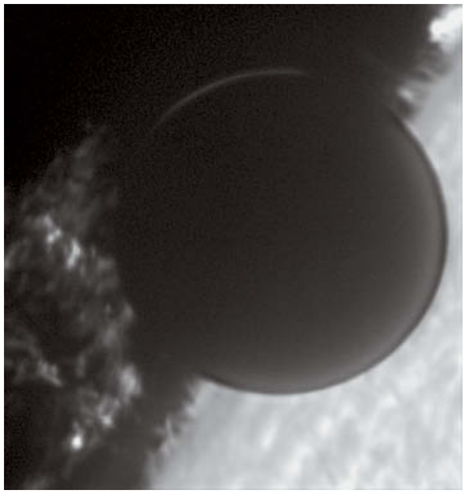
The transit began shortly after noon on Tuesday, June 5th, with the Sun high overhead. We were relieved that the sky was clear. Indeed, the sky was what solar physicists call "coronal": it was so clear and pure that coronagraphs could detect the solar corona without an eclipse, and the sky was the same color blue, with no scattering, when I blocked the Sun with my thumb held at arm's length. But we were forced to contend with steady winds of about 30 miles per hour (13.4 meters per second) and gusts up to 50 mph.

As the transit began, Schneider viewed Venus's disk with a Questar, and cameras and CCDs clicked away. Two minutes before first contact, our coronagraph detected the aureole. Our sister planet's atmosphere showed as a bright sliver standing on edge, on view for perhaps 15 minutes — enough time that I could leave the cameras to catch occasional glimpses with my own eyes. Sheehan, observing visually from Lowell, could follow the partial arc of atmosphere from just before first contact right up until second contact, about 20 minutes in all.

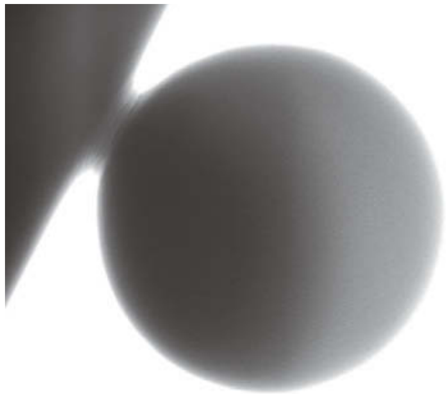
A telescope drive borrowed by Dantowitz failed, so he manually tracked the Sun and Venus for the entire 6½ hours of the event. He compiled more than 600,000 images, short exposures to be assembled and analyzed together. We offered to give him a break, but things were going so well that he didn't want to take a chance on a different observer using his equipment.

As expected, we saw the aureole for most of the interval between first and second contacts, but we were surprised that we could see it for an almost equal duration between third and fourth contact, when the Sun was descending to only 3.5° above the horizon. The atmosphere looking west was clear enough that we could follow the entire egress, though the images required longer exposures. We were helped by Haleakalā's 10,000-foot elevation, which means the actual horizon is depressed about 2°, so fourth contact was easily visible above the Pacific Ocean.

Though our coronagraph bounced a bit in the wind, we have wonderful images showing partial and complete arcs of the Venusian atmosphere at ingress and egress. We're now analyzing these data, which we have also sent for comparison to our French colleagues, who have gathered the coronagraph observations from around the world. Their early analysis shows that the aureole appeared considerably different in 2012 than it did in 2004. The 2012 results also confirm observations from previous transits that high-latitude regions on Venus produce the most intense aureole brightness.



K. REARDON / J. PASACHOFF / G. SCHNEIDER / WILLIAMS TOV EXP. / NSO



VASYL YURCHYSHYN (NJIT) / BIG BEAR OBSERVATORY / NSO

VENUS IN TRANSIT ***Top:*** **This hydrogen-alpha image from the Dunn Solar Telescope on New Mexico's Sacramento Peak catches Venus between first and second contact. Venus is occulting a prominence and small spicules on the solar limb. Note the aureole over Venus's north polar region.** ***Above:*** **A frame from a movie taken by the New Solar Telescope at California's Big Bear Solar Observatory shows the black-drop effect shortly after second contact.**

The Big Bear New Solar Telescope in California provided beautiful high-resolution images. But for those of us on Haleakalā who saw the entire transit, the Big Bear movie ends abruptly much too soon, because the telescope reached its lower limit of pointing when Venus was less than halfway across the Sun. Still, the Big Bear observations of the aureole and the formation and variation of the black-drop effect were of the highest quality.

Reardon, at New Mexico's Sacramento Peak, had the best solar telescope and a new high-quality carbon-dioxide filter on an imaging spectrometer in addition to its standard solar filters, so his observations are fantastic. One dramatic set shows Venus in silhouette drifting past a solar prominence (see page 25).

From space, the two cameras on NASA's Solar Dynamics Observatory provided exquisite observations showing the aureole's evolution. A camera on the Japanese Hinode spacecraft, observing in several colors, made the highest-resolution observations ever of Venus's atmosphere from Earth. The pixels are only about 0.05 arcsecond across, one-tenth the size of SDO's pixels. These observations will take months to analyze. Hinode's X-ray Telescope returned vivid images of Venus drifting past the hot solar corona. The spacecraft's Extreme Ultraviolet Imaging Spectrometer also observed the transit.

The Exoplanet Connection

Since the 2004 transit, astronomers have found hundreds of new exoplanets, including more than 230 confirmed worlds that transit their host stars. In addition, NASA's Kepler Space Telescope, using photometric data, has identified more than 2,300 transit-planet candidates, the large majority of which will turn out to be bona-fide planets when detailed follow-up studies have been completed. It therefore behooves us to study transits in our own solar system. After all, if we can't pick up the atmosphere of Venus during a transit, how can we trust reports of such atmospheric discoveries in distant planetary systems? And in contrast to the 2004 transit, the recent transit took place with numerous sunspots on the solar disk — a factor that can contribute to brightness changes on exoplanet host stars.

NASA's ACRIMSAT and SORCE satellites also made observations relevant for exoplanet research. Both passed through the zone from where the transit could be seen. Each spacecraft recorded the expected 0.1% dip of sunlight that matches the geometrical obscuration of Venus's disk. In the satellites' inclined orbits, they also detected the effect of Venus's silhouette being projected slightly farther north or south on the

NASA / LOU MAYO

NASA TEAM The NASA team that conducted the transit of Venus webcast from the summit of Mauna Kea poses in front of NASA's Infrared Telescope Facility.

NASA's Transit Outreach Extravaganza

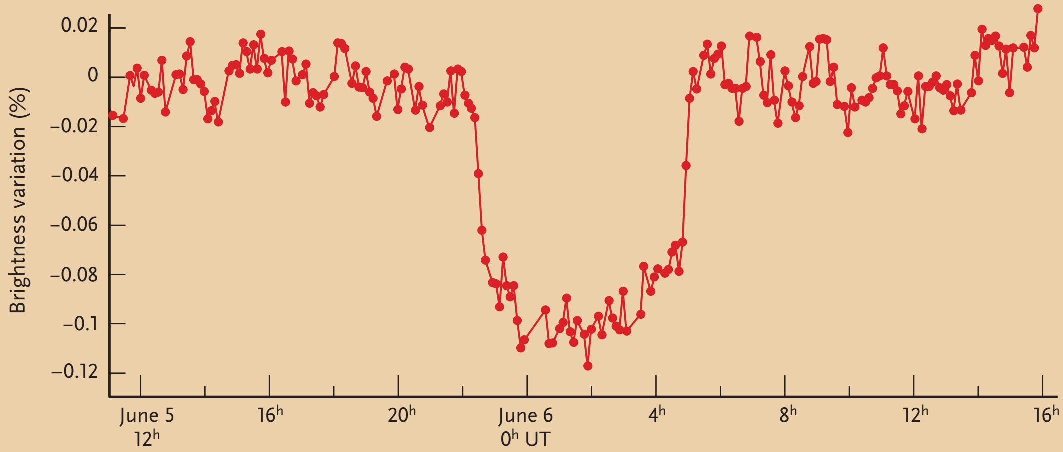
NASA's 2012 Sun-Earth Day program featured the transit of Venus. A NASA-sponsored team of scientists, social-media experts, telescope technicians, students, and webcasters journeyed to the 13,800-foot summit of Mauna Kea in Hawaii to view and share with the world this last-in-a-lifetime show. The team filmed the entire 6-hour 40-minute event in high definition through white-light, hydrogen-alpha, and calcium-K solar telescopes made specifically for the occasion by Andy Lunt of Lunt Solar Systems, Inc.

The views were amazing! In the cold, dry, thin air at the summit, NASAEdge co-hosts Blair Allen and Chris Giersch interviewed solar and heliophysics scientists and planetary astronomers from NASA and other institutions. Just after first contact, CBS and NBC picked up the feed to air on their nightly newscasts. NASA TV broadcast the event as well as video streams from 16 other locations, including India, Norway, Australia, Alaska, Mount Wilson, and the historic English town of Much Hoole, where Jeremiah Horrocks viewed the 1639 transit (January issue, page 64). NASA also broadcast real-time images from its Solar Dynamics Observatory and the International Space Station, where astronaut Don Pettit took nearly 3,000 images, making him the first human to film a transit of Venus from outer space. An estimated 20,000 amateur astronomers around the world participated, sending more than 2,000 images to the NASA transit Flickr site (**http://www.flickr.com/groups/venustransit**) and deriving the astronomical unit in the NASA Observing Challenge Certificate program (**http://venustransit.nasa.gov/2012/getinvolved/aa.php**).

Social media was in full swing too, with a huge following on Facebook, Twitter, and YouTube. Fifteen NASA missions provided educational resources and science content. When it was all over, it was the biggest online event NASA ever held: more than 600 million web hits, 7.7 million web streams, and an estimated 500 million to 1 billion people reached. How will NASA top this before the 2117 transit of Venus? Perhaps by viewing it from Mars...in 2030!

***Lou Mayo** is a planetary scientist at NASA's Goddard Space Flight Center in Greenbelt, Maryland.*

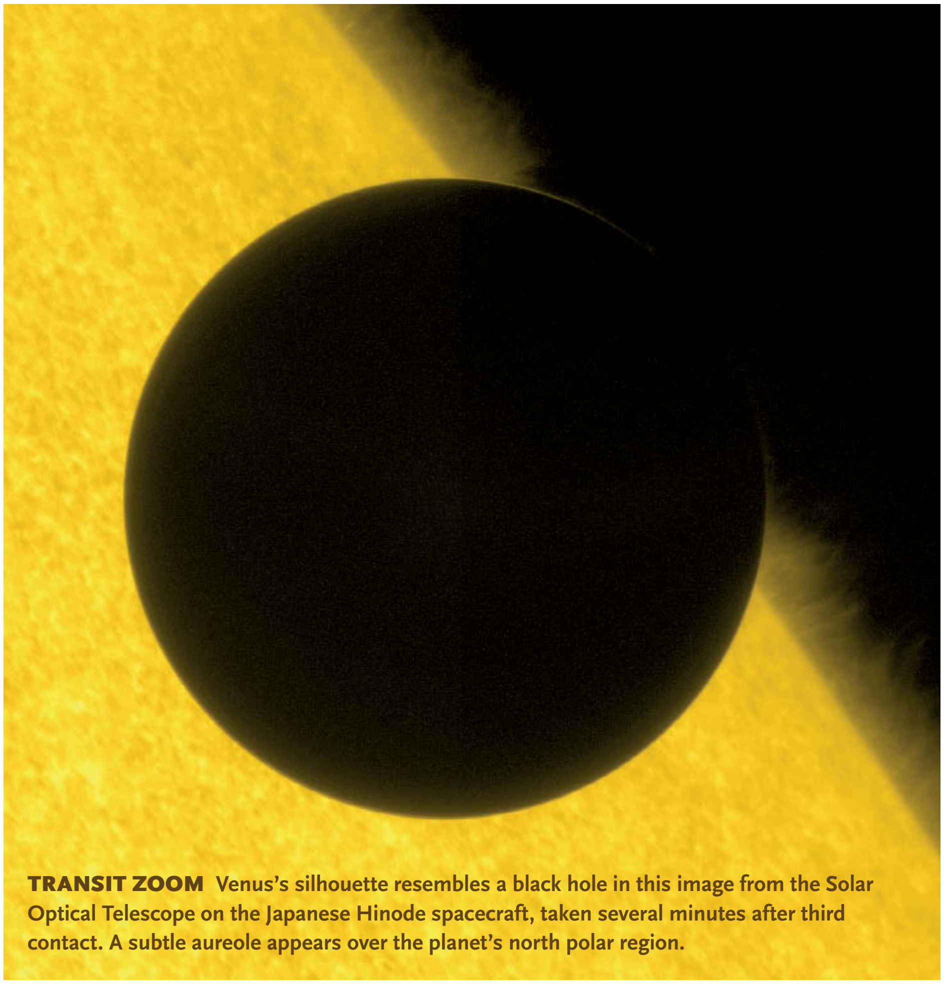
EXOPLANET ANALOG NASA's ACRIMSAT spacecraft observed the Sun during the transit, and scientists compiled its brightness measurements to produce this light curve. The 0.1% drop in brightness due to Venus's disk was easily detected. A civilization with similar technology orbiting a star up to a few thousand light-years away could catch a transit of Venus (or Earth) if its home planet happens to lie in the proper line of sight.



SOURCE: ACRIM / RICHARD C. WILLSON

solar disk, which changed the Sun's total brightness depending on the bit of the Sun that was hidden with limb darkening being taken into account. Further data reduction will reveal these effects even more clearly. Being able to account for these subtle effects bodes well for our ongoing efforts to discover and characterize transiting exoplanets.

I'm delighted to receive so many excellent observing reports from around the world of the 2012 transit of Venus, since I feel a responsibility to 22nd-century astronomers to provide them as good a baseline of comparison as possible, given the advances in instrumental and observational techniques that will undoubtedly occur during the next century. These scientists will no doubt look back on us with the same bemused appreciation with which we look back at the capabilities of the scientists studying the transit pairs of 1761/69 and 1874/82. So many resources from today's astronomical community were brought to bear on the 2012 transit of Venus that I hope that these future astronomers are proud of our accomplishments and are grateful for our attempts. ✦



TRANSIT ZOOM Venus's silhouette resembles a black hole in this image from the Solar Optical Telescope on the Japanese Hinode spacecraft, taken several minutes after third contact. A subtle aureole appears over the planet's north polar region.

JAXA / NASA / LOCKHEED MARTIN

***Jay Pasachoff** is a solar and planetary astronomer at Williams College in Williamstown, Massachusetts, who has studied Mercury and Venus transits and 55 solar eclipses. He is coauthor of* The Cosmos, *whose fourth edition (Cambridge University Press) is in press, and of* Peterson's Field Guide to the Stars and Planets. *He is on sabbatical at Caltech.*

SEE A VIDEO & PHOTOS FROM THE AUTHOR'S TRANSIT EXPEDITION

Videographer Aram Friedman accompanied the author's group on Haleakalā. Friedman produced a time-lapse movie of team members operating their equipment and of the transit itself. Music accompanies the video, which is posted at skypub.com/transit_movies. Friedman also produced a gorgeous time-lapse movie showing clouds streaming across and down Haleakalā's slopes. You can also find additional images of the transit of Venus at the website above.

The Great Galactic

ROBERT GENDLER

New observations suggest that the Magellanic Clouds — for decades considered satellites of the Milky Way — have taken an unexpected path.

Robert Zimmerman

SCIENCE ALWAYS SURPRISES. Decades of observations and theoretical work had firmly established that the two respectable-sized galaxies closest to our Milky Way — the Large and Small Magellanic Clouds — have orbited our Galaxy many times over the past several billion years. Every time the Clouds approached each other or dived down close to the Milky Way, a new burst of star formation would blossom.

Then in 2002 and 2005, Nitya Kallivayalil (now at Yale University) and her colleagues used the Hubble Space Telescope to measure the Magellanic Clouds' proper motion across the sky by using distant quasars as fixed points of reference. To their astonishment they discovered that the Clouds are moving much faster than anyone had

Travelers

ROBERT GENDLER / JOSCH HAMBSCH

GALACTIC NEIGHBORS
Far left: **The Large Magellanic Cloud is near the upper end of what astronomers consider to be a "dwarf" galaxy. The LMC's off-center bar is easily seen in this image. Large stellar nurseries show up as bright red and blue patches. The famous Tarantula Nebula is the largest and brightest of these regions.** ***Near left:*** **The Small Magellanic Cloud is less than half the diameter of its big brother, and it is forming stars at a much lower rate. The magnificent and much closer globular cluster 47 Tucanae lies at the top of the image.**

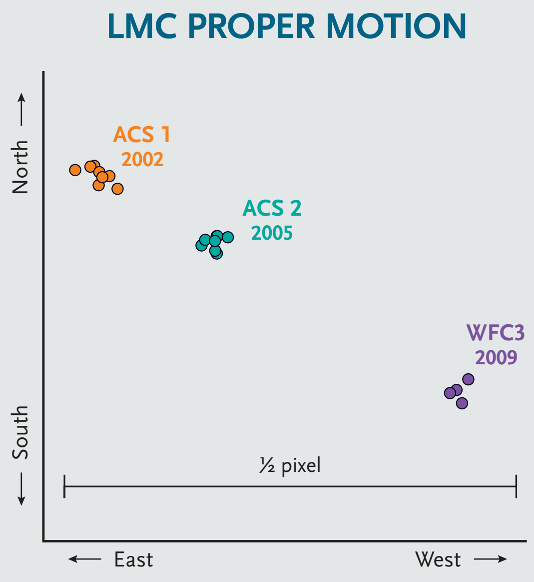
expected. "When we did the math modeling we found that it was really hard to keep these objects bound to our galaxy," recalls Kallivayalil. "And that was a huge surprise."

Two recent proper-motion studies, one led by Kallivayalil that uses a different instrument on HST, and the other by Kathy Vieira (also at Yale), have confirmed this result, though the currently measured velocity of about 320 to 350 kilometers per second (716,000 to 783,000 mph) turns out to be a bit slower than Kallivayalil's first measurement. Nonetheless, the implied speed is still so fast that another group, led by Gurtina Besla (now at Columbia University), concluded that the Clouds have probably never completed an orbit around the Milky Way. "We calculate an orbit where the Magellanic Clouds have come

GALAXIES COMPARED

Large Magellanic Cloud:	Small Magellanic Cloud:	Milky Way:
Optical diameter: ~32,000 light-years, or ~10° across the sky	Optical diameter: ~13,000 light-years, or ~4° across the sky	Diameter of halo: 1.6 million light-years
Mass within optical extent of galaxy: ~5 billion solar masses	Mass within optical extent of galaxy: ~2 billion solar masses	Mass: ~1 trillion solar masses
Distance from the Sun: ~160,000 light-years	Distance from the Sun: ~200,000 light-years	

Distance from each other: ~75,000 light-years



Using Hubble's Advanced Camera for Surveys in 2002 and 2005, Nitya Kallivayalil measured the position of an LMC star field with respect to a distant quasar, which serves as a fixed reference point. Four years later, she did the same measurement with Hubble's Wide Field Camera 3 (the ACS was no longer operational). The colored circles indicate the quasar's position relative to LMC stars. The measurements show consistent linear motion, but the diagram is less than 1 pixel across, demonstrating the LMC's tiny (and difficult to measure) amount of sky motion — a function of its distance.

S&T: LEAH TISCIONE; SOURCE: NITYA KALLIVAYALIL (YALE UNIVERSITY)

MAGELLANIC STREAM Astronomers combined data from several radio telescopes with a visible-light mosaic of the Milky Way from Axel Mellinger to create this image. The entire Magellanic system extends for an enormous 200°. Astronomers have known about the Stream for decades, but recent radio observations show that it's much larger than previously thought.

in very recently, so that this would be their first infall into our galaxy," explains Besla. "The orbit is completely different from the picture that had existed before."

So instead of being our long-time neighbors, the Magellanic Clouds now appear to be visitors from elsewhere, right now making their first close approach to the Milky Way. Astronomers are still debating whether they will remain bound to the galaxy after this approach. "The best solution for the orbit is one that is bound to the Milky Way, but an unbound solution is within the errors of the measurements," notes William van Altena (Yale University).

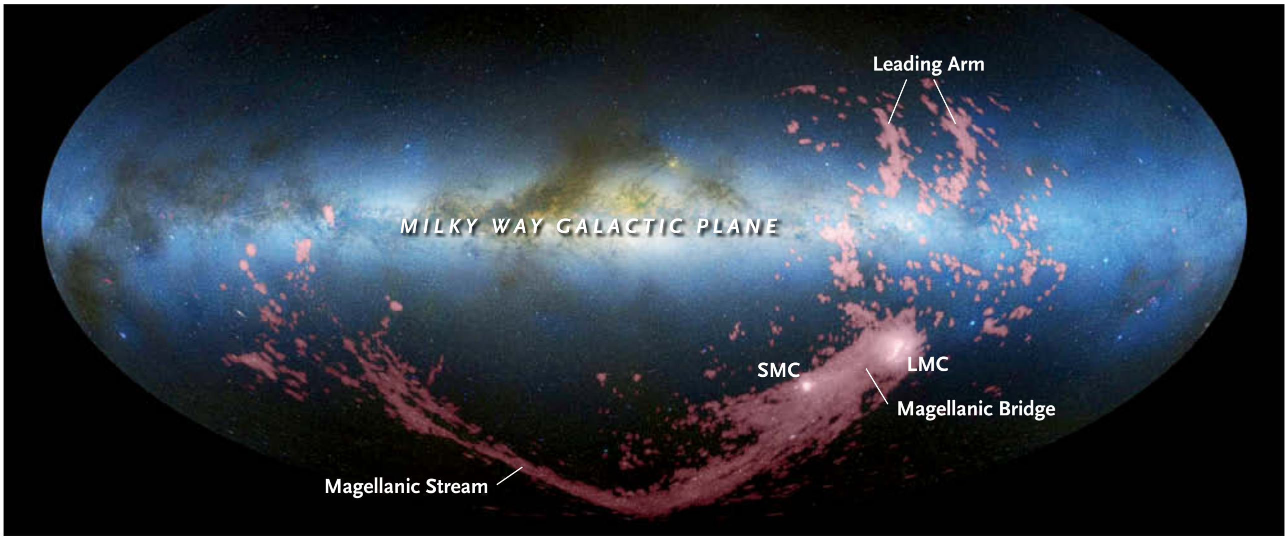
Because these new observations invalidated all the past models about the orbital history of the Clouds, theorists have been trying to figure out where in our Local Group of galaxies the Clouds came from and how their unexpected arrival from afar has made them what they are.

In the Beginning

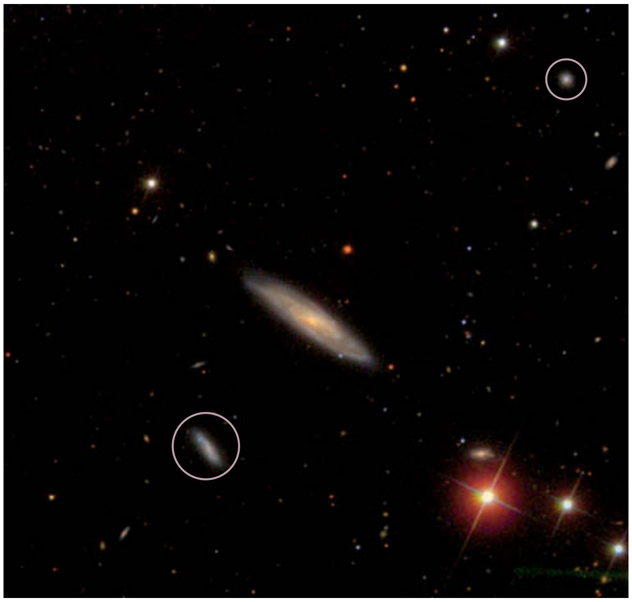
Although the Magellanic Clouds are blocked from view from northerly latitudes, humans have known about them for millennia. Some Australian Aborigines thought they were two great men who sometimes came down to Earth to choke people in their sleep. In the 10th century, Arabian astronomer Abd al-Raymah al-Sufi named the LMC Al Bakr (The White Ox), noting that it was only visible to those south of the Gulf of Aden.

It wasn't until the great ocean voyages in the 15th and 16th centuries that the existence of the Clouds became common knowledge in Europe. In the 15th century they were dubbed the Cape Clouds by Portuguese sailors, who used them as a southern pole star in their travels down the coast of Africa to round the Cape of Good Hope.

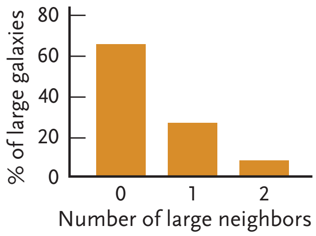
Their modern name arose many decades after the voyage of Ferdinand Magellan, but the Portuguese explorer himself never wrote anything about the Clouds, having been killed in the Philippines in 1521 before completing his intended round-the-world journey. Instead, one of his



D. NIDEVER / NRAO / AUI / NSF / A. MELLINGER / LABS / PARKES / WESTERBORK / ARECIBO



RISA WECHSLER (STANFORD UNIVERSITY), ET AL. (2)



LONELY GALAXIES ***Left:*** **The distant spiral galaxy in the center is a rare large galaxy with two sizeable companions (circled) comparable to the Magellanic Clouds. The spiral is similar to the Milky Way, but unlike the Clouds, its two companions are far from each other.** ***Above:*** **This histogram shows that large satellite galaxies are rare within an 800,000-light-year distance of a major galaxy.**

officers, Italian Antonio Pigafetta, provided an eyewitness description, even correctly guessing (before Galileo and the telescope!) that the Clouds consisted of innumerable stars. "Many small stars clustered together are seen which have the appearance of two Clouds of mist," Pigafetta wrote. "There is little distance between them, and they are somewhat dim."

Minimal detailed research on the Clouds took place before the 20th century, mostly because of the lack of good telescopes in the Southern Hemisphere. But after those facilities were built, the Clouds became a key component in establishing the distance scale to other galaxies, and thus they helped humanity figure out that the universe is much larger than was previously thought.

The Old Paradigm

How the Clouds formed and where they came from remained a complete mystery until the Space Age. Astronomers must also account for structures associated with the Clouds. A gaseous "Magellanic Stream" trails the SMC and extends across the sky for 140°. A "Magellanic Bridge" of gas and stars connects the two galaxies, while ahead of the LMC is a gas finger called the Leading Arm.

In addition, recent work by Erik Tollerud (University of California, Irvine) and his colleagues show that the Clouds are much bluer and younger than comparably sized irregular galaxies, and they form stars at a much higher rate. The history of this starbirth needs to be explained. In both Clouds, the evidence suggests that overall star formation generally ceased about 10 billion years ago, then re-ignited with a fury between 3 to 5 billion years ago and has continued ever since, with comparable peaks in both Clouds every few hundred million years. As one paper noted, "The re-ignition of star formation about 5 billion years ago, in both the Large and Small Magellanic Clouds, is suggestive of a dramatic event at that time in the Magellanic system."

Complicating matters further, the two Clouds show striking differences in their histories of star-cluster formation. In the LMC, cluster formation ceased from about 10 billion to about 4 to 5 billion years ago. But the clusters in the SMC show less evidence of this gap, with cluster formation occurring more randomly over the last 10 billion years.

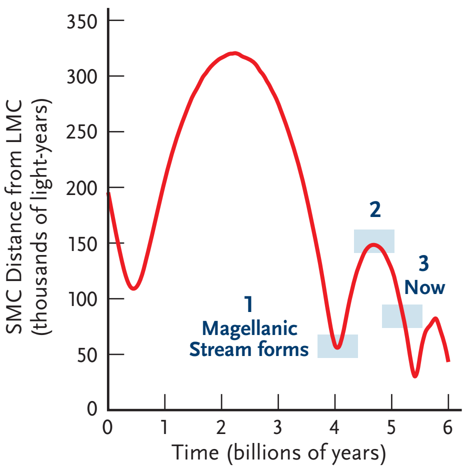
Thus, any orbital theory of the Clouds' past history must account for the formation of the Stream, the Bridge, and the Leading Arm, as well as the star-formation histories. By the 1990s astronomers thought they had a reasonable explanation for these observations. The two Clouds had been orbiting the Milky Way every 2 billion years or so for at least the last 6 billion years. In addition, the SMC was thought to orbit the LMC every few hundred million years. With every close pass to each other as well as to the Milky Way, gravity compressed the gas in the Clouds and ignited a new burst of star formation, the most recent of which occurred just 100 to 200 million years ago, when the Clouds passed about 150,000 light-years from the galactic center. The LMC tidally yanked gas from the SMC during that close encounter, forming the Magellanic Bridge, while Milky Way tides helped stretch that gas into the Magellanic Stream and Leading Arm.

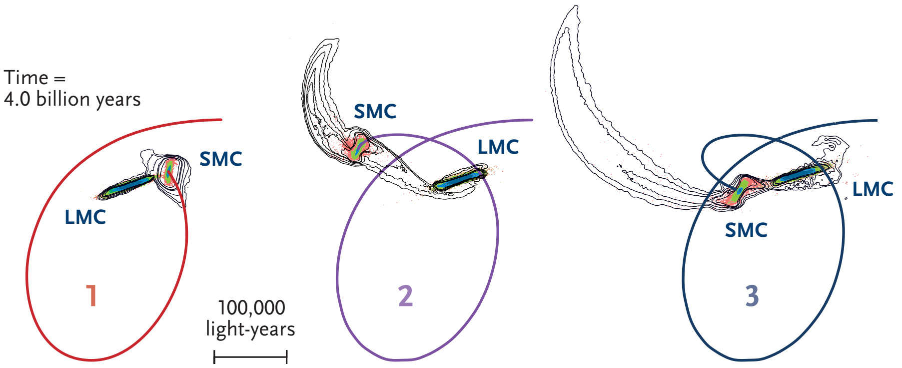
Modern Confusion

But the 2006 proper-motion data invalidated this model. The Clouds have apparently *not* orbited the Milky Way multiple times in the last 6 billion years. Instead, like a comet diving into the inner solar system for its first visit, the Clouds are strangers, having come from elsewhere within the Local Group. "It definitely took me by surprise," says Besla. "And I think it largely took the community by surprise as well."

Moreover, the Clouds appear to be relatively rare objects. For example, a careful survey of more than 22,000 other galaxies similar to the Milky Way found that more than 80% have no large satellites at all within a radius of 500,000 light-years, and 11% having only one satellite. Only 3.5% had two large companions like the Magellanic Clouds. And when the scientists widened their view, looking as far away as 800,000 light-years from

Binary Evolution





These panels come from Gurtina Besla's model of how the Magellanic Cloud binary system may have evolved over billions of years without any involvement from the Milky Way Galaxy. *Far left:* This plot shows the changing separation of the two Clouds from the time the LMC captured the SMC. *Above:* These panels illustrate the SMC's orbital motion around the LMC, which is treated as stationary because it's the system's center of mass. Contour lines show the distribution of gas and colors indicate stars. In this model, the LMC alone can tidally strip a significant amount of material from the SMC to form the Magellanic Stream.

SOURCE: GURTINA BESLA (COLUMBIA UNIV.) / NITYA KALLIVAYALIL (YALE UNIV.) / LARS HERNQUIST (CFA)

the central galaxy, the number of galaxies with two comparable satellites still barely rose to 8%. "This lends some support to the idea that the Clouds are coming in for the first time," says Risa Wechsler (Stanford University).

Faced with these new data, the theorists have come up with a host of new models, all of which exclude the presence of the Milky Way in the past history of the Clouds. One theory, for example, has the two Clouds interacting twice, once about 2.5 billion years ago and again about 150 million years ago. The first encounter produced the Stream, while the more recent event — when the Clouds ventured as close as 30,000 light-years to each other — created the Bridge and Leading Arm.

A theory proposed by Besla's team also postulates that the Clouds are a binary, but with the SMC in an extremely eccentric orbit that shrinks with each revolution. Three billion years ago the two Clouds were more than 300,000 light-years apart, with the SMC diving down to a distance of 50,000 light-years a little over a billion years ago, then flying out to 150,000 light-years before diving back to its present 75,000-light-year distance from the LMC. The close approaches produced the Stream, Bridge, and Arm, as well as the bursts of star formation when the gas surrounding the Clouds collided and began condensing into stars.

THE FUTURE OF THE MAGELLANIC CLOUDS

Recent research suggests that the Milky Way and Andromeda galaxies will collide 4 billion years from now and will eventually form a giant elliptical galaxy (last month's issue, page 18). Because the LMC and SMC appear to be captured into an elongated orbit around the Milky Way, they will probably be too far away from the colliding galaxies to be absorbed immediately. The pair will orbit the supergalaxy a number of times but will ultimately fall in and suffer the same fate as many other satellite galaxies: cannibalization.

Interlopers

But none of this modeling of the two Clouds as a binary system tells us much about where they came from originally, although everyone agrees they were born somewhere in our Local Group. The models also have a difficult time explaining why the burst of star formation began about 5 billion years ago.

Interestingly, back in 1991 W. L. H. Shuter (University of British Columbia, Canada) had proposed that the Clouds were not bound to the Milky Way and had originally come from the region around the Andromeda Galaxy (M31), ejected there during a tidal encounter around 6 billion years ago. At the time Shuter's model didn't fit the more accepted idea that the Clouds are satellites of the Milky Way, so it was generally ignored.

With the new proper-motion data, a group of French and Chinese scientists have taken a second look at Shuter's model and, using today's better data and more sophisticated computers, have come up with a few variations. In one, the Magellanic Clouds were originally dwarf galaxies that roughly 4 to 8 billion years ago were involved in a merger with M31. In another, the Andromeda merger event was not the absorption of a small dwarf galaxy but a major event involving the merger of two massive galaxies to *form* M31. In both cases, the Andromeda merger event ejected the Clouds in our direction. It also triggered the star formation that began in both Clouds around 5 billion years ago, which is ongoing today and is periodically juiced up when the two Clouds approach each other in their own binary dance.

But other astronomers have serious doubts about these models because they treat the masses of the galaxies as static over time. When models include the growth of the galaxies as they accrete material, it becomes much harder to come up with the same answer. As Besla notes, "We looked at the orbital history of the Clouds including M31, trying to see if we could get the orbits anywhere close to

Andromeda. We couldn't do it." Instead, Besla thinks the burst of star formation about 5 billion years ago could have been triggered when the LMC gravitationally captured the SMC, forming the binary system.

Whether or not the Clouds came from Andromeda originally, many astronomers now think they have been recently captured by the Milky Way and from now on will be traveling in an extremely elongated orbit that has just made its closest approach to the galaxy, with the LMC passing at a distance of about 160,000 light-years. They will then fly outward and return many billions of years in the future, their orbit slowly shrinking with each pass as the Milky Way's powerful gravitational field methodically reels them in (see "The Future of the Magellanic Clouds," page 32).

Science at Its Best

The surprising 2006 discovery that the Magellanic Clouds are traveling faster than anyone had predicted immediately invalidated almost 30 years of theoretical research. Still, the earlier models gave astronomers a solid foundation for further research. When improved data came along, scientists were ready to move forward with new ideas. As Kallivayalil notes, "For me this has been an eye-opening experience. I was very surprised and impressed by the fact that people were really willing to speak to the data and allow the data to inform their models."

Open-mindedness in this field is definitely a requirement. Despite these recent advances, the field still has a large number of "free parameters" — areas of doubt where data are sparse and assumptions have to be made. "It's very easy for the theorists to sort of tweak some numbers and come up with another plausible scenario," says van Altena. "The observational data have not been able to put enough constraints on the theoretical models."

Just as disagreements remain about whether or not the Clouds came from Andromeda, some scientists can still create perfectly good models of the Clouds as long-time orbiting Milky Way satellites, despite the new high-proper-motion data. They assume that the Clouds' orbit is much larger than calculated in previous models, and they increase the Milky Way's mass — one of those free parameters where there's still plenty of uncertainty.

Only when the European Space Agency launches its Gaia mission later in this decade will some of these issues finally be addressed. Gaia will measure the motions of about 1 billion stars so that astronomers can accurately model the formation and evolution of the Milky Way and its satellites. "At that point then we will be able to nail the theories and they will be more tightly restricted," adds van Altena.

Only with these further advances will astronomers be able to re-create the history of the Magellanic Clouds much more precisely, not only telling us where they came from, but where they will eventually end up. ✦

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*Contributing editor **Robert Zimmerman** writes frequently about space and astronomy, both for* S&T *and on his webpage,* ***behindtheblack.com***.

AKIRA FUJII

SOUTHERN SENTINELS
Easily visible to the naked eye from dark locations in the Southern Hemisphere, the Magellanic Clouds have been known since the dawn of humanity. Visually, the two neighbor galaxies actually resemble small clouds in Earth's sky, except they move with Earth's rotation rather than with the wind.

To watch several videos about the Magellanic Clouds, visit skypub.com/MagClouds.

NuSTAR Probing the Energetic Universe

SPACECRAFT: NASA / JPL-CALTECH; BACKGROUND: NASA / CXC / UMASS / D. WANG ET AL.

Monica Young

On June 13th, Fiona Harrison, Caltech astronomer and lead scientist of NASA's Nuclear Spectroscopic Telescope Array (NuSTAR), waited at mission control in Berkeley, California. Observing the preparations for NuSTAR's launch, she felt exhilarated, but oddly remote. After 17 years of hard work, it was surreal to do nothing but watch. She couldn't see anything on the TV screens — the launch was taking place in the dark, early morning hours above the Pacific Ocean — but the telemetry told her what was happening.

At 16:00 UT, the L-1011 "Stargazer" plane had climbed to 40,000 feet. A Pegasus XL rocket dropped from its belly, free-falling for five seconds before igniting. Thirteen minutes later, NuSTAR was in orbit. That's when the adrenaline rush hit Harrison. Soon the science could begin.

Over the next two years, NuSTAR will focus on the universe at X-ray energies of 5,000 to 80,000 electron volts (eV), a little-explored window of astronomy. Technological innovations will allow astronomers to capture images 10 times crisper and 100 times more sensitive than before, and spectra with 10 times sharper resolution. With a better view of the energetic universe, NuSTAR can address questions about a range of exotic phenomena, including black holes, supernovae, and maybe even dark matter.

New Technologies

To capture high-energy X-rays, Harrison and her colleagues took a new approach to mirror, telescope, and camera design. X-rays directed straight at a mirror don't reflect like visible-light photons; they are either absorbed or they pass right through. X-rays will only bounce at a glancing angle. One mirror deflects such a small number of X-rays, a number that gets smaller at higher energies, that many mirrors must be nested inside one another like layers of an onion. While NASA's Chandra X-ray Observatory uses four exquisitely smooth mirrors to bring the low-energy X-ray universe to a sharp focus, NuSTAR's 133 mirrors focus photons with 10 times more energy.

"The mirrors need to be very thin and very smooth," explains Harrison. "Our shells are only 200 microns thick, about the thickness of your fingernail."

Thin, smooth — and cheap. NuSTAR's mirrors cost only $20 per sheet because the mirrors are made of the same smooth glass produced commercially for laptop displays. A reflective coating only a few atoms thick covers each surface.

Because X-rays bend so slightly when they graze off mirrors, they come to a focus only after a great distance. So the camera imaging the X-rays had to be placed far away from the mirrors themselves, held in place by a lightweight and incredibly stiff mast 10 meters (33 feet) long. The mast was folded up for launch and unfurled in orbit, 56 segments unfolding and latching into place like a Tinkertoy set.

The camera itself is another new piece of technology. Detectors working at lower energies, such as those aboard Chandra and XMM-Newton, are silicon-based, similar to those found in a digital camera. But high-energy X-rays would pass right through them. Harrison built a new, denser detector in her lab using a cadmium-zinc telluride crystal capable of reining in high-energy X-rays.

Combined with the extendable mast and nested mirrors, NuSTAR's detectors will provide an unprecedented, focused view of the energetic universe, all while staying within a comparatively inexpensive budget of $165 million.

New Science

NuSTAR's innovative design allows the telescope to witness some of the most violent events in the universe. Relativistic jets, exploding stars, stellar corpses, and supermassive black holes gorging on gas make up the core science program. With unprecedented sensitivity in a little-explored window of the electromagnetic spectrum, NuSTAR is poised to make new discoveries wherever it points.

One of NuSTAR's primary science goals will be to take a census of supermassive black hole populations. NuSTAR can't detect black holes themselves, but as gas spirals into a black hole, magnetic field lines snap like rubber bands in the turbulent flow. NuSTAR will see the X-rays that are released. Observing these X-rays might help astronomers count how many black holes hide behind a thick shroud of dust.

Chandra has already begun this black hole census, but most of the X-rays suffusing the universe are emitted at energies beyond Chandra's range. For every supermassive black hole Chandra can detect, there might exist three or four "hidden" black holes, veiled by dust that traps low-energy X-rays. Only high-energy X-rays, like those detected by NuSTAR, can penetrate the veil. NuSTAR will resolve 25 times more sources at high energies than was possible before, closing in on the nature of hidden black holes.

"NuSTAR is going to take us a long way toward understanding black hole populations," NuSTAR project scientist Daniel Stern (JPL) notes. "There are definitely sources NuSTAR will see that Chandra hasn't."

NuSTAR will also look at the wispy remains of exploded stars. Supernovae are poorly understood — computer simulations have a hard time making stars explode. NuSTAR will produce the first maps of radioactive titanium-44 in supernova remnants, maps that astronomers can use to rewind back to explain the explosion itself. Even better would be if a supernova exploded nearby; NuSTAR would provide an unmatched view of the high-energy action.

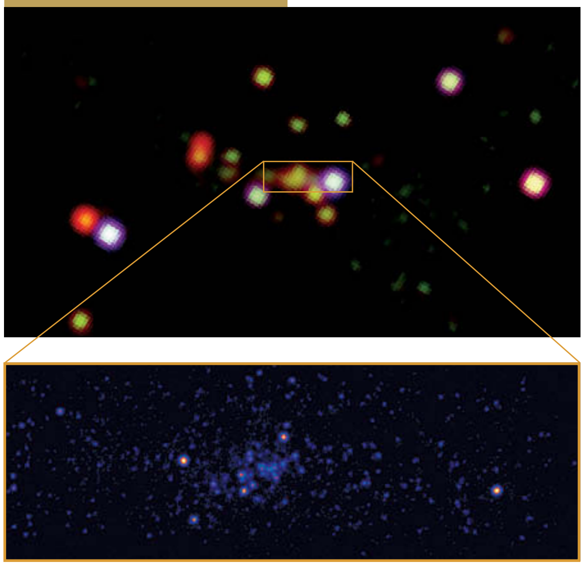
NuSTAR's science program evolved as the project developed. "When we first put in the proposal, we never thought of pointing at the Sun," says Stern. Then two solar physicists, Hugh Hudson and David Smith, contacted the team. "[They] came to us and asked, 'Can you point at the Sun? Because if you can, give us two weeks, and we'll give you three solid science results and possibly a Nobel Prize.'"

The pitch — which mission scientists were quick to agree to — came in part because NuSTAR could be the first space telescope capable of seeing the X-ray signature of *axions*, a hypothetical component of dark matter. Axions are bizarre theoretical particles that transform into high-energy photons in the presence of a strong magnetic field (July issue, page 17). So axions produced in the Sun's core could stream out, interact with the strong magnetic field on the Sun's surface, and turn into high-energy photons detectable by NuSTAR. If axions exist (and that's a big if), the X-ray signal will be unmistakable — a fuzzy splotch of X-rays centered on the Sun.

Nobel Prize or no, NuSTAR has a busy two years ahead, with a schedule packed full with observations of exotic objects. "We're incredibly excited to start the science program," says Harrison. "It's been a long time coming, and here we are!" ✦

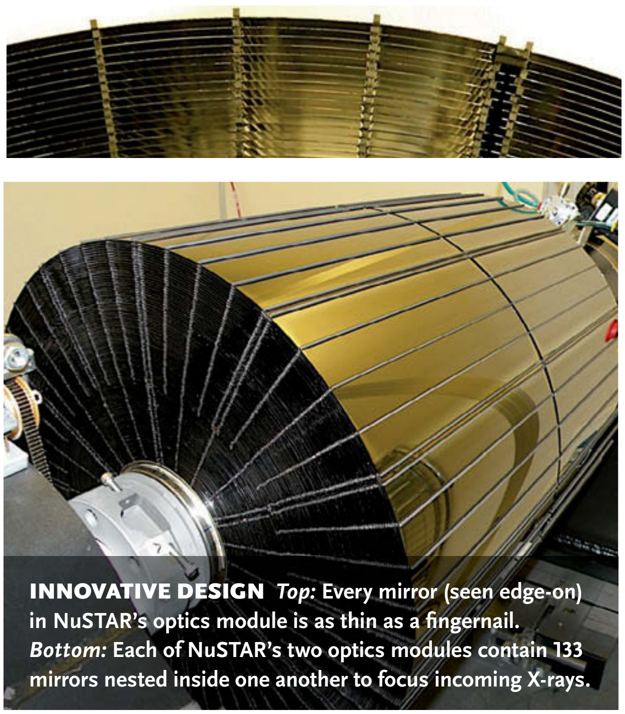
S&T web editor ***Monica Young*** *worked on NuSTAR's science team, and she looks forward to reporting its results.*

A More Focused View



BOTTOM: NASA / JPL-CALTECH; TOP: ESA / ISOC

MILKY WAY CENTER *Top:* The International Gamma-Ray Astrophysics Laboratory (Integral) peers deep into the Milky Way's center, but the view is fuzzy. *Bottom:* NuSTAR will resolve blobs into sharp points of X-ray light, bringing the high-energy universe into focus.



NASA / JPL-CALTECH

INNOVATIVE DESIGN *Top:* Every mirror (seen edge-on) in NuSTAR's optics module is as thin as a fingernail. *Bottom:* Each of NuSTAR's two optics modules contain 133 mirrors nested inside one another to focus incoming X-rays.

The Las Cumbres Obser

CAMERON WALKER

Thanks to the vision of a Silicon Valley legend, the world's most ambitious telescope network to date will soon keep astronomers in the dark around the clock.

ALL IMAGES ARE COURTESY OF THE LAS CUMBRES OBSERVATORY GLOBAL TELESCOPE UNLESS OTHERWISE CREDITED. *ABOVE:* MATTHEW C. MILLER / HAZARDOUS TASTE

3 telescopes on their way to Chile will soon join a network whose aim is to stop the Sun from rising. For astronomers, the coming dawn usually means that the chance to study a new supernova or planet is about to end. But this growing network of telescopes distributed around the globe promises to keep observers in the dark 24 hours a day.

Earlier this year the Las Cumbres Observatory Global Telescope (LCOGT) installed a 1-meter (39-inch) telescope at McDonald Observatory near Fort Davis, Texas. Pictured on the opposite page, it's the first of up to 40 scopes designed and fabricated at LCOGT's headquarters in Goleta, California, and destined for observatories around the world. The three 1-meter telescopes headed to Chile's

vatory Global Telescope

Cerro Tololo Inter-American Observatory will be the next to come online.

If all goes according to plan, LCOGT will have a network of telescopes at six sites worldwide within two years. Each site will start with at least one 1-meter and one 0.4-meter telescope. By the time the network is complete, LCOGT will deploy as many as fifteen 1-meter telescopes and two-dozen 0.4-meter instruments. They will join a pair of 2-meter telescopes built by Telescope Technologies in the U.K. and already stationed at observatories in Hawaii and Australia.

One major objective of this ambitious project is to do unprecedented science by capturing time-sensitive events and transient objects such as supernovae, exoplanets, and near-Earth objects — "anything that orbits, pulsates, or blows up," says LCOGT science director Tim Brown.

LCOGT astronomers want to respond quickly to events that can only be observed for a short time. The telescope network will also target specific objects over longer time periods, making extended observations that are not possible with just one telescope. "To do the physics to understand a lot of objects out there, you need to watch what they're doing on their time scales, which are hours, minutes, half a day," says Brown. "And that's something that the current suite of facilities is ill-prepared to do."

Three Northern Hemisphere observatories and three more in the Southern Hemisphere will host the LCOGT telescopes in exchange for observing time. Negotiations are also underway for a site in China. "Our goal is to have the entire southern network up and running this year," says vice president of operations Mike Falarski. Located in Australia, South Africa, and Chile, these telescopes will have many scientific objectives, including the search for planets orbiting stars in the Milky Way's central bulge, which is best seen from the Southern Hemisphere.

Observatories in Hawaii and the Canary Islands will begin receiving 1-meter telescopes in the coming years. During that time the telescopes will also multiply. McDonald Observatory will gain at least another 1-meter telescope and three 0.4-meter telescopes, if not more.

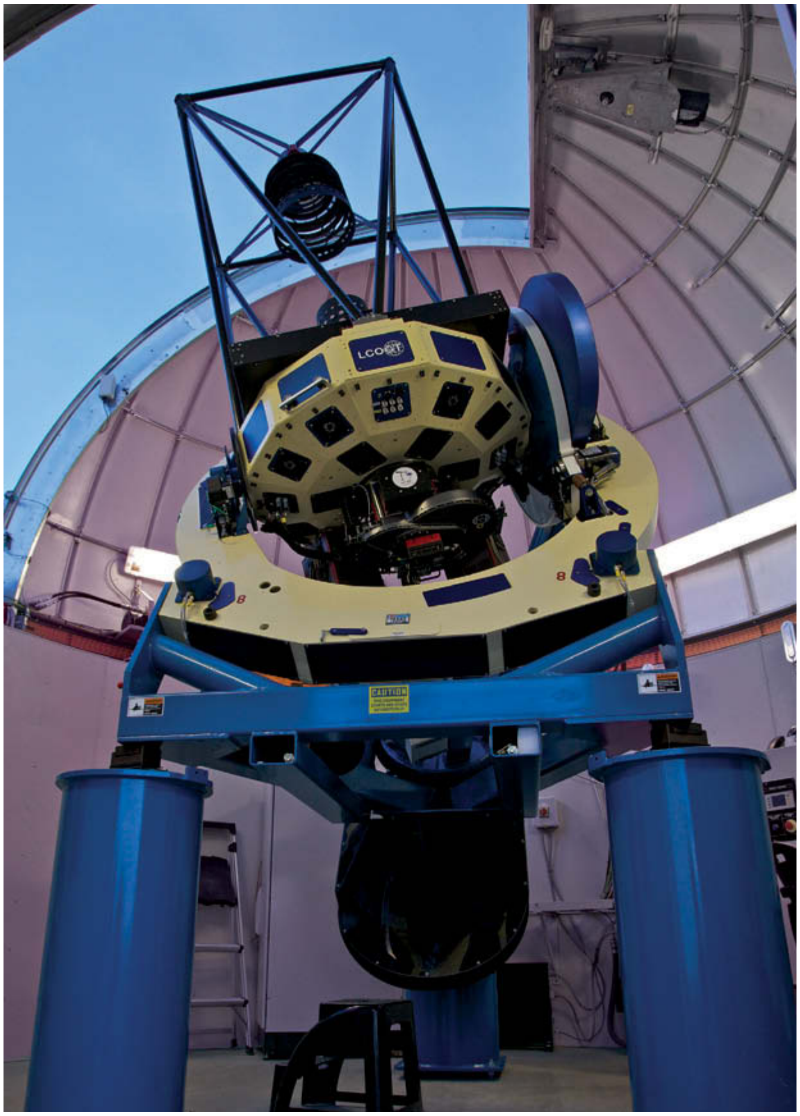
Computer Guru and Telescope Nut

Both professional astronomers and "citizen scientists" will use the network. This is particularly important to LCOGT founder Wayne Rosing, former vice president of engineering at Google and a self-described telescope nut.

Inside LCOGT's Goleta headquarters, Rosing takes a well-worn copy of Scientific American's classic *Amateur Telescope Making, Book One* off the shelf, flips through it, and points to a drawing of a horseshoe mount. "I thought, that's an interesting design for a telescope," he says, referring to the drawing he first saw more than 50 years ago. Just down the hall, assembly rooms hold the 1-meter-telescope mounts being readied for the network — royal-blue, slightly modified versions of this very design.

Rosing's love of astronomy runs through his earliest memories. As a 3½-year old, he studied the night sky with his grandfather from their Cleveland backyard. By high school, he was building telescopes and developing an interest in computers that would take him into the highest ranks of Apple, Sun Microsystems, Sun Labs, and Google. Even though the internet, robotic telescopes, and

***Facing page:* Equipment gets a shakedown test at LCOGT headquarters in Goleta, California. Below: The LCOGT reflector at McDonald Observatory in Texas is the network's first 1-meter scope.**



FRANK CIANCIOLO / MCDONALD OBSERVATORY

CCD cameras were still relatively new in 1984, he was already thinking of combining these technologies to create an array of telescopes all over the world.

Rosing founded Las Cumbres Observatory as a non-profit organization in 1992. When he retired from Google in 2005, Rosing began transforming the project from a one-person dream to an organization with close to 50 employees — from astronomers to software engineers and machinists.

The idea of a worldwide telescope network is not new. For example, in 1995, the Global Oscillation Network Group deployed a six-station network to continuously monitor solar oscillations. The collaborative Whole Earth Telescope has studied variable stars by picking a few targets each year and patching together time on telescopes around the world. And a Denmark-based project, Stellar Observations Network Group, also plans an eight-node network of 1-meter telescopes; the prototype was installed on Tenerife in the Canary Islands earlier this year.

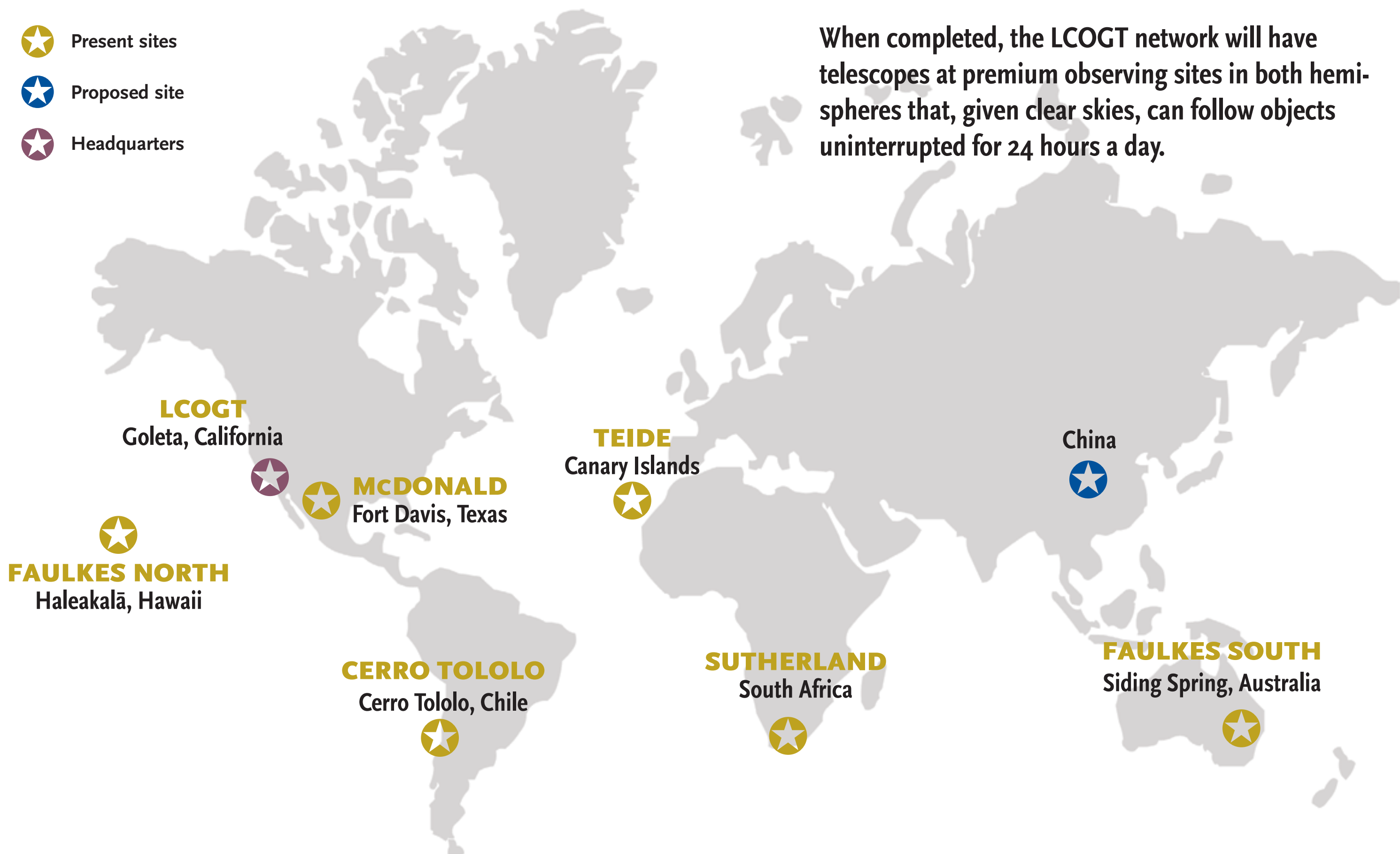
But Rosing's aim is to organize a network that is more than just a series of telescopes filling the observing gaps that occur when the Sun rises at specific sites. With its combination of custom telescopes and top-flight software controlling them simultaneously, LCOGT really is like a single robotic telescope operating on a global scale.

Rosing didn't want to waste time wrangling with someone else's technology, so he built his own. Almost everything in the network — from the clamshell enclosures for the 0.4-meter telescopes known as Aqawans ("to be dry" in the local Chumash language) to the spectrographs — is designed and built in Goleta. A piece of equipment begins as a computer model, and it later heads through the machine shop, assembly areas, and the headquarter's observatories for testing.

A few years ago, the LCOGT team built a small-scale prototype telescope. After ironing out several issues with the drive system, the design was scaled up for the 0.4-meter telescopes, and then scaled up again, with several modifications, for use with the new 1-meter scopes.

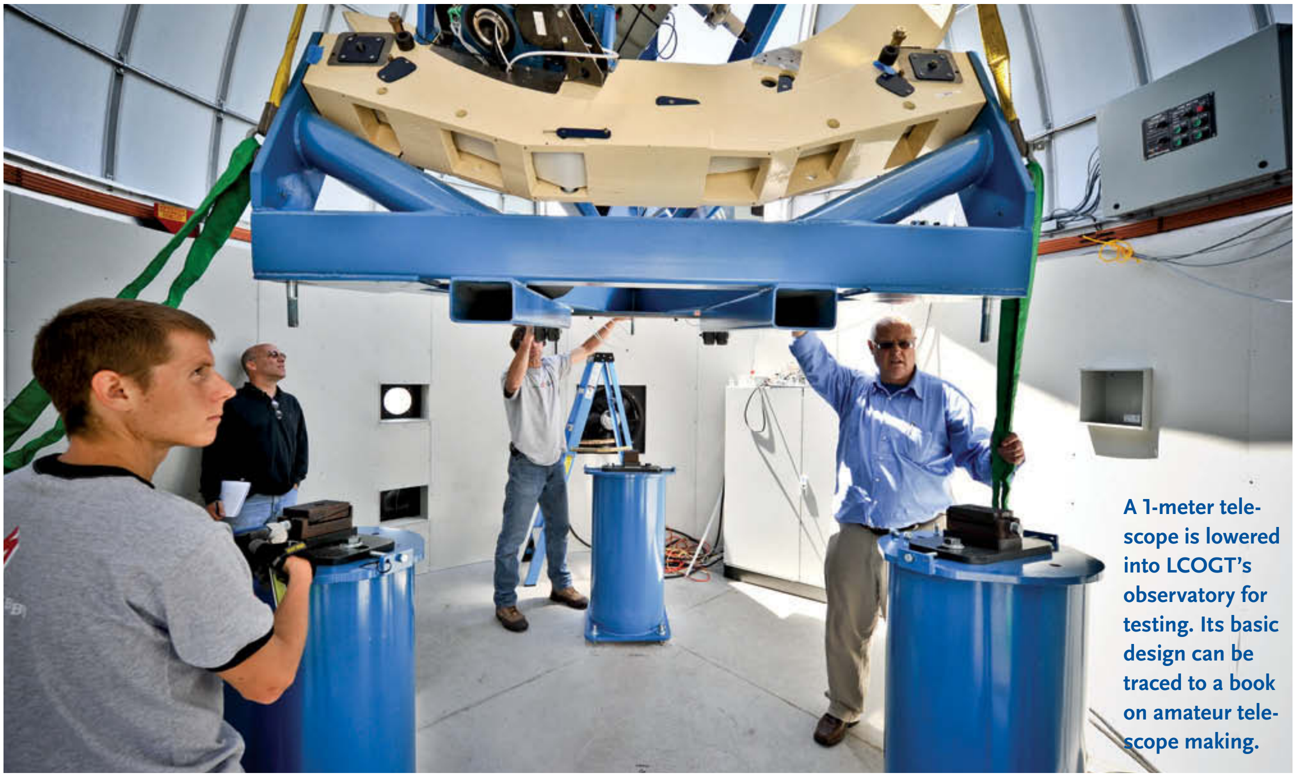
Everything happens by way of parallel development. Mechanical engineers design, build, and test telescopes, while software engineers are writing code. It's a way to kick start the network's evolution that involves little bureaucracy, but with a fair amount of risk. Rosing estimates the project, which he and his wife support through a private foundation, will cost tens of millions of dollars.

For the rest of the astronomy community, there will be no cost at all. The entire network, from software to hardware, will be open source. Even LCOGT's observational data will be available online.



When completed, the LCOGT network will have telescopes at premium observing sites in both hemispheres that, given clear skies, can follow objects uninterrupted for 24 hours a day.

BIGSTOCK.COM / LCOGT



A 1-meter telescope is lowered into LCOGT's observatory for testing. Its basic design can be traced to a book on amateur telescope making.

From Parking Lot to Mountaintop

Inside an observatory dome in LCOGT's back parking lot, mechanical engineer Matt Dubberley presses a few buttons on a laptop. A horseshoe mount holding a 1-meter telescope whirs into a slow waltz. A few yards away, two 0.4-meter telescopes sit inside one of the Aqawans, waiting for nightfall. Servers lined up inside a neighboring shipping container manage all the data streaming in from the sky. Back inside his office, Dubberley clicks through a computer model of the same telescope he just tested. The models help LCOGT's engineers refine the equipment. The 1-meter telescopes slew rapidly and can smoothly track objects with arcsecond precision for extended periods. They also have optical performance that is limited only by the astronomical seeing at their sites.

Apart from the 2-meter Faulkes reflectors already in operation, almost all of the network telescopes and scientific instruments are being designed and fabricated at LCOGT's headquarters.

Much of the work right now at LCOGT headquarters is focused on the first-to-deploy 1-meter telescopes. In early spring, just before the 1-meter telescope was shipped to the McDonald Observatory, LCOGT astronomer Rachel Street and others were hard at work in front of their computer monitors, putting the telescope through its paces. "This is our test-bed for everything — hardware, software, operations, and science operations as well," says Street. "We're basically throwing at it the sorts of observations we want to do, and seeing whether or not it can do them."

Once the LCOGT team deems the telescope network ready, the process for using it will require nothing more complex than an internet connection and a web browser. When observations are approved, astronomers will review the details of their observing plan online. Later, they can log on to track the progress of their observations and obtain immediate feedback on their results.

Users won't see the incredibly intricate software that the LCOGT staff says outshines even their custom telescopes. "The complexity is in the software, because it's a lot easier to change software remotely than it is to change hardware," says Eric Hawkins, LCOGT's director of engineering. By some estimates, the code is currently only halfway to where it will be when the entire network is in place.

Most robotic telescopes perform a single task, night after night. In LCOGT's case, each telescope will need to respond quickly, switching from tracking an asteroid to following up a supernova. The scheduler lies at the heart

Clamshell enclosures called Aqawans ("to be dry" in the Native American Chumash language) will house smaller telescopes.

of the network's software. It makes the decisions on how to distribute observations around the network.

To do this, the scheduler looks at each proposal's priority level, which has been assigned by a telescope-allocation committee. The scheduler also takes into account where and when each celestial target will be visible. Long-term projects that involve multiple targets and sequential observations, in which each observation depends on the success of a previous one, require even more finesse. Weighing all of these considerations, the scheduler produces a daily observing program for each observatory.

Observing schedules are based on ideal conditions. "Conditions, however, are never ideal," says Eric Saunders, the scheduler's architect. Astronomers may change their existing proposals or introduce new ones. A gamma-ray burst might require the scheduler to drop everything to respond. Clouds can blanket a site or technical difficulties can fell a telescope. All of these things need to be taken into account. LCOGT's software team is working toward a scheduler that can make minute-by-minute adaptations to new developments. Faced with a just-spotted supernova or an incoming thunderstorm, the scheduler can redistribute observations to make sure astronomers gather the data they need.

Faulkes Telescopes North and South

Even though the LCOGT-made telescopes are just starting to see first light, LCOGT's dozen staff astronomers have already been studying supernovae, exoplanets, and near-Earth objects with a pair of 2-meter telescopes that are part of the network. Known as the Faulkes Telescope North and Faulkes Telescope South, they are located on Hawaii's Haleakalā (on Maui) and at Siding Spring Observatory in Australia. Because of their expertise and ability to respond quickly, LCOGT's astronomers are collaborating with multiple surveys for supernovae and exoplanets.

Last summer, the Palomar Transient Factory caught an exceptional supernova in spiral galaxy M101 less than a day after it exploded. The LCOGT supernova group, led by staff scientist Andy Howell, quickly turned the Faulkes Telescope North to the exploding star and gathered observations that are still fueling important scientific research papers.

LCOGT astronomers are also using the Faulkes telescopes to study some of the more than 2,000 planet candidates spotted by NASA's Kepler mission. These exoplanets transit their parent stars, causing the star to dim, if only by a tiny fraction. Once the LCOGT network is complete, its flexibility and speedy reaction time will be a boon to astronomers investigating these planetary transits, which generally last for just a few hours, says Street.

Street and her colleagues are also contributing data to international groups that search for planets by gravitational microlensing. The gravitational field around massive stars can act as a lens, focusing the light of more distant stars as seen from Earth. If a planet orbits the star, its own gravity can bend the light coming from the more distant star. To find an exoplanet this way, astronomers must catch a microlensing event during its short lifespan, which can range from days to months. Having a number of telescopes with ample observing time is critical for attaining sufficient coverage of the event.

One of the important roles of a telescope network such as LCOGT is to provide follow-up study of objects discovered by larger telescopes, says Michael Strauss, a Princeton University astronomer involved in the 8.4-meter Large Synoptic Survey Telescope, a project in which LCOGT is also a partner. "Las Cumbres is very much oriented toward giving astronomers the facilities they need to fol-

A primary goal of the network is the ability to respond quickly to transient objects such as this supernova in M101, recorded by LCOGT's Benjamin Fulton in August 2011.

Faulkes Telescope South in Australia

low up transient and variable objects that require continuous monitoring or that need a quick response," he says.

LCOGT is also contributing to the work of the Panoramic Survey Telescope & Rapid Response System, a wide-field imaging facility on Haleakalā only a football field's distance from Faulkes Telescope North. This sky survey searches for asteroids that come close to Earth.

The Amateur Connection

LCOGT's astronomers and other professionals aren't the only ones who will use the network to better understand asteroids, exoplanets, and more. While the exact design of the program is still in the works, Edward Gomez, LCOGT's education director, estimates there will likely be as many as 100 hours of observation time with network telescopes set aside daily for citizen scientists.

Educational projects will include comet and asteroid research, exoplanets, and astrophotography. As much as half of the 0.4-meter telescope's time and some fraction of the 1-meter's time will be dedicated to citizen scientists pursuing scientific research. The 2-meter Faulkes telescopes already have educational projects with schools in the United Kingdom and Hawaii. In addition, LCOGT's current citizen-science project, Agent Exoplanet, provides images from the Faulkes telescopes and from a LCOGT-built 0.8-meter telescope housed in an observatory near Goleta. Anyone can visit LCOGT's website and study transiting exoplanets by measuring the changing brightnesses of their host stars, helping the LCOGT science team learn more about each planet.

As the telescopes have started settling into place, Rosing and others have set their sights on data calibration. "Making our data easily interchangeable is going to be highly valuable," says Rosing. With telescope time in high demand, the full network will eventually be capable of providing nearly 60,000 hours of annual observing time to astronomers of all levels.

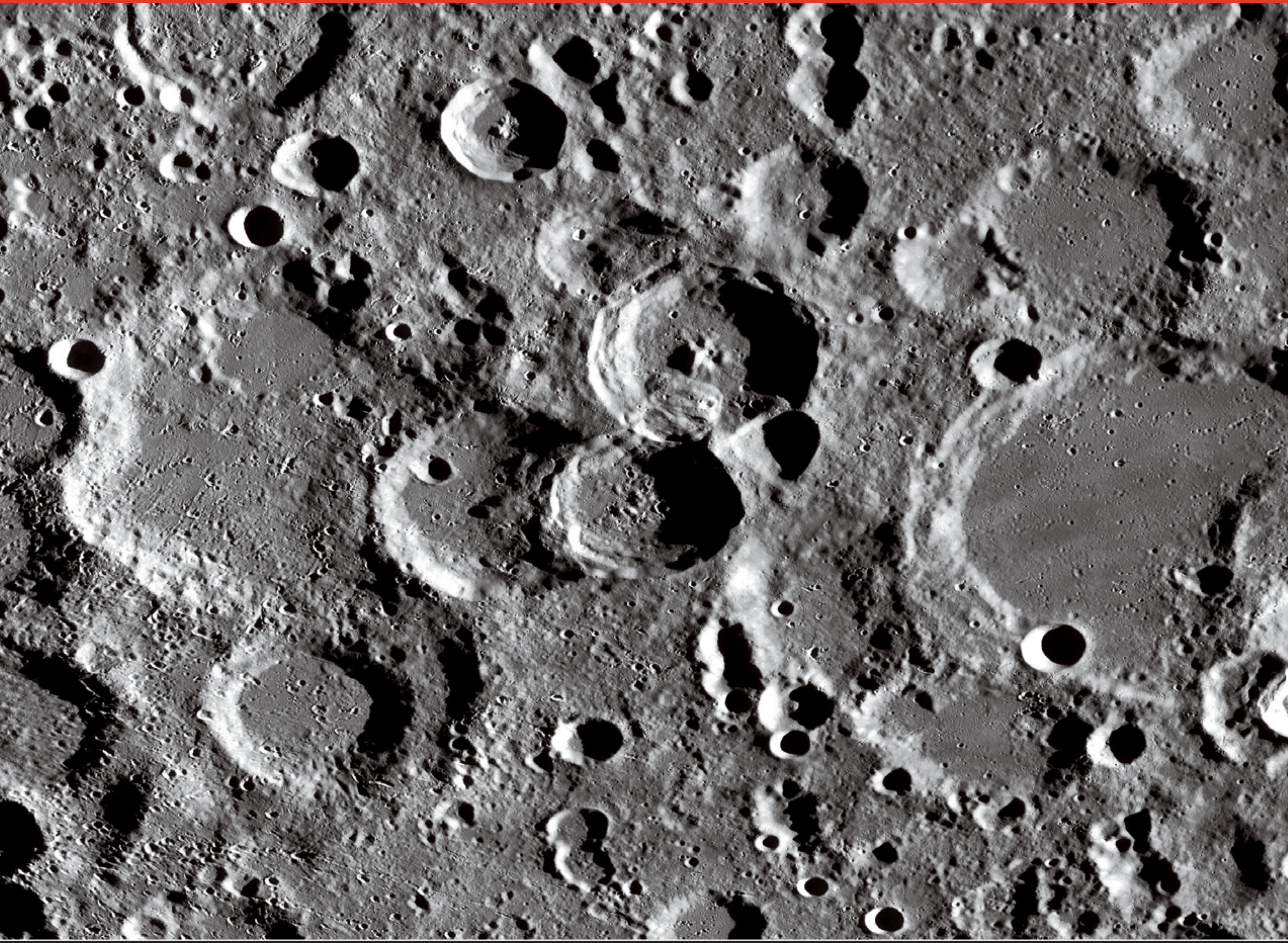
And these hours might be used to pursue high-level research that, even now, seems nearly impossible. Today, an astronomer traveling to an observatory that allocates blocks of observing time by the week may run into logistical and financial barriers when trying to gather a handful of observations over the course of several months. But within a few years, the LCOGT team hopes astronomers using its network can make the same observations from anywhere in the world with a few keystrokes on a laptop.

In fact, one of the biggest challenges may be that astronomers must recalibrate their own vision to take advantage of what a global robotic telescope offers. With the network, almost any observation can be made at any time. "This is going to be something very, very new, and it's a different mindset," says Street. "We're still learning how to make best use of it." ✦

Cameron Walker *covers science, travel, and the environment and writes for the blog* The Last Word On Nothing.

S&T: ROBERT NAEYE

Faulkes Telescope North in Hawaii



In This Section

PHOTOGRAPH: NASA / GSFC / ARIZONA STATE UNIVERSITY

On the Moon, older craters often affect the morphology of craters that form atop them; see page 54.

OBSERVING

Sky at a Glance

OCTOBER 2012

1–5 **DAWN:** Venus is within 2½° of Regulus. They're less than ¼° apart at their closest approach for North America; see page 48.

5 **NIGHT:** The waning gibbous Moon rises around 10 p.m. 3° or 4° below Jupiter (in North America).

12 **DAWN:** Venus shines 6° or 7° left of the waning crescent Moon.

13–27 **DAWN:** Look for the zodiacal light in the east 120 to 80 minutes before sunrise from dark locations at mid-northern latitudes.

14 **DAWN:** Look for a very thin crescent Moon very low in the east starting 45 minutes before sunrise. Bring binoculars.

16 **DUSK:** Use binoculars to search for Mercury and the very thin crescent Moon very low in the west-southwest shortly after sunset.

17, 18 **DUSK:** The waxing crescent Moon passes Mars and Antares low in the southwest.

18–22 **DUSK:** Mars passes a few degrees above Antares — a fine opportunity to compare these deceptively similar-looking objects. Look for them low in the southwest 45 to 90 minutes after sunset.

20–22 **PREDAWN:** Conditions are excellent for the modest Orionid meteor shower; see page 50.

Planet Visibility

	◄ SUNSET	MIDNIGHT	SUNRISE ►
Mercury	SW	Visible through binoculars in late October.	
Venus			E
Mars	SW		
Jupiter	NE	S	W
Saturn		Hidden in the Sun's glow all month.	

PLANET VISIBILITY SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

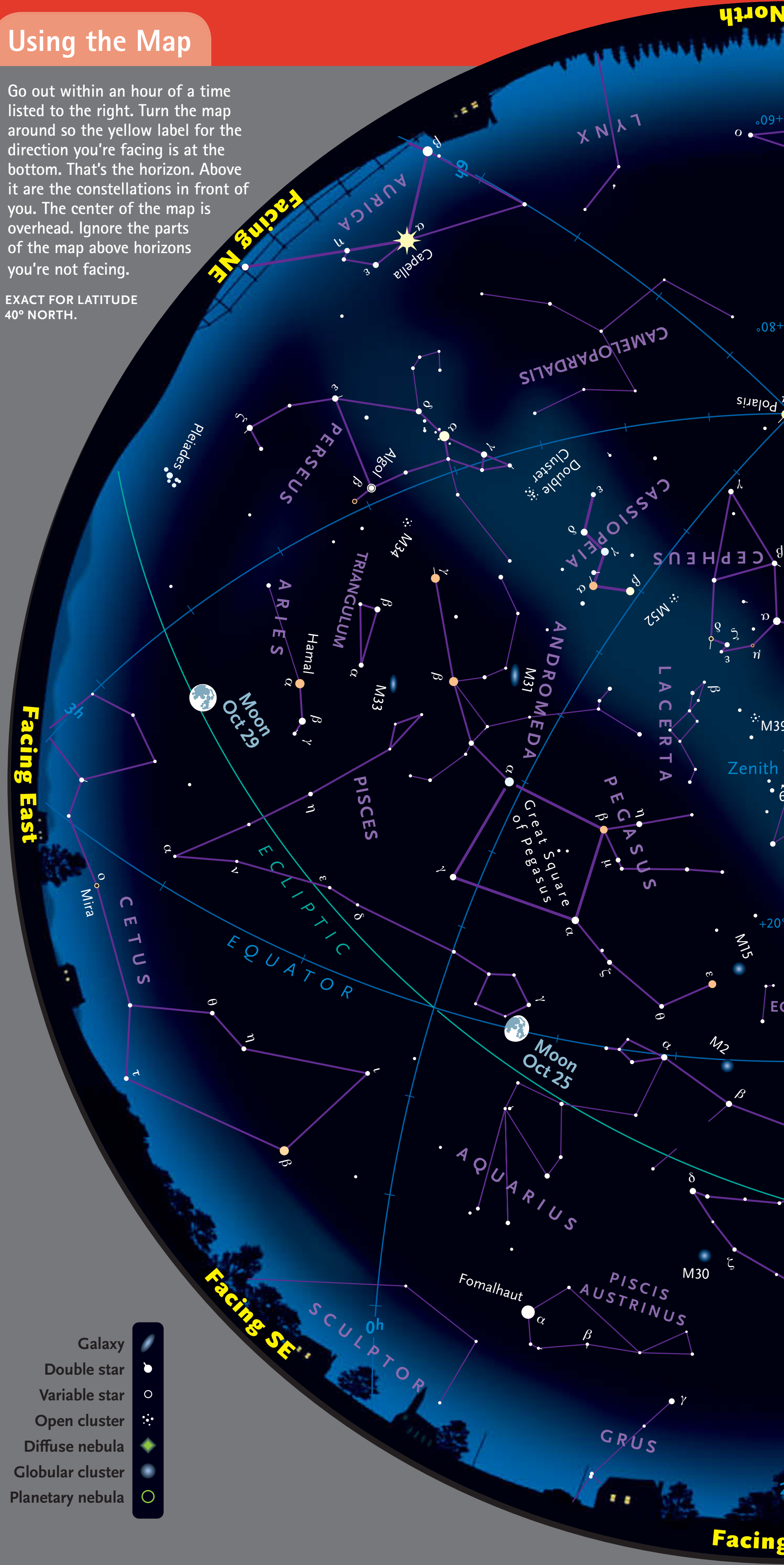
Moon Phases

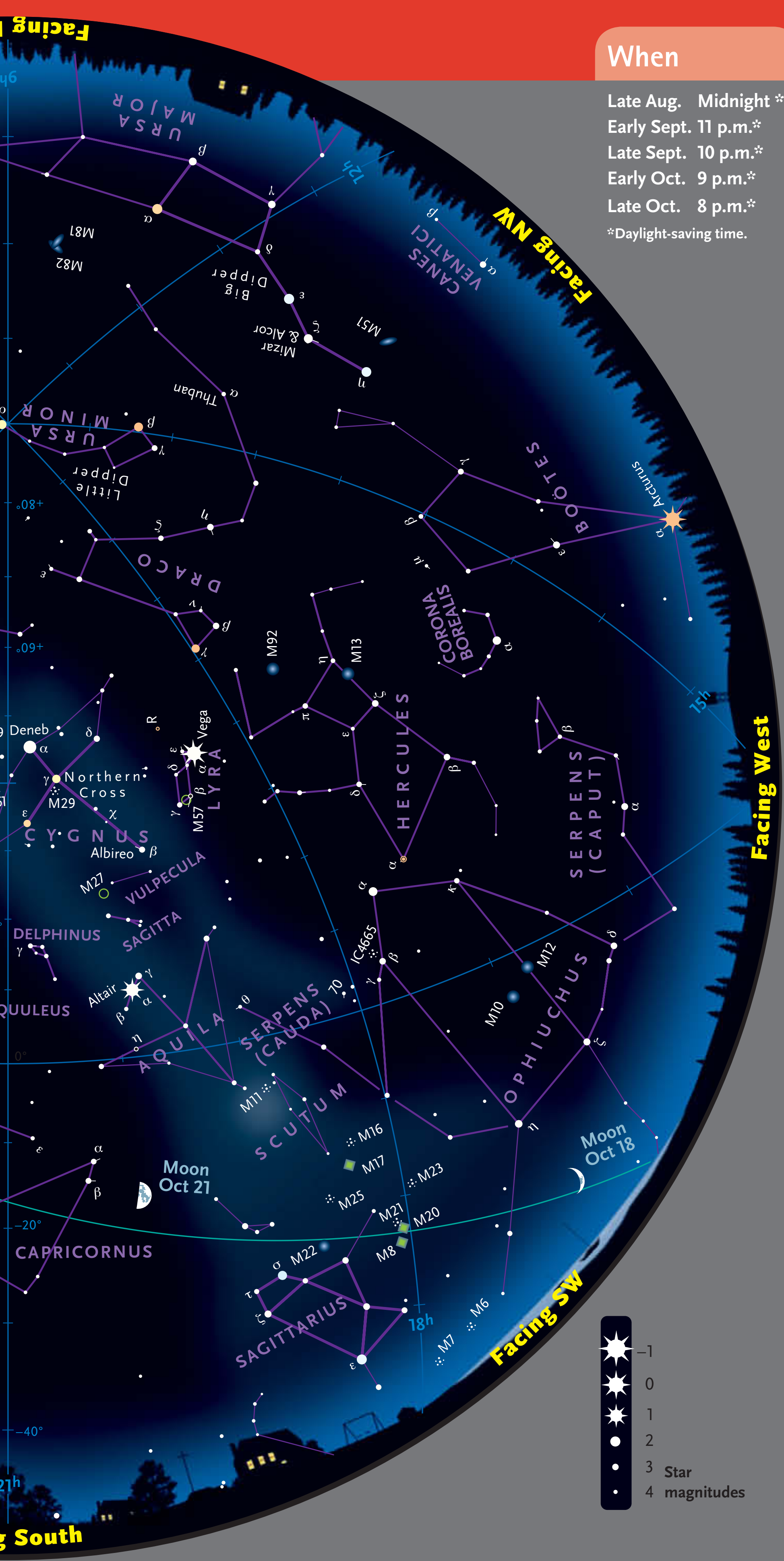
SUN	MON	TUE	WED	THU	FRI	SAT
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

Late Aug. Midnight*
Early Sept. 11 p.m.*
Late Sept. 10 p.m.*
Early Oct. 9 p.m.*
Late Oct. 8 p.m.*

*Daylight-saving time.

Binocular Highlight

NGCs Near and Far

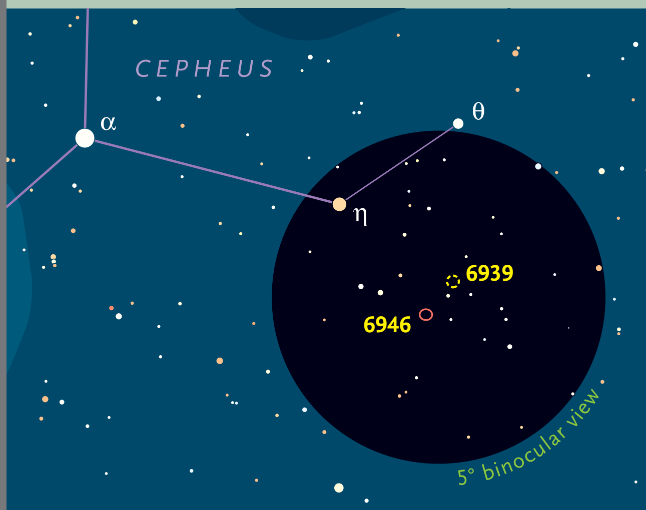
If you own a camera, you're probably familiar with the term "depth of field." Photographers use it to describe the range of distances over which subjects will be rendered sharply focused. A lens setting yielding a large depth of field will show everything from foreground trees to distant mountains clearly. But if you want to see extreme depth of field, train your binoculars on **NGC 6939** and **6946**, situated near the Cepheus/Cygnus border.

The easiest way to locate this deep-sky duo is to imagine that the stars Alpha (α), Eta (η), and Theta (θ) Cephei form a stubby hockey stick. (I'm Canadian, so I can't help seeing hockey sticks in the sky.) The NGC pair is found just off the heel of the stick, less than a half binocular field southwest of Eta. You're going to need reasonably dark skies to see these NGCs — significant light pollution will make them much harder to pick out.

NGC 6939 is a 7.8-magnitude open cluster, while NGC 6946 is a face-on spiral galaxy glowing at magnitude 9.1. Both objects were discovered in 1798 by the great sky surveyor William Herschel, and the galaxy is also designated Caldwell 12 — though curiously, Patrick Moore overlooked its brighter cluster neighbor when he compiled the Caldwell list.

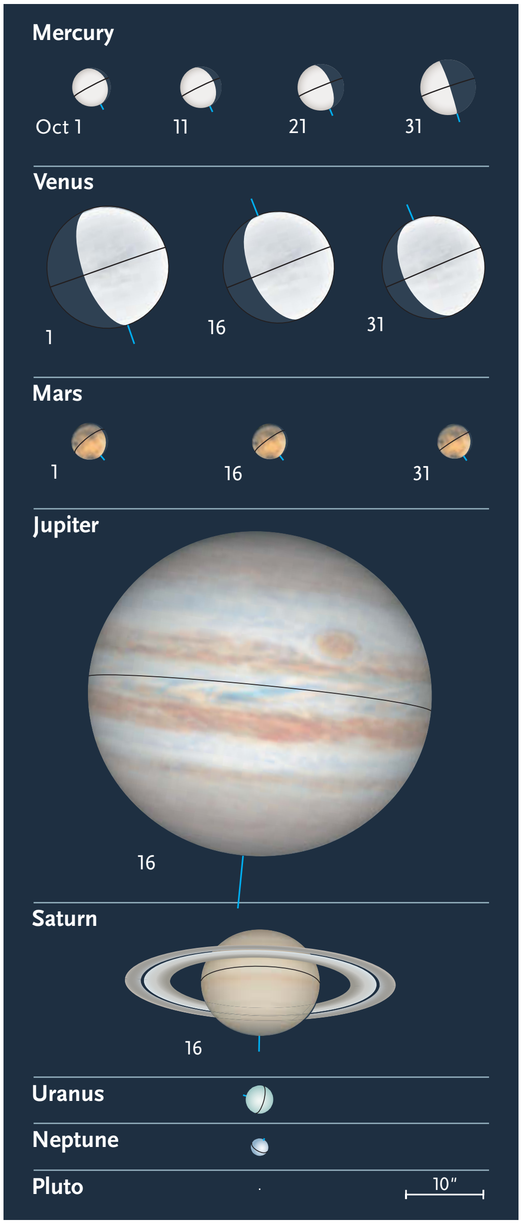
Both objects appear roughly the same size, but when I view them in 10×50 binoculars, the light from galaxy NGC 6946 seems to have a soft quality that the cluster lacks. Do you see this too? In spite of their visual similarity, the two objects lie at vastly different distances. NGC 6939 is nestled in the foreground Milky Way, some 3,900 light-years away, while NGC 6946 lurks far out in deep space, 18 million light-years distant! Now that's what I call *real* depth of field. ✦

— ***Gary Seronik***



Watch a SPECIAL VIDEO

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

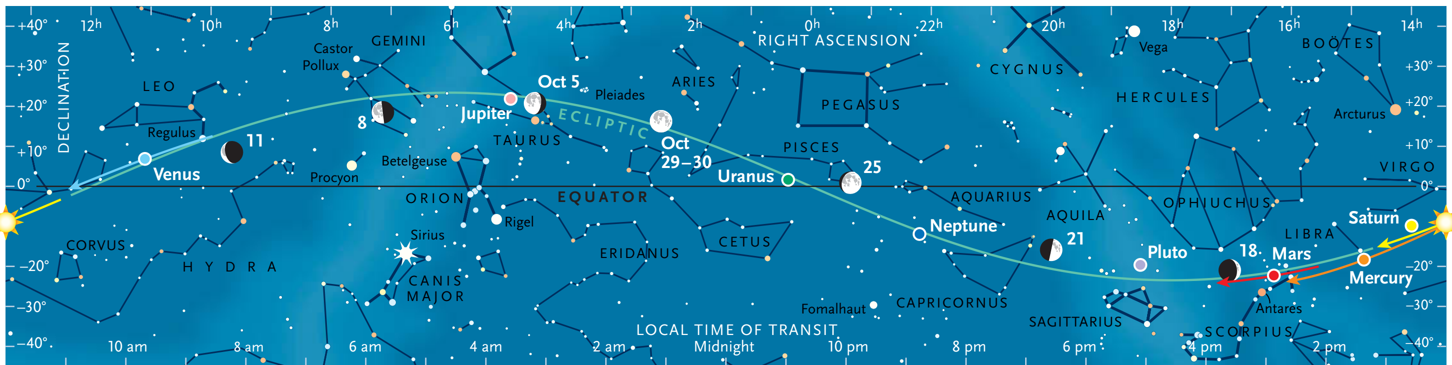


Sun and Planets, October 2012

	October	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	12^h 29.5^m	–3° 11′	—	–26.8	31′ 57″	—	1.001
	31	14^h 21.7^m	–14° 06′	—	–26.8	32′ 13″	—	0.993
Mercury	1	13^h 24.8^m	–9° 20′	15° Ev	–0.4	5.0″	91%	1.346
	11	14^h 19.9^m	–15° 37′	20° Ev	–0.2	5.4″	84%	1.254
	21	15^h 11.7^m	–20° 28′	23° Ev	–0.2	6.0″	73%	1.117
	31	15^h 53.8^m	–23° 17′	24° Ev	–0.1	7.2″	53%	0.936
Venus	1	9^h 57.8^m	+12° 39′	41° Mo	–4.1	15.8″	71%	1.056
	11	10^h 43.0^m	+8° 59′	39° Mo	–4.1	14.8″	74%	1.124
	21	11^h 27.9^m	+4° 49′	37° Mo	–4.0	14.0″	77%	1.189
	31	12^h 12.8^m	+0° 20′	35° Mo	–4.0	13.3″	80%	1.251
Mars	1	15^h 31.8^m	–19° 56′	47° Ev	+1.2	4.8″	93%	1.942
	16	16^h 16.3^m	–22° 16′	43° Ev	+1.2	4.7″	94%	2.000
	31	17^h 03.3^m	–23° 50′	39° Ev	+1.2	4.6″	95%	2.053
Jupiter	1	5^h 00.3^m	+21° 54′	112° Mo	–2.5	43.1″	99%	4.576
	31	4^h 55.4^m	+21° 46′	143° Mo	–2.7	46.7″	100%	4.218
Saturn	1	13^h 52.0^m	–9° 06′	21° Ev	+0.7	15.5″	100%	10.694
	31	14^h 05.6^m	–10° 22′	5° Mo	+0.6	15.4″	100%	10.764
Uranus	16	0^h 22.1^m	+1° 35′	163° Ev	+5.7	3.7″	100%	19.107
Neptune	16	22^h 10.6^m	–11° 56′	128° Ev	+7.9	2.3″	100%	29.376
Pluto	16	18^h 29.6^m	–19° 44′	74° Ev	+14.1	0.1″	100%	32.574

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-October; 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). All Moon dates are in October. "Local time of transit" tells when (in Local Mean Time) objects cross the meridian — that is, when they appear due south and at their highest — at mid-month. Transits occur an hour later on the 1st, and an hour earlier at month's end.

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

Fred Schaaf

The Sky Through the Forest

Trees can frame and enhance a starry night sky.

A lot of backyard astronomers are plagued by trees or buildings that block the view of the sky in some or all directions. Fortunately, many of the best celestial scenes visible on October evenings are high enough in the sky to escape such obstruction. The Summer Triangle, Pegasus and Andromeda, Cassiopeia and Cepheus, and all the tantalizing objects in them, are now above most treetops and city skylines.

But I'm going to argue for what may at first seem an outlandish proposition — that trees and buildings in our skyscape can often *add* to our enjoyment of astronomy.

October's opening skies. October is a month when the trees in many northern lands flame to their brightest — just when the evening's southern sky is dimmest, flooded with faint watery constellations Capricornus, Piscis Austrinus, Aquarius, Pisces, and Cetus.

But October is also when many of us watch the leaves start to fall, opening up more sky to our view. And October's rapidly lengthening nights increase the amount of time that the night sky is visible.

A window on a darker sky. Even after the trees lose their leaves, their trunks and branches partly block the stars. And buildings always maintain the same amount of obstruction. But sometimes, believe it or not, obstruction can be good.

Blocking the lower regions of the sky with trees or buildings hides the brightest glow of light pollution. As a matter of fact, though few observers realize it, looking at a relatively small area of sky from a clearing or path in the forest can improve your naked-eye limiting magnitude hugely. Scores of extra stars stand out. Technically, you can get a similar result by cupping your hands around your eyes. But how much better it is to walk freely, arms down, under a darker, starrier sky.

Can you find a forest road, perhaps at a local state park, which runs northeast to southwest? If so, on an October evening you can turn it into a Milky Way Lane. Above, behind, and ahead the trees block everything but the glorious band of the Milky Way, from Sagittarius low in the southwest through Scutum to Cygnus overhead, then down again through Cassiopeia and Perseus to Capella, which is rising in the northeast. We're always in the equatorial disk of the Milky Way Galaxy. But on a night and a path like this, you're walking more precisely and visibly in this majestic, magical plane.

PER-MAGNUS HEDÉN / TWAN

The Cygnus Star Cloud glimmers through the trees during an autumn evening in Sweden.

Nick Hunter and Delphinus. Next month I will have much more to say about how trees and buildings provide essential borders to the sky in many of our loveliest astrophotgraphs, and how they link our landscape and ourselves to the heavens. But right now I have an answer to last month's question: Who is Nick Hunter?

Nick Hunter is not a film-noir detective. He's the man who has two stars in Delphinus named for him. It's the English translation of Niccolo Cacciatore, observatory assistant to Giuseppe Piazzi (discoverer of the first asteroid). In 1814 Piazzi slyly slipped into his *Palermo Catalogue* the names Sualocin and Rotanev for Alpha and Beta Delphini, respectively. It took decades for anyone to realize that these were backward spellings of the Latinized version of Niccolo Cacciatore — Nicolaus Venator. ✦

Bright Planets Late and Early

Jupiter and Venus dominate the late-night and predawn skies.

Mars is the only planet easily visible without optical aid at nightfall in October, but brilliant Jupiter rises not long after. Then it's a long wait until the next planet — Venus, the brightest — appears about 3 hours before sunrise. But on October 3rd Venus has an extraordinarily close conjunction with Regulus that's well worth rising early to view.

DUSK AND EVENING

Saturn is soon lost in the Sun's afterglow this month, and **Mercury** hardly rises out of it — for viewers at mid-northern latitudes, anyway.

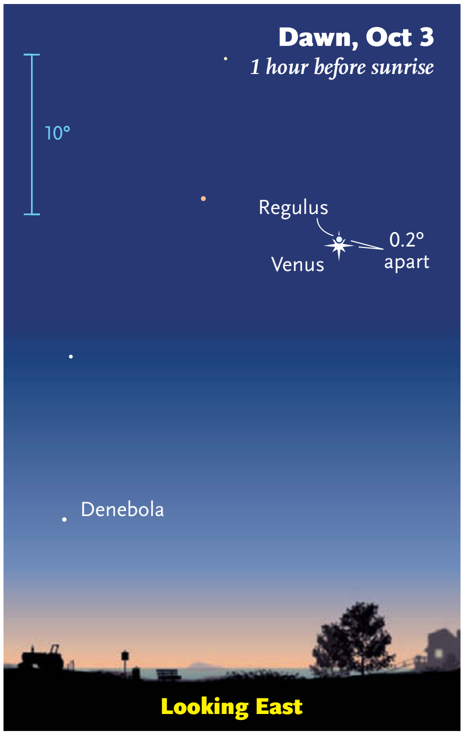
On October 1st Saturn is still 20° from the Sun. But the angle of the ecliptic is shallow for northern viewers, so you will likely need binoculars to spot the 0.7-magnitude planet just 5° above the west-southwest horizon a half hour after sunset.

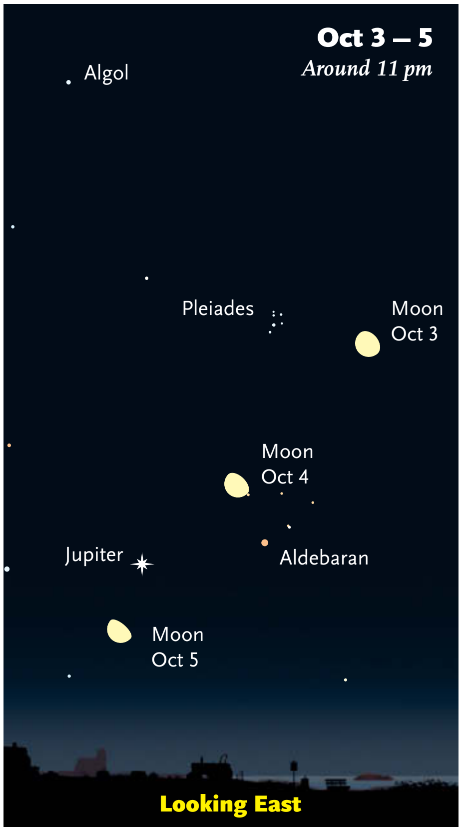
Saturn appears lower every evening, reaching conjunction with the Sun on October 25th. On the next day, Mercury attains greatest elongation, 24° from the Sun. But Mercury is then well south of the already low ecliptic, so it's only 3° to 4° above the southwest horizon a half hour after sunset. That's probably too low to spot without binoculars even though Mercury shines at magnitude –0.1.

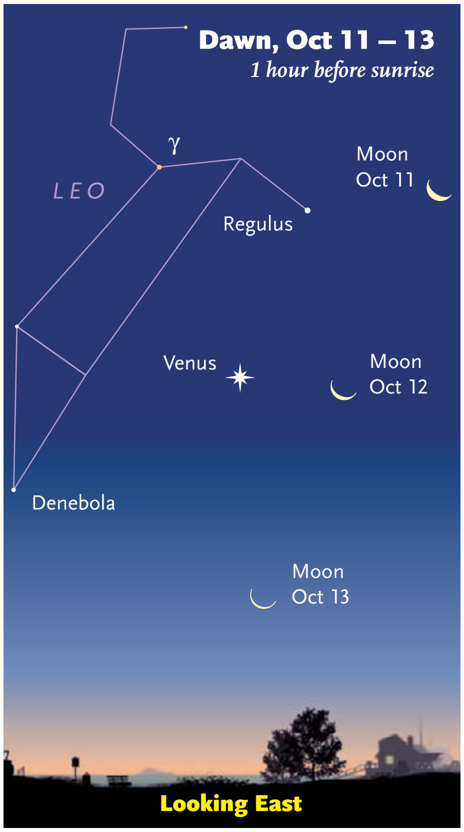
Mars, at magnitude +1.2, is fainter than Mercury but much easier to view because it's higher — about 12° above the southwest horizon 45 minutes after sunset. Remarkably, Mars's continuing swift eastward motion relative to the stars keeps it setting two hours after the Sun from September 1st through the rest of the year.

In a telescope Mars appears tiny, only about 4.7″ across in October — a blurry orange dot. But it will be fascinating to watch the Red Planet cross northern Scorpius with your unaided eyes or binoculars. On October 10th and 11th it passes between the unusual variable star Delta Scorpii and the beautiful, wide telescopic double star Beta Scorpii. On October 20th Mars reaches its minimum distance of 3½° above slightly brighter Antares — a good opportunity to compare their famously similar colors.

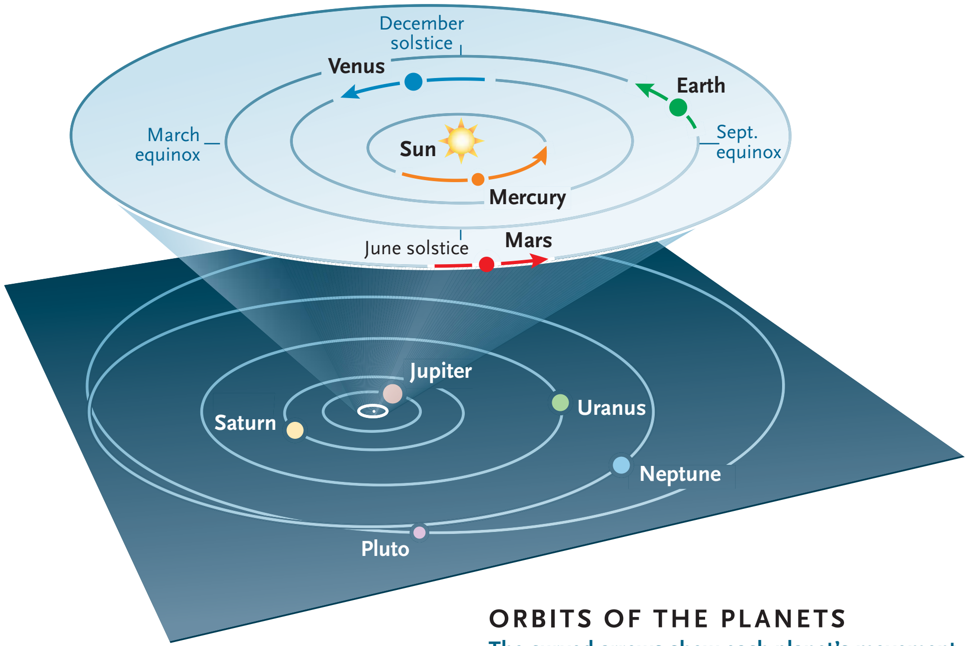
Pluto, in Sagittarius, is best sought at the end of evening twilight, but it's already past its highest in the south even then. Use the chart on page 52 of the June issue to locate its feeble 14th-magnitude light.







Uranus, in Pisces, and **Neptune**, in Aquarius, are both high enough to view as soon as the sky grows fully dark. Neptune reaches its highest point in the south in late evening, and Uranus does the same by midnight. For charts, see last month's issue, page 50, or **skypub.com/urnep**.



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

EVENING TO DAWN

Jupiter rises around 10 p.m. (daylight-saving time) on October 1st and around 8 on October 31st. The giant planet brightens slightly during the month, from magnitude –2.5 to –2.7, and enlarges from 43″ to 46″. Jupiter is well north of the celestial equator, so it's high enough for excellent telescopic observation by midnight. But it's highest in the south — very high indeed — a few hours before dawn.

Jupiter is in Taurus east of Aldebaran and the Hyades. It halts its direct (eastward) motion relative to the stars on October 4th and begins to retrograde slowly back toward Aldebaran, narrowing the gap from 8° to 7°.

Venus shines as the brilliant Morning Star in the east before and during dawn. It rises about 3½ hours before the Sun as October opens, and 3 hours before the Sun at month's end. It fades marginally, from magnitude –4.1 to –4.0, shrinks from 16″ to 13″, and its gibbous phase grows from 71% to 80% illuminated.

From September 29th through October 7th, Venus is within 5° of Regulus, fitting in the same field of view in most binoculars. Throughout this period, some of us may notice an enhancement of their subtle colors because their contrast is more obvious when they're near each other. The hint of yellow in Venus and touch of blue in Regulus should be exaggerated to the unaided eye.

Venus will be within 2½° of Regulus from October 1st through 5th. But the stunning morning, well timed for viewers in the Americas, is October 3rd. Venus and Regulus will be less than 8′ apart when they rise that morning on the U.S. East Coast. The pair is opening hour by hour, so they will be about 12′ apart by the time they rise on the West Coast. Venus shines about 150 times brighter than Regulus. Will the 1st-magnitude star be lost in Venus's glare for naked-eye observers? Certainly the view in binoculars and telescopes will be wonderful.

The closest Venus-Regulus conjunction in modern times was the occultation of Regulus by Venus in September 1959.

Venus races on eastward for the rest of the month, crossing from Leo into Virgo on October 23rd.

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

MOON PASSAGES

The waning gibbous **Moon** is in the Hyades above Jupiter and Aldebaran late on the evening of October 5th and lower left of Jupiter on the 6th. A thin waning crescent poses beautifully to the right of Venus before sunrise on October 12th.

Back in the evening sky, binoculars may show the very thin crescent Moon right of Mercury extremely low in the west-southwest shortly after sunset on October 16th. And the waxing crescent makes compact triangles with Mars and Antares higher at dusk on October 17th and 18th. ✦

October Meteors Slow & Fast

Two contrasting meteor showers enrich mid-autumn's night skies.

As Earth wheels through the October portion of its orbit around the Sun, it passes through two reliable annual meteoroid streams: one fast, one slow, both long-lasting.

• **The Taurids** are slow and graceful. They originate from the unusually short-period comet 2P/Encke and other objects that seem to be ancient Encke breakup products, including the dormant, asteroid-like comet 2004 TG_{10}. The Taurid stream is very broad, so the shower is exceptionally long-lasting; it runs throughout October, November, and into December. It has two distinct portions, the Northern and Southern Taurids, with radiants about 9° apart. Both remain active throughout these 2½ months, though the Southern Taurids come to their full strength first.

The Taurids are not very exciting in terms of numbers. A careful counter might log about a half dozen per hour from late October through November under ideal observing conditions. But at least you don't have to go out at a predawn hour; the radiants in Taurus reach a high altitude by late evening in October and mid-evening in November.

NASA / HIROYUKI IIDA

A Taurid fireball showed through thin clouds over Toyama, Japan, on October 28, 2005. The brightest star is Sirius. Orion is near upper center, and near the top right corner are Aldebaran and some of the Hyades in Taurus.

What's exciting about the Taurids is their occasional dazzling fireballs. Whatever happened to Comet Encke during its putative breakups in the past 20,000 years, the events left an unusual number of large chunks scattered amid the little debris bits of the kind that make up most meteoroid streams. If you see a grand fireball during these months, trace its path backward across the sky and see if the line intersects Taurus. That goes for *daytime* fireballs too, if you see them in the morning. Taurus doesn't set in the west until roughly 9 a.m. daylight-saving time in October, though sooner after sunrise in November. In late October and early November 2005, numerous "Halloween fireballs" made news around the world.

Some have suggested that the brightest meteor in recorded history — the several-megaton Tunguska explosion on June 30, 1908 — was a Taurid. In June Earth passes through a different part of the Taurid stream, causing a daytime shower. However, meteor expert Peter Jenniskens dismisses the idea. "The Tunguska fireball penetrated down to 8 km altitude," he says. "[Zdenek] Sekanina did a nice paper showing that you need relatively strong material to survive this deep into the atmosphere. Taurids have the strength of other cometary materials: they are fragile and fall apart high in the atmosphere."

Interestingly, however, an excess of Earth-crossing asteroids are reported to have Taurid-like orbits.

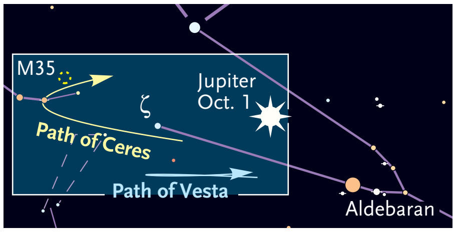
• **The Orionid shower** is more conventional. These fast-moving meteors reach an irregular peak from about October 20th through 24th, though some appear from mid-October into December. They radiate from the top of Orion's Club, which doesn't rise high until early-morning hours. By then the roughly first-quarter Moon this year will have set.

The Orionids are bits of Comet 1P/Halley, as are the Eta Aquariids of May — another case of one meteoroid stream crossing Earth's orbit in two places. Historically the Orionids have produced about 20 swift meteors per hour in a dark sky before dawn, but from 2006 to 2009 the shower was richer, with zenithal hourly rates of 40 to 70 per hour on two or three nights running. In more recent years the numbers have returned closer to normal.

Ceres & Vesta near Jupiter

The two leading lights of the asteroid belt, 1 Ceres and 4 Vesta, continue creeping among the stars near blazing-bright Jupiter in the eastern late-night sky. In September and October the two asteroids are just 6° to 10° apart. In the August issue (page 53) we presented charts for summer months when Venus was also part of the scene. Here we continue the coverage as the asteroids brighten.

Both objects double back on themselves on the chart below, as they begin their westward retrograde loops. Vesta shines at magnitude 8.1, 7.8, 7.2, and 6.6 on the 1st of September, October, November, and December, respectively. Ceres is magnitude 8.9, 8.5, 8.0, and 7.3 on those dates. Stars on the chart are plotted to magnitude 8.5.



The little key chart includes Jupiter, which is plotted for October 1st and remains near this position from September through November. Use it to find 3rd-magnitude Zeta (ζ) Tauri. Then use the big chart to star-hop with your finderscope from Zeta to the asteroids' locations for your date. A 5°-wide finderscope view is half as tall as the chart. (Jupiter and its path are omitted from that chart to keep it simple.)

Stop in for a look at the Crab Nebula near Zeta while you're there, and also check out the lovely double star Struve 742 (magnitudes 7.2 and 7.8, current separation 4.2″) just ½° to the Crab's east.

Vesta will come to opposition on December 9th at magnitude 6.4, Ceres on December 18th at 6.7. We'll resume the map in the December issue.

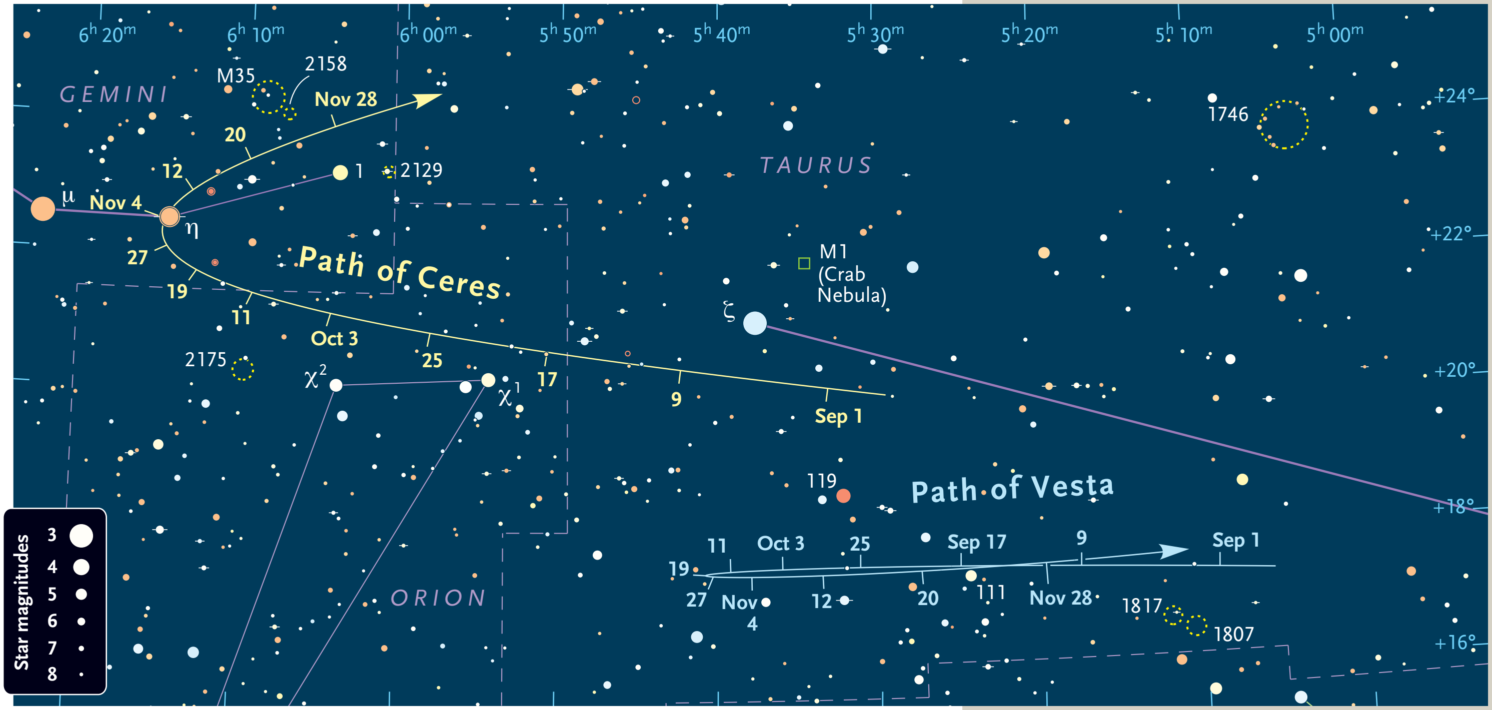
These are the two asteroids that NASA's Dawn spacecraft is visiting for extended stays. Dawn started orbiting Vesta in July 2011. It's scheduled to leave Vesta in late August 2012 and arrive at Ceres in February 2015 (last month's issue, page 32).

A Jupiter Reversal

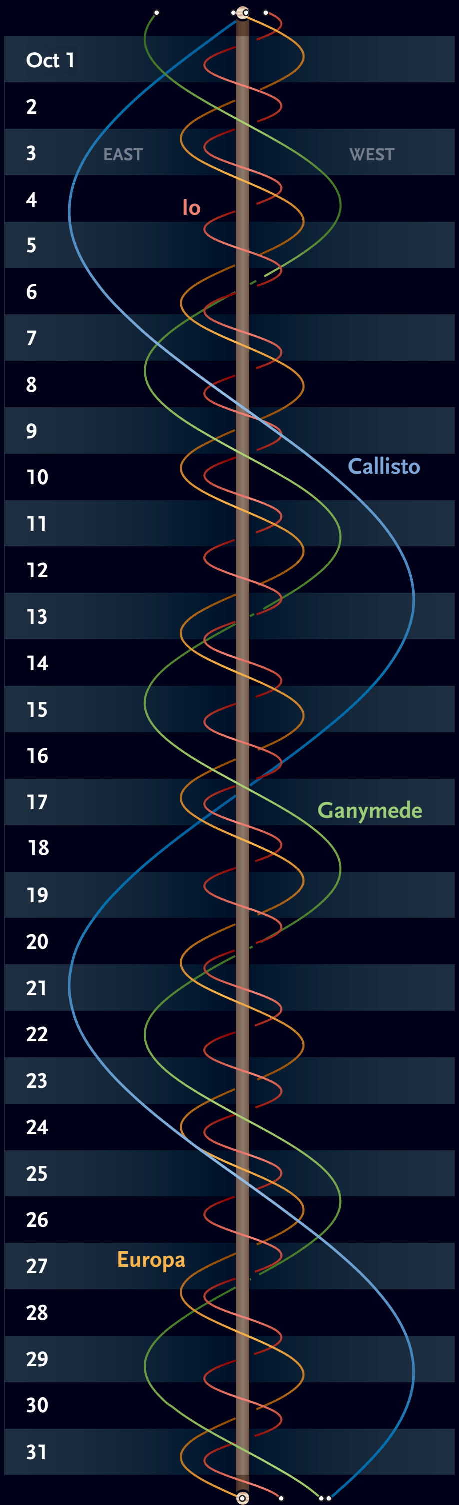
CHRISTOPHER GO

Jupiter is always changing. By July 15th, when the planet was coming out of the pre-dawn murk for its 2012–13 apparition, it was showing a surprising belt reversal. The South Equatorial Belt (just above center) was relatively narrow and dark, while the North Equatorial Belt had grown very broad and pale — their opposite from last year! The Great Red Spot (upper left of center) is pale. A thin Equatorial Band runs along the center of the white Equatorial Zone.

Below: **Ticks mark the asteroids' positions every eight days at 0:00 UT (8:00 p.m. on the previous date EDT).**



Jupiter's Moons



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

Action at Jupiter

Jupiter rises during mid-evening in October, and it's high enough for good telescopic views by midnight, shining in the east between Aldebaran and Beta Tauri. It's highest in the south by 4 a.m. daylight-saving time at the start of October and 2 a.m. at month's end — the best time for observing how the appearances of it two main belts have reversed since last year (see the photo and caption on the preceding page).

Even the smallest telescope shows Jupiter's four big Galilean moons with ease. Binoculars usually reveal at least two or three if you can brace the binoculars steady enough. Identify the moons with the diagram at left. You can see their precise positions at any time using **skypub.com/jupsats**.

All of the moons' interactions with Jupiter's disk and shadow in October are listed on the facing page. The moons are often tricky to spot when they pass in front of Jupiter; their shadows on the planet's disk are much easier to see.

Here are the times, in Universal Time, when Jupiter's Great Red Spot should cross the planet's central meridian, the imaginary line down the center of Jupiter from pole to pole. The dates (also in UT) are in bold. Eastern Daylight Time is UT minus 4 hours; Pacific Daylight Time is UT minus 7 hours. The Red Spot appears closer to Jupiter's central meridian than to the limb for 50 minutes before and after these times:

October 1, 4:39, 14:35; **2,** 0:30, 10:26, 20:22; **3,** 6:17, 16:13; **4,** 2:09, 12:04, 22:00; **5,** 7:55, 17:51; **6,** 3:47, 13:42, 23:38; **7,** 9:34, 19:29; **8,** 5:25, 15:21; **9,** 1:16, 11:12, 21:07; **10,** 7:03, 16:59; **11,** 2:54, 12:50, 22:45; **12,** 8:41, 18:37; **13,** 4:32, 14:28; **14,** 0:24, 10:19, 20:15; **15,** 6:10, 16:06; **16,** 2:02, 11:57, 21:53; **17,** 7:48, 17:44; **18,** 3:40, 13:35, 23:31; **19,** 9:26, 19:22; **20,** 5:18, 15:13; **21,** 1:09, 11:04, 21:00; **22,** 6:56, 16:51; **23,** 2:47, 12:42, 22:38; **24,** 8:34, 18:29; **25,** 4:25, 14:20; **26,** 0:16, 10:12, 20:07; **27,** 6:03, 15:58; **28,** 1:54, 11:50, 21:45; **29,** 7:41, 17:36; **30,** 3:32, 13:28, 23:23; **31,** 9:19, 19:14.

These times assume that the spot is centered at System II longitude 184°. If it has moved elsewhere, it will transit 1⅔ minutes late for every 1° of longitude greater than 184°, or 1⅔ minutes early for every 1° less than 184°. The Red Spot has

Three Asteroid Occultations

In October at least three good asteroid-occultation paths cross thickly settled areas of North America:

• **Before dawn on October 13th,** along a path from Southern California through central Texas, the faint asteroid 371 Bohemia occults an 8.9-magnitude orange star near the Beehive Cluster in Cancer high in the sky. The occultation happens within a couple minutes of 11:54 Universal Time and will last for up to 2 seconds.

• **Late on the night of October 21-22,** along a path from Southern California through Wyoming and Winnipeg, 11.9-magnitude 521 Brixia occults a 10.5-magnitude star by Orion's club within a few minutes of 7:14 October 22nd UT. The asteroid is moving slowly, so the occultation could last for up to 23 seconds.

• Just after dark on the **evening of October 31st,** along a path from Florida through Michigan, faint 35 Leukothea, also slow moving, occults a 10.6-magnitude star in Aquarius for up to 39 seconds within a few minutes of 0:18 November 1st UT.

Finder charts, path maps, further details, and lots more such predictions worldwide are at **www.asteroidoccultation.com/IndexAll.htm**.

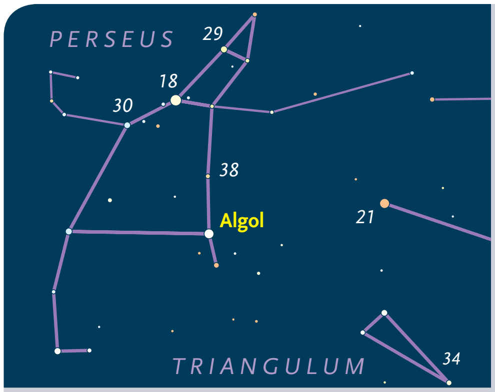
been gradually moving to higher longitudes for many years.

Markings on Jupiter appear a little more contrasty through a blue or green eyepiece filter. The larger your scope, the darker the blue or green can be; you want enough light to see fine details clearly, but not so much that you lose visual details to glare (overexposure).

Try several magnifications to find the one that shows the most detail given the quality of the atmospheric seeing.

And keep looking! More and more flickers of features come out with protracted scrutiny. ✦

Minima of Algol



Algol, the prototype eclipsing variable star, fades every 2.87 days from its usual 2.1 magnitude to 3.4. It stays near minimum light for two hours, and takes several more hours to fade and to rebrighten. Shown above are magnitudes of comparison stars with decimal points omitted. (These geocentric predictions are from the heliocentric elements Min. = JD 2452253.559 + 2.867362*E*, where *E* is any integer. Courtesy Gerry Samolyk, AAVSO.)

Sept.	UT	Oct.	UT
2	17:48	1	9:55
5	14:36	4	6:43
8	11:25	7	3:32
11	8:14	10	0:21
14	5:02	12	21:10
17	1:51	15	17:58
19	22:40	18	14:47
22	19:28	21	11:36
25	16:17	24	8:25
28	13:06	27	5:14
		30	2:03

Phenomena of Jupiter's Moons, October 2012

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

Every day, interesting events happen between Jupiter's satellites and the planet's disk or shadow. The first columns give the date and mid-time of the event, in Universal Time (which is 4 hours ahead of Eastern Daylight Time). Next is the satellite involved: **I** for Io, **II** Europa, **III** Ganymede, or **IV** Callisto. Next is the type of event: **Oc** for an occultation of the satellite behind Jupiter's limb, **Ec** for an eclipse by Jupiter's shadow, **Tr** for a transit across the planet's face, or **Sh** for the satellite casting its own shadow onto Jupiter. An occultation or eclipse begins when the satellite disappears **(D)** and ends when it reappears **(R)**. A transit or shadow passage begins at ingress **(I)** and ends at egress **(E)**. Each event is gradual, taking up to several minutes. Predictions courtesy IMCCE / Paris Observatory.

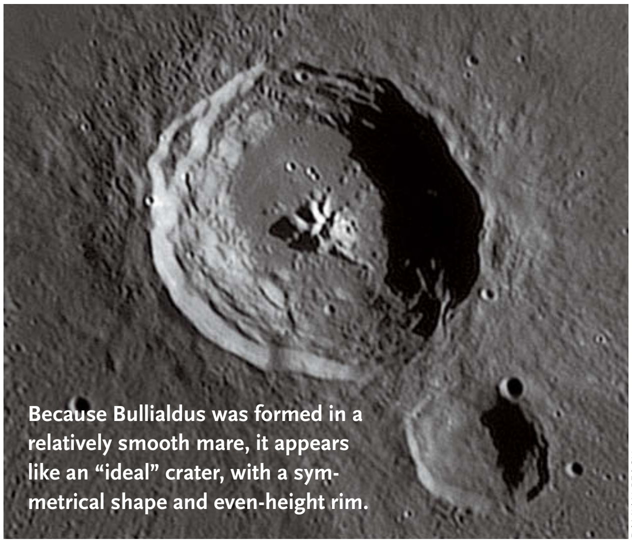
Uneven Targets

Visual clues help observers determine the order of crater formation.

Craters come in many different shapes and sizes. An "ideal" crater forms when a comet or asteroid slams into the lunar terrain, excavating a circular crater with walls roughly the same height all around its circumference. Although small craters closely resemble this ideal, larger craters frequently tend to deviate from the stereotype due to variations in the terrain they marred.

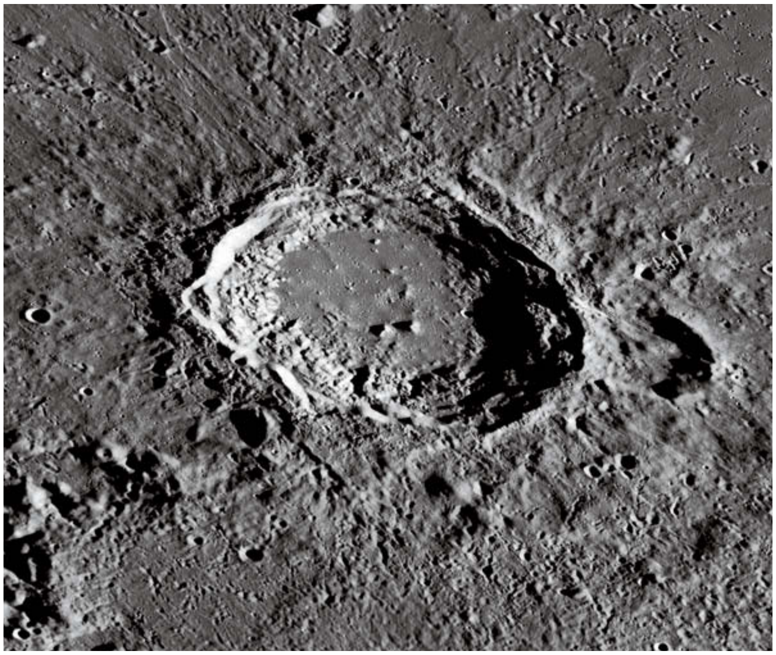
For projectiles that hit a relatively level target area, the dynamics of the impact process control the crater shape. A good example of a large crater with a near-ideal rim is **Bullialdus**. The projectile that formed the 61-kilometer-wide (38-mile) crater crashed into relatively smooth lava flows in western Mare Nubium, excavating a textbook-like crater with a relatively even rim all around.

More commonly, projectiles smash into uneven terrain. This was always true for craters that formed in the lunar highlands, but it happened surprisingly often in the maria, too. A well-known example is the 88-km-wide crater **Aristoteles**, which partially overlaps the 32-km **Mitchell**. Where it covers the smaller crater, the rim of Aristoteles is about 600 meters lower than its average height. Although the rim mostly retains its circular shape, some of its rim material slid across the floor of Mitchell, lowering Aristotles' rim. This demonstrates a common result: the pre-existing feature suffers more modification than the newer crater.



Because Bullialdus was formed in a relatively smooth mare, it appears like an "ideal" crater, with a symmetrical shape and even-height rim.

DAMIAN PEACH



NASA / GSFC / ARIZONA STATE UNIVERSITY

Lunar crater appearances are often influenced by older features. Aristoteles would appear nearly symmetrical had its eastern edge not slumped over Mitchell.

Sometimes though, a pre-existing feature is big enough that it affects the height of the subsequent crater's rim. Let's look at 100-km-wide **Theophilus**. This large crater formed on the rim of the similar-sized crater **Cyrillus**. The side of Theophilus that overlaps Cyrillus is one kilometer higher than its opposite rim. Even the crater floor dips down from the Cyrillus side to the north: strong proof that large, pre-existing craters can effectively influence later overlapping features.

In the lunar highlands, every new crater formed on top of older ones. The 115-km-wide feature **Maurolycus** is a prime example. Maurolycus is not a fresh crater, but it cut through the middle of at least two large, older craters, one to its south and another on its northwest edge. Most of the remaining floor of the southern crater is filled with Maurolycus's collapsed rim, visible in your telescope under low lighting. Because Maurolycus cut through the centers of these large pre-existing craters, its intersections with those craters are the lowest points — by as much as 3½ kilometers — of Maurolycus's rim.

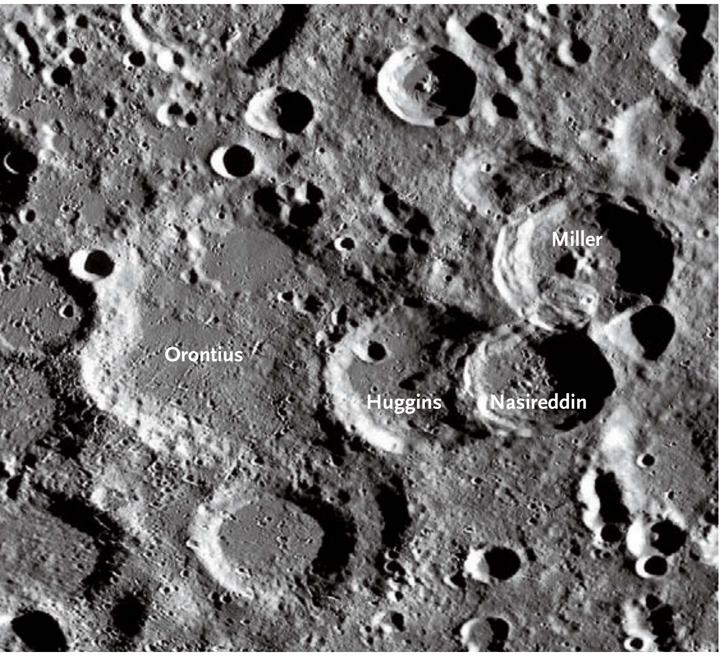
My favorite example of overlapping highland craters is the cluster containing **Orontius**, **Huggins**, **Nasired-**

Maurolycus, like nearly all craters in the southern highlands, formed over older craters, significantly influencing its appearance.

DAMIAN PEACH

din, and **Miller**. The first thing an observer can do while examining this group is to figure out the sequence of formation. The first law of stratigraphy — what is on top is youngest — is all you need. Lots of small craters are piled on the rim of Orontius, proving it must be the oldest. Huggins juts into the eastern floor of Orontius, so it formed next, and Nasireddin slices into Huggins. It would seem at first glance that Miller is even younger than Nasireddin, but look closer. Although the rims of Miller and Nasireddin are tangent, a large mass of rim material extends across Miller's floor nearly to its central peak. This demonstrates that Nasireddin formed last, causing landslides into Miller and, if you look closely, into Huggins too. In fact, the two lowest parts of Nasireddin's rim are where it overlaps Huggins and Miller, those places being 2.1 and 1.7 km lower than the rest of the rim.

Now that you recognize how pre-existing topography affects craters, you can incorporate that into your interpretations of lunar history whenever you observe. ✦



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Carefully observing the overlap of craters can reveal the order in which they were formed. Orontius, Huggins, and Nasireddin formed in an obvious sequence, but Nasireddin and Miller require closer examination to determine which came first.

The Moon • October 2012

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

S&T: DENNIS DI CICCO

Phases

October 8	October 15	October 22	October 29
LAST QTR MOON	**NEW MOON**	**FIRST QTR MOON**	**FULL MOON**
7:33 UT	12:03 UT	3:32 UT	19:49 UT

Distances

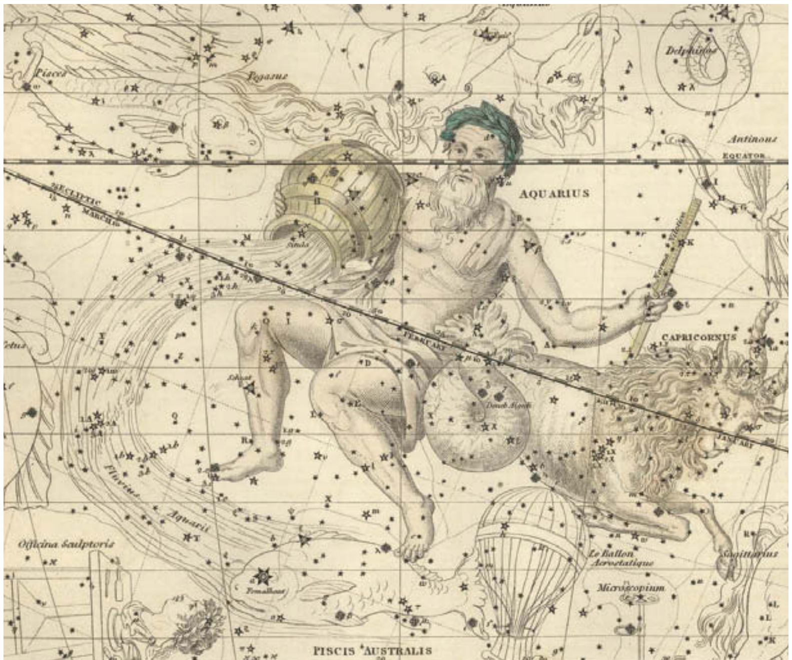
Perigee	October 5, 1h UT
251,755 miles	diam. 29′ 38″
Apogee	October 27, 1h UT
224,111 miles	diam. 33′ 3″

Librations

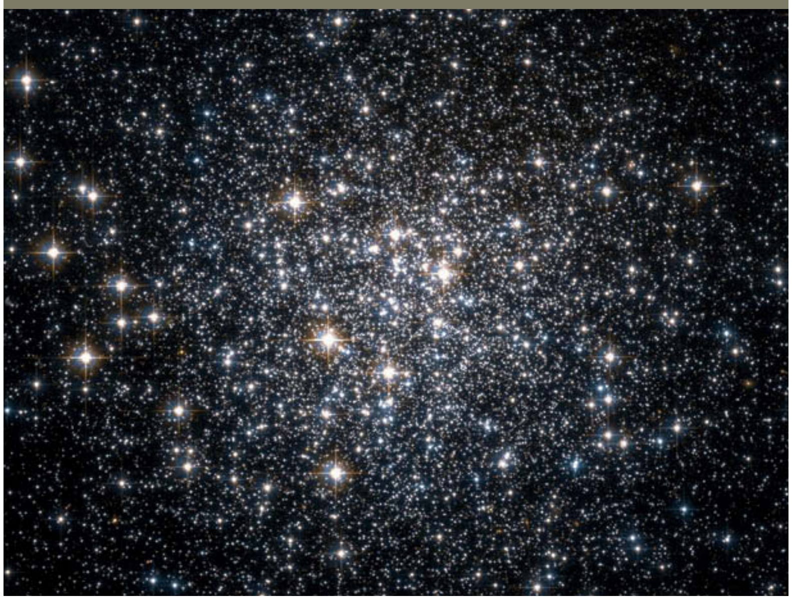
Pythagoras (crater)	October 8
Xenophanes (crater)	October 12
Mare Australe	October 24
Phillips (crater)	October 29

The Left Hand of Aquarius

Diverse deep-sky treasures lie in and near western Aquarius.



Above: Alexander Jamieson's atlas shows Aquarius holding a measuring rod in his left hand. *Below*: Messier 72 is a fine sight through large telescopes, though visual observations will never reveal as many stars as does this photograph from the Hubble Space Telescope.



TOP: U.S. NAVAL OBSERVATORY, *BOTTOM*: NASA / STSCI / WIKISKY

The constellation Aquarius, the Water Carrier, represents a man pouring water from a jar. On the all-sky chart at the center of this magazine, the stars labeled Alpha (α) and Beta (β) mark his shoulders. His Water Jar is to the left of Alpha, and his left arm stretches over the back of neighboring Capricornus, the Horned Goat. The Water Carrier's left hand is usually shown holding part of his robe, adorned by the stars Mu (μ) and Epsilon (ε). In his 1822 atlas, Alexander Jamieson was the first to show Aquarius clutching *Norma Nilotica*, a graduated pole for measuring the rising of the river Nile during its annual floods. This is a fitting addition, as some tales claim that Aquarius triggers these floods when he plunges his Water Jar into the river.

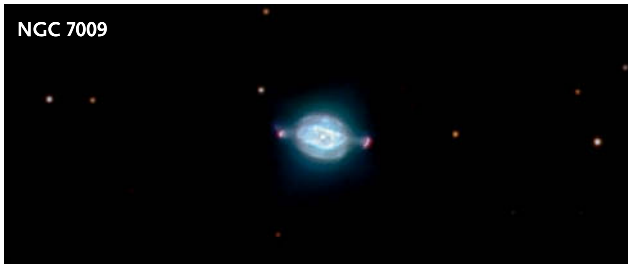
The left hand of Aquarius is a great springboard for finding several celestial treats. Diving 3.6° southward from Mu brings us to the globular cluster **Messier 72**. Although it's the faintest globular cluster in Charles Messier's famous 18th-century catalog, I've managed to spot it in 14×70 binoculars as a very small and dim fuzzy patch. It occupies the right angle of the 1° triangle it makes with two 6th-magnitude stars.

My 130-mm (5.1-inch) refractor at 23× displays a moderately faint, hazy ball with a brighter center. A 9th-magnitude star sits near the cluster's east-southeastern side. A magnification of 63× shows two fainter stars guarding M72 from the east and south, while a third star is nestled in the southern fringe of the cluster's 5′ halo. The outer halo is faint, but it begins to brighten at a diameter of about 3′. A broadly brighter 2′ core dominates the cluster. At 117× several tiny stars fleck the globular, most in its halo and outer core. Through my 10-inch reflector at 299×, M72 is delightfully sprinkled with very faint to extremely faint stars across its entire face.

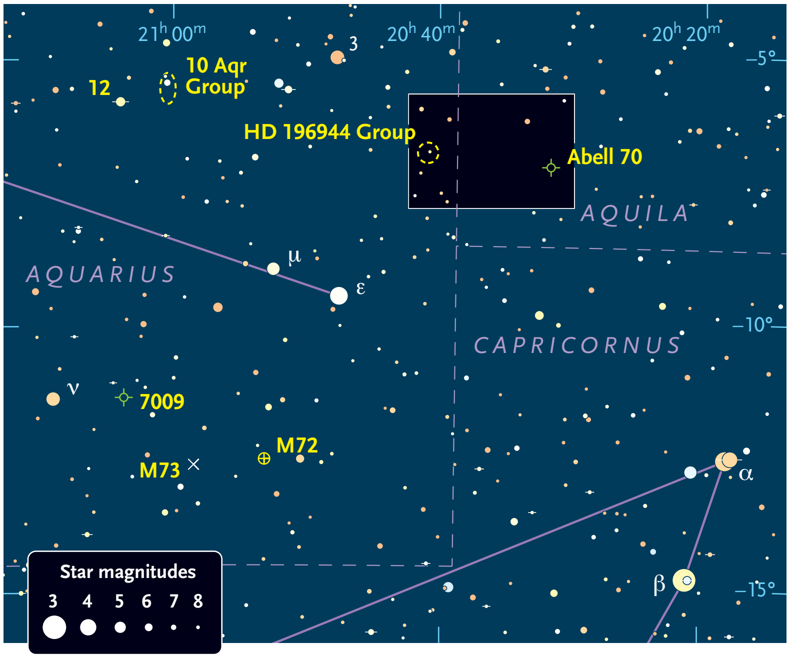
The meager asterism **Messier 73** sits 1.3° east of M72. They share the field of view in my 130-mm scope at 23×, which shows M73 as a tiny grainy patch with one star distinguishable on its southern edge. At 63× I see four stars forming a petite checkmark only 1′ long.

Astronomers debated M73's status as a cluster or asterism until the question was laid to rest in a 2002 journal paper by Michael Odenkirchen and Caroline Soubiran. The

The atlas above, and many other historical artworks, can be download from the U.S. Naval Observatory website at http://aa.usno.navy.mil/library.



BOTTOM: DANIEL VERSCHATSE / OBSERVATORIO ANTILHUE / CHILE, TOP: POSS-II / CALTECH / PALOMAR OBSERVATORY



authors investigated the four checkmark stars, plus two stars of similar magnitude 4′ to the south, and state that the group is "clearly not a physical stellar ensemble." The study indicates that these stars move in different directions through space and lie at different distances from Earth.

Charles Messier discovered M73 in 1780, but M72 was discovered earlier the same year by Pierre François André Méchain. Like Messier, Méchain discovered other celestial objects while sweeping the sky for comets. He passed his finds on to Messier, who included them in his catalog. Of the 110 deep-sky wonders we list as "Messier objects" today, 26 were original discoveries by Méchain — though some people dismiss M102 as a duplicate of M101.

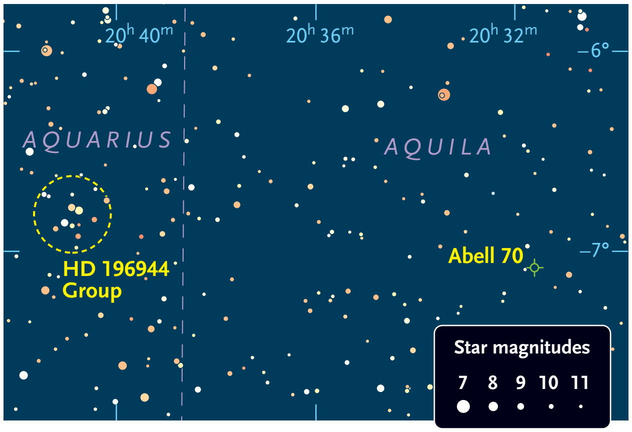
The beautiful planetary **NGC 7009** (widely know as the Saturn Nebula) also inhabits this part of the sky, handily resting 1.3° west of deep yellow, 4.5-magnitude Nu (ν) Aquarii. I can pick out the nebula as an obvious "star" with a little blue halo through my 130-mm scope at 23×. At 37× the halo stands out better, but the color fades to blue-gray. At 68× the color is almost gone. The somewhat oval nebula is spanned by a brighter, greatly flattened oval that runs east-northeast to west-southwest and harbors a brighter center.

My 10-inch scope at 213× shows short spikes extending the long ends of the bright bar. It also teases out a small darker region at the nebula's heart. Despite the central star's visual magnitude of 12.7, it tends to be lost in the glow of this bright planetary nebula. High magnifications help, and oddly enough, I've seen a hydrogen-beta filter kill enough of the nebula's light to reveal the star.

On September 7, 1782, William Hershel discovered NGC 7009 with his 12-inch reflector, making this the first nebula to be discovered with a reflecting telescope. The extensions that give the nebula its Saturnian profile did not surrender to a telescope until Lord Rosse turned his 72-inch "Leviathan" toward it in 1848. In his observing notes the following year, Rosse coined the nebula's now famous nickname, and he later wrote, "...it has ansae, which probably indicate a surrounding nebulous ring seen edgeways."

Springing northward, we come to the attractive double star **12 Aquarii**. In my 9×50 finderscope, it lies at the western end of a rambling trail of fainter suns traversing 2.8°. Through my 130-mm refractor at 102×, the pale yellow primary star closely guards a considerably fainter alabaster attendant to the south-southwest. The colors show better when the stars are pulled farther apart at 234×.

Nearby 10 Aquarii dwells in the northern reaches of an interesting mélange of bright and faint stars. Through my 130-mm scope at 37×, the **10 Aquarii Group** is bejeweled with 25 stars down to 12th magnitude. It's elongated ½° north-south and widens as it tumbles southward. The double star Roe 148 (separation 12.9″) stands out in the southern part of the group, while at 63× Roe 114 (separation 6.5″) pops up in the southwest. Their components weigh in at magnitude 10.0 to 10.7. Edward Drake Roe, Jr. discovered these pairs in the late 19th century. He found most of the doubles that bear his name with the 6½-inch Alvan Clark refractor at his private observatory during his tenure as a Syracuse University mathematics professor.



The galaxy PGC 187663 appears to be pinned onto the northern rim of the planetary nebula Abell 70. But studies place Abell 70 roughly 10,000 light-years from Earth, while the galaxy probably lies at least 100 million light-years behind it.

The **HD 196944 Group** is a more memorable sight in my 130-mm scope at 37×. It reminds me of a Christmas tree with its tip pointed south. The tree is lit with 20 moderately bright to faint stars in a 23′ bunch. Its brightest bulb shines pale yellow, while the second brightest glows deep yellow. Named for one of the designations of its brightest star, this asterism lies 3.2° north-northwest of Epsilon Aquarii.

Large scope enthusiasts may enjoy hunting **Abell 70** and **PGC 187663**, an unparalleled blend of a planetary nebula and a remote galaxy shining through its rim. They lie just over the border in eastern Aquila, forming a nearly equilateral triangle with Epsilon Aquarii and the orange star 3 Aquarii. Look for this strange pair 9.7′ east and a bit north of a 9th-magnitude star, the brightest in the area.

My 14.5-inch reflector at 63× shows a small, round nebula 3½′ west of an 11th-magnitude star. At 170× it becomes a subtle, wide ring crowned with a brightening on its northern rim. If I didn't know about the galaxy, I could easily mistake this brightening for part of the nebula. A 14th-magnitude star sits a scant ½′ southeast of the ring's edge. At 276× the annularity is easier to see, and the galaxy behind its northern edge looks a bit too straight to be part of the ring. This duo is nicknamed the Diamond Ring because of the bright spot on its rim, an effect that is quite striking on astrophotos.

You don't necessarily need a big scope to try for Abell 70. Experienced observers under dark skies have been able to discern the planetary nebula's ring with scopes as small as 8 inches in aperture.

Abell 70 has an unusual binary central star composed of a white-dwarf star and a dwarf or subgiant barium star. A barium star is enriched in barium and other elements that it's not evolved enough to produce. These elements were presumably transferred to the barium star by a stellar wind from its companion when it was in the late stages of its life as a red-giant star. ✦

Treasures in and near Western Aquarius

Object	Type	Mag(v)	Size/Sep	RA	Dec.
Messier 72	Globular cluster	9.3	6.6′	20^h 53.5^m	−12° 32′
Messier 73	Asterism	9.7	1.4′	20^h 58.9^m	−12° 38′
NGC 7009	Planetary nebula	8.0	44″ × 23″	21^h 04.2^m	−11° 22′
12 Aquarii	Double star	5.8, 7.5	2.5″	21^h 04.1^m	−5° 49′
10 Aquarii Group	Asterism	5.8	29′ × 15′	21^h 00.5^m	−5° 35′
HD 196944 Group	Asterism	6.6	23′	20^h 40.9^m	−6° 49′
Abell 70	Planetary nebula	14.5	42″ × 37″	20^h 31.6^m	−7° 05′
PGC 187663	Galaxy	16	42″ × 18″	20^h 31.6^m	−7° 05′

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.

Dennis di Cicco

Two German Equatorials from iOptron

ALL PHOTOGRAPHS BY THE AUTHOR

The iEQ30

U.S. price: $1,299

The SmartEQ

U.S. price: $399

ioptron, 6F Gill St., Woburn, MA 01801, ioptron.com; 866-399-4587

iEQ30	SmartEQ
WHAT WE LIKE:	**WHAT WE LIKED:**
Lightweight, well made, and portable	Extremely light and portable
Accurate Go To pointing and tracking	Self-contained power
Intuitive hand control	Good Go To performance
WHAT WE DIDN'T LIKE:	**WHAT WE DIDN'T LIKE:**
Limited astronomical data for objects	Limited to relatively compact telescopes

LONG-TIME AMATEUR astronomers certainly know that the equipment side of our hobby is always evolving. Over time, even once-dominant companies such as Unitron and Criterion have faded away to be replaced by new major players. But some of these changes happen surprisingly fast. Take, for example, iOptron. Five years ago most readers had never heard of this company, even though its astronomical roots stretch back to building observatory control systems in China almost two decades ago. Today iOptron has grown to become one of the leading suppliers of popular Go To telescope mounts.

iOptron introduced its novel Cube in late 2007 (we reviewed it in our February 2008 issue, page 34). It was the first Go To alt-azimuth mount available as a stand-alone product. Advanced versions of the Cube followed. Then came the heavier-duty MiniTower (reviewed in the December 2008 issue, page 48) and its variants. These were followed by the company's first commercial German equatorial mount, the iEQ45 that we reviewed in our July 2011 issue, page 60. Now there are two new German equatorials: the iEQ30, which is essentially a smaller version of the iEQ45; and the lightweight, highly portable SmartEQ. They round out an unusually complete line of Go To mounts from a single manufacturer.

The iEQ30

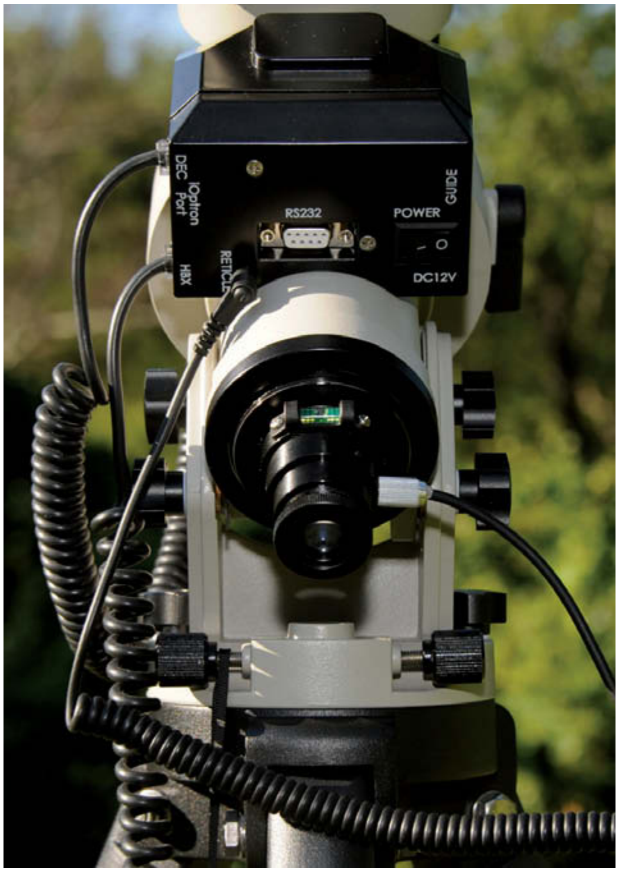
I liked the iEQ30 the moment I laid eyes on it, because it promised to be a modern-day version of my Vixen Great Polaris DX German equatorial. No piece of telescope hardware has served me more faithfully than the Vixen, which has made numerous cameo appearances in our product reviews as I tested telescopes and cameras. With its dual-axis motor drives, the Vixen cost me $1,600 in 1999, or $2,200 in today's dollars. The iOptron iEQ30 has a higher load capacity than the Vixen, is lighter in weight, and offers Go To pointing all for hundreds of dollars less. I knew that if the iEQ30's performance lived up my experiences with iOptron's earlier mounts, it was sure to be a winner. In the end, it exceeded my high expectations.

Each new mount introduced by iOptron seems to build on the success of its predecessors. There are design features on the iEQ30 that I like better than those of the beefier iEQ45, such as the single-lever locking mechanism for the right-ascension and declination clutches.

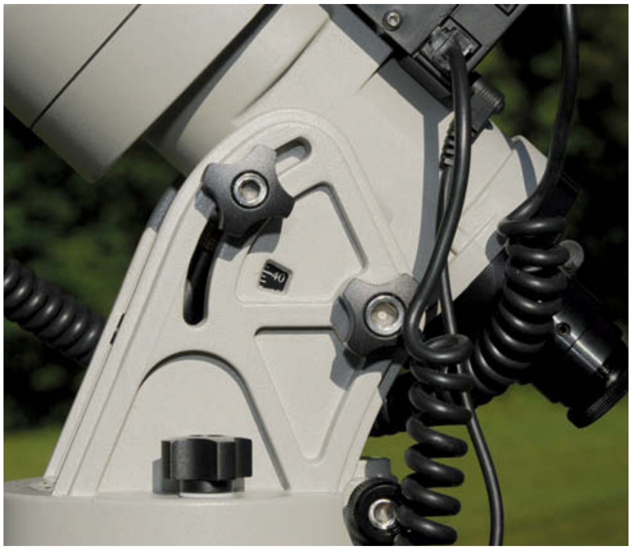
The mount is very compact, but that also means it's a good idea to keep a set of appropriate hex wrenches handy, since it's difficult to tighten some knobs with just your fingers, especially those for the azimuth locks on the base. The equatorial head is notably rigid given its size and weight. The weakest link in the overall package is the 10½-pound (4¾-kg) tripod. When I was viewing with a hefty 4-inch refractor, vibrations took almost 4 seconds to dampen. A set of commercial anti-vibration pads placed under the tripod legs cut the dampening time by more than 50%, which is very good performance.

The iEQ30 has one of the best polar-alignment systems I have ever used. An alignment scope built into the right-ascension axis has an illuminated reticle that's calibrated for both Polaris (Northern Hemisphere) and Sigma Octantis (Southern Hemisphere). As shown on the next page, the hand control graphically displays where these stars should be positioned on the reticle to achieve polar alignment given your date, time, and location (all of which are determined automatically from the mount's built-in GPS receiver).

Speaking of GPS, perhaps it was just the unit I tested, but unlike iOptron's other GPS models, the iEQ30 often took upwards of 5 minutes to acquire signals from an ade-



You'll want to have a flashlight handy if you set up the mount after dark, because the separate cords for the hand control and declination motor use identical modular jacks on the same side of the electronics box. There's also a modular jack for an autoguider based on the standard ST-4 wiring format, and a 9-pin serial plug for controlling the mount with a computer. The green bubble level is for positioning the reticle in the polar-alignment scope.



A bubble level in the mount's base (not visible here), and a latitude scale marked in degrees, help you set the polar axis altitude.

quate number of GPS satellites (the other mounts often took less than a minute). The iEQ30's GPS antenna is located on the top of the electronics module where it was easily "shadowed" by my telescopes. Swinging the scopes to the side of the mount to give the antenna a clearer view of the sky seemed to help.

As I've come to expect from iOptron's earlier mounts, the iEQ30's Go To pointing is very good, even when I did only a quick polar alignment and synced the scope on a single star. This always put my Go To target close to the center in the moderate-power field of view. If you do a two- or three-star alignment when syncing your scope, it adds a little time to the setup procedure, but it leads to even better Go To performance. The multi-star alignments also allow the electronics to calculate how far the polar axis is offset from the celestial pole, but it isn't easy to use this information to refine your polar alignment because there are no fine calibration marks on the mount's altitude and azimuth adjustments.

Hand Controller

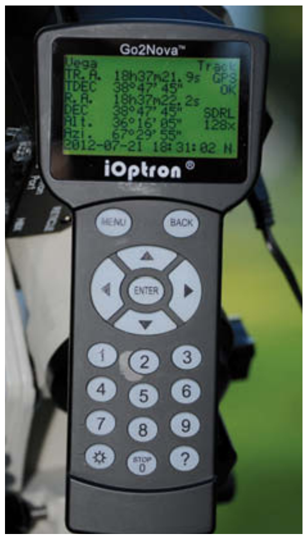
The Go2Nova 8407 hand controller that comes with the iEQ30 is noteworthy. Since the earliest days of Go To telescopes, I've worked with hand controllers from Astro-Physics, Celestron, Meade, iOptron, and others. Most have been easy to master, but none that I can recall have been as intuitive as iOptron's controllers. Furthermore, unlike those from other manufacturers, I don't need a refresher course when I haven't used an iOptron controller for a while. The basic menus for setting up and using the telescope are all very straightforward. Advanced features that are not needed for basic operation (backlash control and periodic-error correction, for example) may require you to check the manual for details, but anyone having a modest familiarity with telescopes can probably noodle through most of these menus without a manual.

All German equatorial mounts have limitations when tracking objects across the meridian. The iEQ30 offers three options to deal with that. One is to have the mount stop tracking the moment it reaches the meridian. Another is to continue tracking, but then you need to be mindful that the telescope can track into the tripod or mount. The third option is to have the mount automatically flip both axes and continue tracking your target in the western sky. Although this function worked well, I don't recommend using it because the telescope gives no warning that it's about to start slewing at high speed.

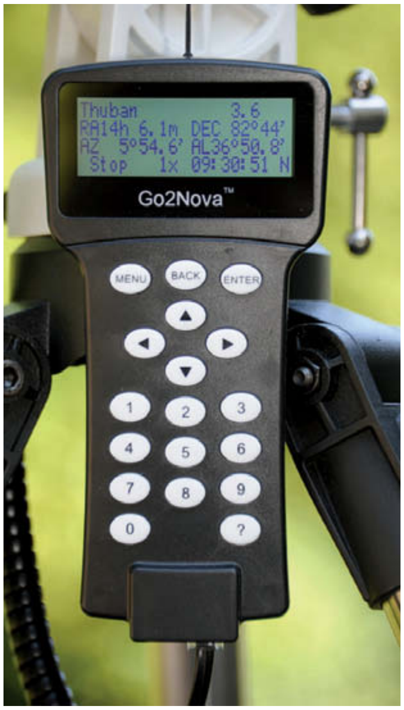
In past reviews, I've grumbled about two aspects of iOptron's hand controllers. The first is the limited amount of descriptive astronomical data displayed for objects called from the internal database. This is particularly the case for iOptron's advanced controllers that have eight 21-character lines of text available in the display. The databases contain 99% of the objects most observers will likely want to see, but there's little information beyond the positions needed for the Go To slewing. This hasn't changed with the latest controller.

My other, larger concern has been the controllers' sluggish keypad entry, which meant that keys had to be pressed slowly in order to enter data. In this regard, the controller for the iEQ30 is much better. It's not perfect, but you can now navigate menus and enter data quickly without losing key strokes. Furthermore, you can set an audible beep that confirms each key press. That's nice for data entry, but there's also a beep when you press the direction buttons while slewing the telescope, reminding me of the old adage about being careful what you wish for.

Overall, I'm impressed with the iEQ30. From experience, I can confidently say that a solid, portable, mid-weight German equatorial mount is a blessing for amateurs like me who do observing and astrophotography with a variety of telescopes at different locations. My Vixen has served me well, but as much as I like it, I'd trade it in a heartbeat for the iEQ30!



A robust screw (*left*) provides precise adjustment of the polar-axis altitude. The hand control's 8-line display (*right*) also shows the location of Polaris on the polar-alignment reticle when the mount is properly aligned (*below*).



The counterweight shaft on the SmartEQ (*far left*) retracts into the declination-axis housing for storage. Because the shaft can be locked at any portion of its extension, this feature is useful for fine-tuning the mount's balance. As with all of iOptron's hand controls, the one for the SmartEQ (*near left*) is extremely intuitive, and many users will probably discover that they can master its basic operation without even having to refer to the mount's Quick Start Guide.

The SmartEQ

The newest member of iOptron's Go To family has benefitted from the company's experience building other Go To mounts. Debuting at NEAF earlier this year, the SmartEQ packs many of the features found in its bigger brethren into a 6¼-pound German equatorial head. The included tripod adds another 5¾ pounds and the counterweight 2 more, but that's all you need for a nice little travel mount suitable for small telescopes and wide-field astrophotography.

Except for its smaller database and lack of GPS, the SmartEQ has all the features described above for the iEQ30, including the graphical position of the pole stars used for alignment with, in this case, an optional polar-alignment scope. An internal set of eight AA batteries will power the mount for about 20 hours of average use, and there's a provision for running it from an external 12-volt DC power supply.

A pair of internal compartments hold a total of eight AA batteries, which can power the SmartEQ for about 20 hours.

Tracking and Go To pointing are very good, especially given the relatively small diameter of the mount's plastic drive gears. But, as with all small mounts I've used, there's more to consider than just the SmartEQ's 11-pound load capacity. You also need to consider the physical size of the telescope because a large scope or camera setup will require additional counterweights and the total weight will compromise the mount's performance. I tested the SmartEQ with a 4-inch Maksutov that weighs about 5 pounds (and requires a 4-pound counterweight). It performed well. One of today's compact 5- or 6-inch Schmidt-Cassegrain telescopes is probably about the mount's limit.

Given that virtually all wide-field astrophotography with digital cameras involves exposures of 5 minutes or less, the SmartEQ makes an excellent photography platform. Just eyeballing Polaris through the mount's hollow polar axis shaft gave me good enough polar alignment to make fine 3- and 4-minute exposures from my back deck with a 50-mm lens. This inexpensive unit is a great little mount for constellation and meteor-shower photography or the next bright comet — perhaps Comet PanSTARRS (C/2011 L4), which everyone is hoping will put on a first-class show early next year. ✦

Sky & Telescope *senior editor* ***Dennis di Cicco*** *remains ever the observational optimist despite having seen his share of "great" comets go bust.*

S&T: SEAN WALKER

▼ **MILC TELESCOPE ADAPTER** CNC Parts Supply now offers a low-profile T-adapter for Mirrorless interchangeable-lens cameras (MILC). The T-Minus 2″ UltraWide Adapter ($89) allows users to attach these Sony and Olympus MILC directly to any T-threaded accessory. Normal stock T-adapters for these cameras incorporate a 37-mm-long integrated tube (shown below at right) to allow for the proper spacing required to place a conventional 35-mm camera lens at the optimum distance from the camera's sensor. The T-Minus 2″ UltraWide Adapter eliminates this unnecessary spacing to allow users to incorporate additional accessories between the camera and telescope, such as filter wheels or off-axis guiders. The adapter allows telescopes with limited focus range to use MIL cameras without the need of custom modifications. Currently available for the Olympus PEN series, Panasonic/Lumix G series, and Sony NEX series cameras.

CNC Parts Supply
4023 SW 8 Ct., Cape Coral, FL 33914
www.telescopeadapters.com

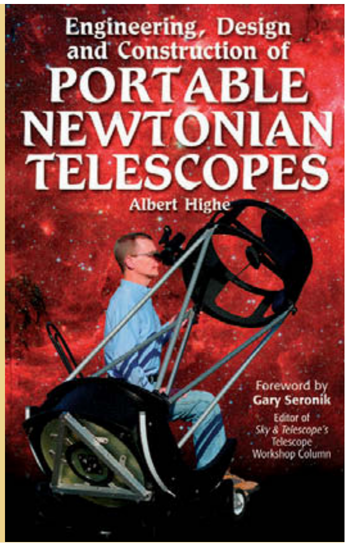

CNC PARTS SUPPLY

▲ **NEW PLANETARY CAMERA** Celestron recently announced its latest planetary-imaging camera, the Neximage 5 ($189). This CMOS color video camera boasts a generous 2,592 × 1,944 array of 2.2-micron square pixels in an extremely compact housing. The camera features a rolling shutter capable of recording up to 52 frames per second in certain capture modes. The Neximage 5 includes *ICap 2.2* camera control and *RegiStax 6* stacking software, allowing users to combine only the sharpest frames recorded, producing a highly detailed final picture. Each camera comes complete with a C-to-1¼-inch nosepiece adapter and USB 2.0 cable. Requires *Microsoft Windows XP*, *Vista*, or *Windows 7*.

Celestron
2835 Columbia St., Torrance, CA 90503
310-328-9560; www.celestron.com

DOBSONIAN HOW TO Have you ever had the desire to build a big, portable Newtonian telescope, but lack the knowledge or abilities to get the job done yourself? The new book *Engineering, Design and Construction of Portable Newtonian Telescopes* by Albert Highe ($39.95) is a massive 694-page tome that teaches you everything necessary on how to design and build a portable Newtonian telescope that will increase your enjoyment of observing. The author distills his years of experience into concise descriptions of engineering principles relevant to amateur telescope making. The book also details the construction of two large-aperture, Dobsonian-mounted reflectors usable without the need of a step-stool or ladder. A CD-ROM with *Microsoft Excel* tables and worksheets is included with purchase. Hard cover, 694 pages, ISBN 978-0-943396-95-8.

Available from Willmann-Bell
P.O. Box 35025, Richmond, VA 23235, 800-825-7827; www.willbell.com



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

Mirror Cooling with Heat Sinks

Is there an easy way to cool your primary without using a fan?

TELESCOPE MAKERS CAN BE a funny bunch. Although our passion for building instruments and making optics is usually rooted in a careful, scientific approach, we also tend to put a lot of stock in hand-me-down knowledge. Some of it withstands scrutiny, some of it doesn't. So I take special note when I hear of carefully controlled experiments to investigate telescope performance.

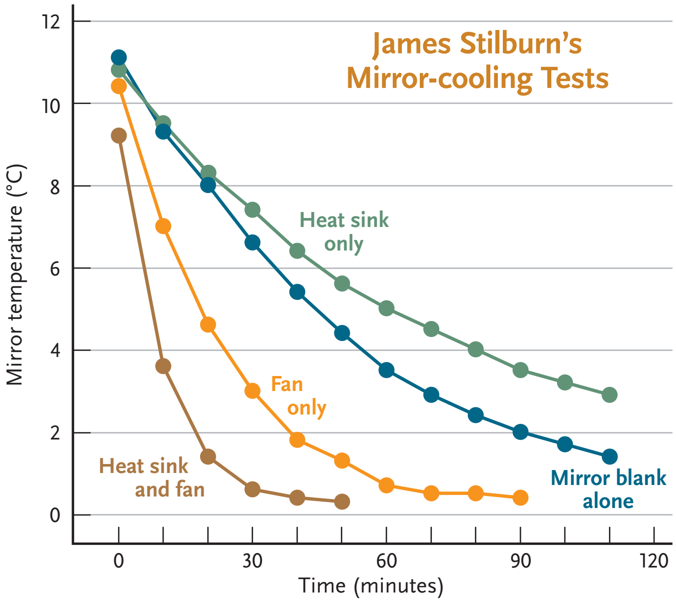
In last May's column I discussed telescope thermals, concluding that a cooling fan for the primary mirror is usually a necessity for optimal performance. But is that the only way to chill the mirror close to the ambient air temperature and keep it there?

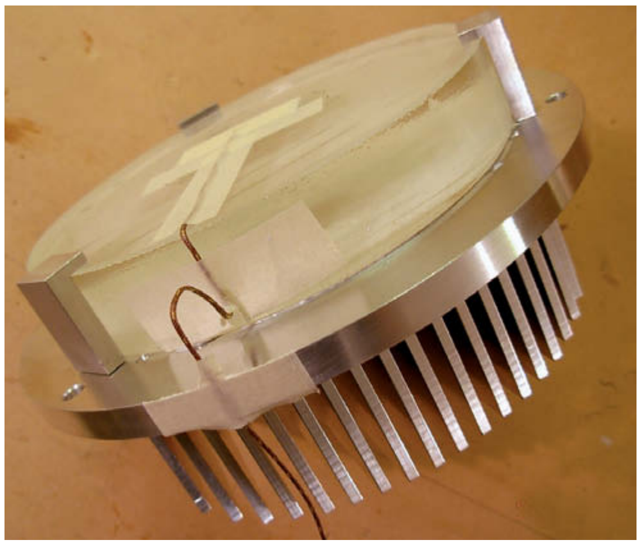
Among those wondering the same thing is James Stilburn of Victoria, British Columbia, whose binocular telescope was featured in last April's column. Instead of simply posing the question to an online forum, Jim did some experimentation.

"The idea was to see if a heat sink could eliminate the need for a fan, thus removing the potential for vibration and the need for a battery," explains Jim. "There was a lot of speculation on some ATM forums about how this might work, but apparently it hadn't been tried yet." So he set about running a series of cool-down trials. His test subject was a 6-inch-diameter, 1-inch-thick Pyrex mirror blank mounted in an 8-inch-diameter, Protostar lightweight, resin-impregnated cardboard tube.

To take an accurate reading on the blank's temperature, he used thermal paste and tape to affix a thermocouple probe to the front face of the glass. A second probe monitored the ambient air temperature inside the garage where his trials took place.

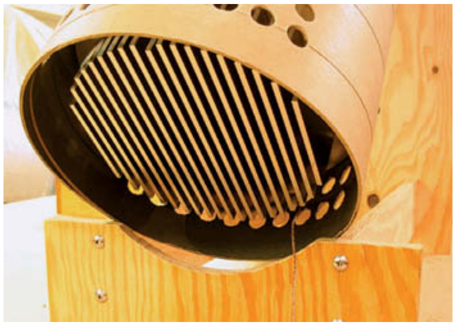
Jim ran several tests, the first two without a heat sink. He monitored the blank's cooling by convection alone, and then with a fan generating 27 cubic feet per minute (CFM) of air flow. He then attached a custom-made





JAMES STILBURN (2)

James Stilburn used a 6-inch mirror blank and his custom-made heat sink for his series of tests. A thermocouple attached to the front of the mirror blank monitored the blank's temperature.



The mirror blank and heat sink were installed in a telescope tube angled at 45° for the tests.

aluminum heat sink to the back of the blank with a thin layer of thermal paste, and ran three more tests. First he tried just the heat sink and convective cooling. Then he ran two tests with fans blowing air across the heat-sink fins — one trial with a low-speed fan, the other with the 27 CFM model. The results are shown in the accompanying graph.

A few surprises emerged from the tests. The most striking one is that attaching only a heat sink made matters worse. "The heat sink has about twice the heat capacity of the Pyrex blank, but its surface area is 14 times greater than one side of the blank," Jim notes. "My guess is that the convective airflow within the fins is very poor and that's why a heat sink alone didn't help."

The test results for the heat sink and low-speed fan are indistinguishable from those using the bigger fan without a heat sink, leading Jim to conclude that adding a heat sink means you can potentially get away with a smaller fan. But, as he points out, "Considering the additional trouble and expense of adding a heat sink, it's hardly worthwhile." As the graph illustrates, the heat sink and larger fan allowed the mirror blank to come within 2°C of the ambient temperature about 20 minutes sooner than with the fan alone. For me, this isn't enough of a difference to bother with acquiring a heat sink and dealing with the mirror-mounting complications that arise from such a scheme. Jim summarizes it best; "Fan 1, heat sink 0. Fun experiment though." ✦

Gary Seronik has a collection of "cool" home-built reflectors. He can be contacted through his website, ***www.garyseronik.com****.*

The Messier Catalog:

Try this minimalist approach to sharpen your observing skills and enhance your enjoyment.

GARY SERONIK

On the night of September 12, 1758, French astronomer Charles Messier began compiling a catalog of deep-sky objects in the hope of saving fellow comet-hunters from wasting time with ersatz comets. In the 18th century, as now, time was money — and there was potential wealth and fame to be had in discovering new comets. Deep-sky objects? Not so much. It's ironic that Messier's list has helped so many discover the joys of observing the very clusters, galaxies, and nebulae he sought to avoid.

Today, bagging all 109 Messiers is a rite of passage for many new observers, and even grizzled veterans spend a lot of time with the catalog's showpieces. But one odyssey I'll wager that few readers have undertaken is to log every Messier with only ordinary binoculars. If you're up for a challenge, or simply want to enjoy some of the sky's finest sights, this is a tremendously rewarding project.

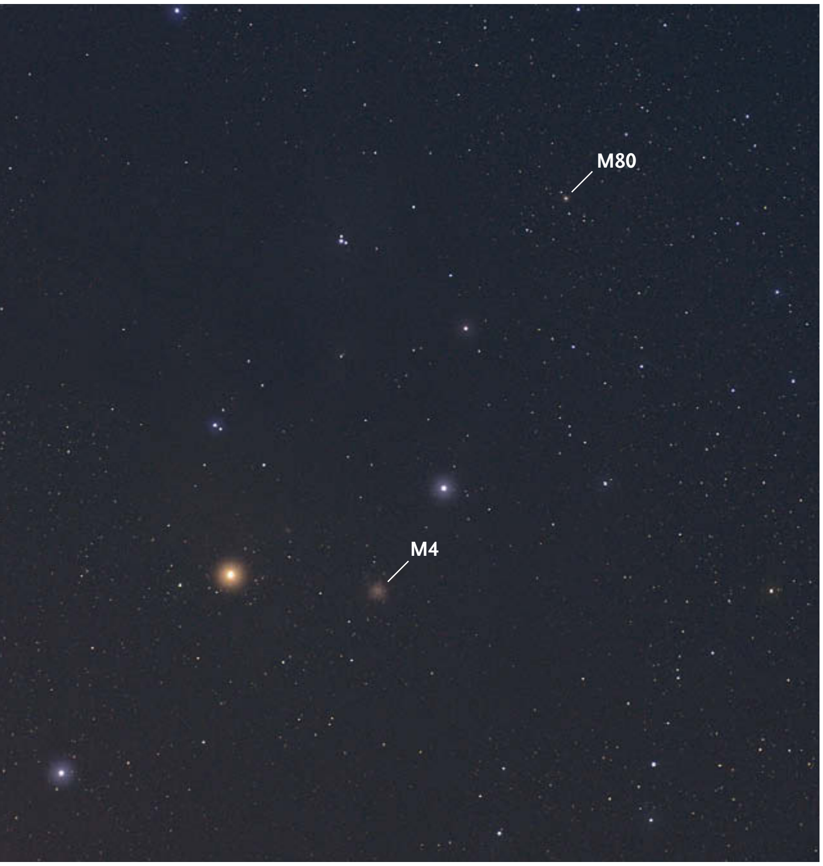
Choose Your Weapon

So what exactly are "ordinary" binoculars? I use the term to describe any model that can be hand-held *productively*. That spans instruments from tiny opera glasses all the way up to lightweight 15×70s.

I completed most of my Messier survey with image-stabilized 10×30 and 15×45 binos, but I resorted to 15×70s for a handful of the most difficult objects. I also used my 10×50s to view virtually every Messier. I conducted the survey under reasonably dark skies — where the Milky Way is readily visible but not spectacular.

In the December 2011 issue (page 38) I detailed the most important factors that govern the visibility of deep-sky objects in binoculars. I singled out binoculars' light-gathering capability and magnification, the steadiness of the view, the quality of your sky, and the brightness of the target as most important. But when it comes to the Messiers in particular, I'd put binocular magnification close to the top of the list. That's because most of the catalog's clusters, galaxies, and nebulae are reasonably bright, but many appear tiny at typical binocular magnifications. A little extra power often makes the difference between being able to identify an object and missing it completely. For that reason, my 15×45s worked better than my 10×50s despite having slightly smaller objective lenses. Similarly, my 10×30s were more useful than my 7×50s.

A Binocular Odyssey



Neighboring Scorpius globular clusters M4 and M80 provide a study in contrasts. M4 is large and easy when viewed through binoculars under reasonably dark skies. Nearby M80 is tiny, making it much more challenging— especially in low-power 7× or 8× binos. The author photographed all the sky scenes in this article to resemble their true appearance through binoculars.

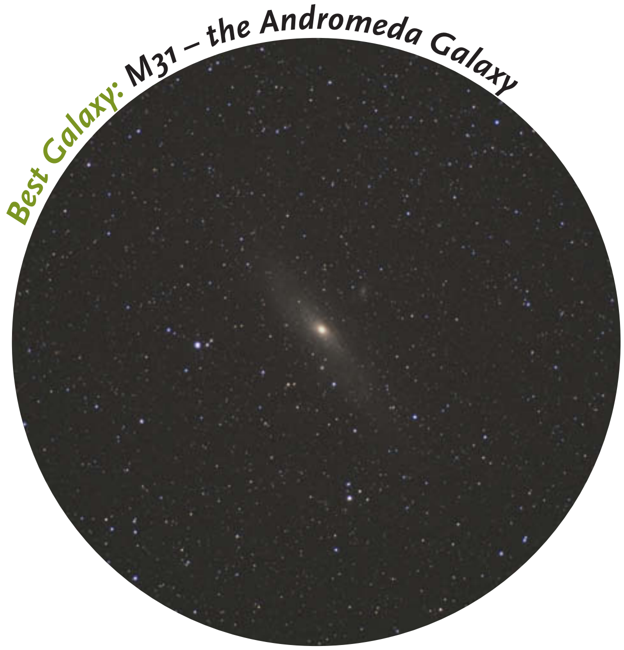
If magnification is so crucial, why not go whole hog with 20×80 binoculars or even 25×100s? No question about it — such instruments would make a Messier survey much easier. But by the same token, why not just use a telescope? The point of this odyssey isn't just to log all the Messiers, but also to challenge yourself and improve your observing skills. And that's where the fun lies. With ordinary binoculars you can enjoy the same thrill hunting down a difficult Messier target that people with a 16-inch scopes experience when they finally sight an elusive 14th-magnitude galaxy. The equipment and targets may be radically different, but the sense of accomplishment is the same.

Personal challenges aside, binocular astronomy also has a wonderfully minimalist appeal. The only extras you require are a comfortable reclining chair (or patch of soft grass) and some charts. For me, even the addition of a mount (which larger binoculars require) changes the experience significantly. It's not necessarily less fun — just different.

Messiers by the Numbers

Messier objects are numbered up to 110, but most people consider M102 to be a duplicate observation of M101, leaving 109 objects in total. (Others think that M102 is the galaxy NGC 5866, in Draco.) The 109 Messiers that are recognized by almost everyone include 39 galaxies, 29

The author took these photos, which show most of the binoculars used for his Messier survey. From left to right, they include 15×70s, 10×50s, image-stabilized 15×45s and 10×30s, and compact 8×25s and 8×21s.



The Andromeda spiral, M31, is the most spectacular Messier galaxy. While most of the catalog's galaxies are dim and small, M31 is easy to see even in light-polluted conditions. This binocular view simulates the galaxy's appearance in 7×50s.

globular clusters, 26 open clusters, 7 diffuse nebulae, 4 planetary nebulae, a supernova remnant, a double star, a star cloud, and an asterism.

In general, open clusters are easiest to observe and galaxies are toughest. This is doubly true if you live under light-polluted skies where the individual stars found in many open clusters are bright enough to penetrate the gloom, but many galaxies vanish altogether. The take-away lesson here is start with open clusters if your skies are far from ideal, and save galaxies for dark-sky outings.

One of the most important things I learned on my binocular Messier odyssey is that an object's stats don't always predict its visibility. In particular, a target's magnitude was often less important than its apparent size. With a telescope, you can simply change eyepieces to boost the power and make the object bigger and easier to see, but with binoculars, the magnification is fixed and very low. So, big-but-dim is often easier than small-but-bright. For example, the globular clusters M80 and M30 have the same magnitude, yet my 10×50s easily show M30, whereas M80 is a nearly stellar dot that requires precise star-hopping to pin down.

The Best of the Bunch

After surveying the Messiers, I compiled a highly personal and subjective list of the very best object from each deep-sky category. Your choices might be different, but these are the Messiers that I found most striking.

Best Globular Cluster: M22. Some might opt for better-known M13, but I find that the Sagittarius cluster jumps out from the background a little better. With globulars, size is everything, and M22 is noticeably bigger than its Hercules sibling. It also happens to be a hair brighter. The only knock against M22 is that it never rises very high at mid-northern latitudes — so you're often looking through a fair amount of atmospheric haze. And the window of opportunity for viewing it is much shorter than for M13.

Best Galaxy: M31, the Andromeda Galaxy. No contest here. M31 is big, bright, and nicely placed. In badly light-polluted conditions, it might even be the only galaxy within reach of your binoculars. And under dark skies, M31 is a wonder. Throw in its challenging companion galaxies M32 and M110, and you have a rewarding target indeed! Under pristine conditions, spiral galaxy M33 in Triangulum is also a fine object, but it's nowhere near as impressive as Andromeda.

Best Open Cluster: M45, the Pleiades. I doubt many will disagree with me on this one — the Seven Sisters is not only the list's best open cluster, it's arguably the finest binocular Messier of them all. In fact, that's an argument I'd make! In any size binoculars, the tiny, jewel-like Dipper of the Pleiades is simply lovely — and that's true no matter how bad your skies are. The bonus attractions of a challenging double star in the "bowl" and a striking, curving arc of stars under the "handle" add to the sparkle.

The Pleiades Cluster in Taurus (M45) is a magnificent scene through binoculars. Like many other Messier open clusters, M45 survives the deleterious effects of light pollution well.

Honorable mention goes to M24, the Small Sagittarius Star Cloud. Some sources list it as an open cluster, though it is in fact an isolated patch of Milky Way. It's a wonderful binocular target nonetheless — especially under dark skies.

Best Planetary Nebula: M27, the Dumbbell Nebula. Planetary nebulae are the most poorly represented class of deep-sky object in the Messier catalog, and no wonder — virtually all of them are tiny. Although the Ring Nebula, M57, is arguably a better target for telescopes, it finishes a distant second to M27 for binocular users. The Dumbbell is both much larger and considerably brighter. Even my 10×30s show M27 as not quite round, while the 15×45s begin to hint at the apple-core shape the nebula displays in telescopes.

Best Diffuse Nebula: M42, the Orion Nebula. This is another easy choice, but it's not as if it's the only good binocular nebula. Indeed, most of the Messier nebulae show pretty well. The Lagoon (M8), the Swan (M17), and the Eagle (M16) are also fine binocular objects under dark skies. But magnificent M42 is in a class by itself — the only nebula bright enough to show well even in light-polluted skies. Looking like a softly glowing, upturned rose, the nebula also happens to reside in one of the most striking binocular regions in the entire sky: the Sword of Orion. Taken as a whole, this field rivals the visual splendor of the Pleiades and will surely rank number one overall for many, many readers.

The Dumbbell Nebula (M27) appears small even through 15×70 binoculars — as this simulated view illustrates. M27 is the largest and easiest of the Messier catalog's four planetary nebulae.

M42, also known as the Great Nebula in Orion, is the finest Messier nebula. Orion's sword fits easily in the field of view of 10×50 binoculars and also includes the nebula M43 and the loose open cluster NGC 1981, both north of M42.

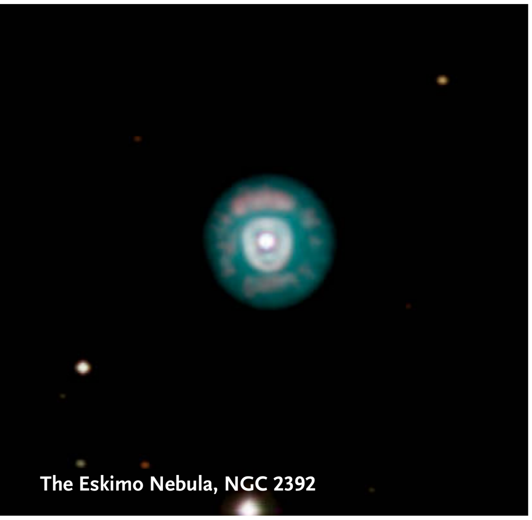
The Toughest Messiers

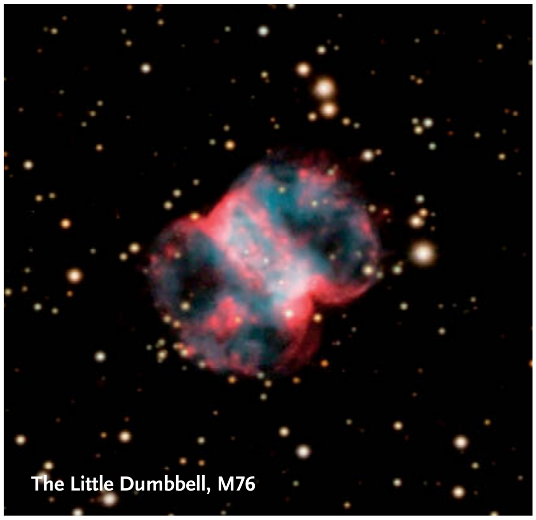
If you're up for some real challenges, the Messier list is packed with difficult binocular targets. Faint objects such as the diffuse nebula M78, in Orion, and the planetary nebula M76, in Perseus, are notoriously troublesome, but most of the really tricky Messiers are galaxies. Virgo and Coma Berenices are chock full of them (18 in total), with only a few that could be described as moderately easy. Indeed, Virgo proved to be my Messier Waterloo — home to galaxy M91, the one object in the entire list that eluded me. Even with 15×70s, the best I could muster was a hesitant "maybe." It can be done, however. My *S&T* colleague Tony Flanders has seen M91 in his 15×45s. Knowing that it's possible only fuels my determination — I'll be back next spring to give M91 another try. M58, M59, M61, M98, and M99 are also among the most difficult Messiers, but at least I managed to see them.

Although I enjoy showpiece Messiers such as the Pleiades and the Orion Nebula, I have to admit there's nothing quite so rewarding as sighting a difficult object for the first time. Maybe that's part of what keeps us deep-sky hunters going, no matter if we're using a giant Dobsonian or plain ol' binoculars. Sometimes the challenge is the reward. ✦

Contributing editor ***Gary Seronik*** *authors this magazine's monthly* Binocular Highlights *column. He can be contacted through his website:* ***www.garyseronik.com***.

Targeting Hidden Gems


The Eskimo Nebula, NGC 2392


The Little Dumbbell, M76


The Owl Nebula, M97

Planetary nebulae are stunning objects for astrophotographers working from almost any location.

RUBEN KIER

TAKING DEEP-SKY astrophotos from urban locations can be a challenging endeavor. Ever-increasing levels of light pollution limit your choice of targets; galaxies are virtually erased from view, and star-forming nebulae require narrowband filters to cut through the thick orange glow of pervasive city lights. Although open and globular star clusters manage to peek through the bright sky, imagers often long for more colorful targets than these. Fortunately, one class of object is bright enough to punch through the veil of urban sprawl: planetary nebulae.

Planetary nebulae are some of the most colorful and visually diverse celestial targets in the night sky. These emission nebulae consist of an expanding shell of ionized gas ejected during a star's red-giant phase, and are illuminated by the exposed stellar core. No two are alike. Those with spherical or elliptical shapes — such as the iconic Ring Nebula (M57) — often have a central bright, inner rim surrounded by an extended outer shell. The rim arises from the interaction of a fast stellar wind as it impacts slower-moving material expelled from the star during an earlier evolutionary phase.

Despite their name, planetary nebulae have nothing to do with planets; the name comes from descriptions by the British astronomer William Herschel, who thought the circular shapes were reminiscent of planetary disks as seen through a small telescope. Large planets that still orbit these dying stars might contribute to the elliptical shape of many of these gaseous shells. A few planetary nebulae show even greater aspherical geometry, possibly resulting from the gravity of unseen stellar companions.

Due to the nature of their formation, planetary nebulae begin with intrinsically high surface brightness. Though none are bright enough to see with the naked eye, many are visible in small telescopes even through strong light pollution because their brightness is concentrated in a very small area. Most range from only a few arcseconds to a few arcminutes in diameter. This makes them particularly good targets for urban astrophotographers because light pollution is more severe on big, extended objects. As emission nebulae, planetaries also respond particularly well to narrowband imaging techniques.

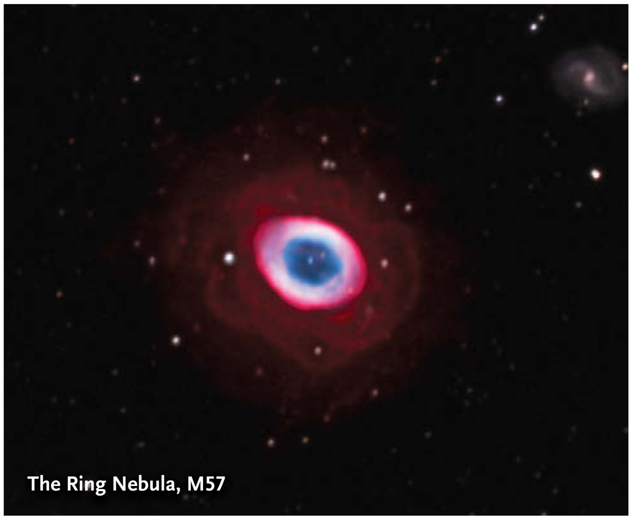
Shooting Planetaries

Most planetary nebulae have small apparent sizes, so imagers targeting them will need telescopes with relatively long focal lengths to resolve any small-scale details. Small planetaries such as the Owl Nebula (M97), the Eskimo Nebula (NGC 2392), or the Blue Snowball Nebula (NGC 7662), require a generous image scale, ideally around 1 arcsecond per pixel or better. For an average CCD or DSLR camera with pixels of 6 to 10 microns, you'll need a focal length of at least 1,500 millimeters to resolve any small-scale features.

Because many planetary nebulae are intrinsically bright, imagers using monochrome CCD cameras don't need to capture an additional unfiltered luminance image to record the best photographs. Indeed, unfiltered luminance frames often overexpose the core of the nebulae — red-, green-, and blue-filtered images will suffice, as do single-shot color images. To properly record the core of most planetaries, you'll have to keep your exposures relatively short compared with other deep-sky objects, assuming that your effective focal ratio is still moderately fast, such as f/7. For example, if you usually expose your deep-sky subframes for five minutes, two- or three-minute exposures will be more than enough to capture the inner details without overexposing the image. I suggest you continue to capture as many exposures as possible throughout the night. These numerous short exposures will result in about twice as many usable frames as you usually acquire for other deep-sky targets, in the same amount of time.

Your goal in capturing these dozens of sub-frames is to end up with enough so that you can eliminate the fuzziest images and only keep the sharpest ones (much like solar system imagers do). Slight variations in atmospheric seeing, gusts of wind, and transient tracking errors usually

The Blinking Planetary, NGC 6826



The Ring Nebula, M57

Above, left to right: **Planetary nebulae are one of the few classes of deep-sky objects bright enough to image through strong light pollution. As these examples show, many planetaries present urban imagers with pleasing color and intricate detail. Both the Blinking Planetary and the Ring Nebula reveal extended halos in long-exposure photographs. All images are courtesy of the author.**

12 Bright Planetary Nebula Targets for Urban Imagers

Nebula	Popular Name	Constellation	RA	Dec.	Magnitude (v)	Diameter
M76	Little Dumbbell	Perseus	$1^h\ 42.3^m$	+51° 34′	10.1	2.7′ × 1.8′
NGC 1514	Crystal Ball	Taurus	$4^h\ 9.2^m$	+30° 47′	10.0	2.3′ × 2.0′
NGC 2392	Eskimo	Gemini	$7^h\ 29.2^m$	+20° 55′	9.1	47″ × 43″
M97	Owl	Ursa Major	$11^h\ 14.8^m$	+55° 01′	9.9	3.4′ × 3.3′
NGC 6543	Cat's Eye	Draco	$17^h\ 58.6^m$	+66° 38′	8.1	23″ × 17″
M57	Ring	Lyra	$18^h\ 53.6^m$	+33° 02′	8.8	86″ × 62″
NGC 6826	Blinking Planetary	Cygnus	$19^h\ 44.8^m$	+50° 31′	8.8	27″ × 24″
M27	Dumbbell	Vulpecula	$19^h\ 59.6^m$	+22° 43′	7.4	8.0′ × 5.7′
NGC 7008	Fetus	Cygnus	$21^h\ 0.5^m$	+54° 33′	10.7	98″ × 75″
NGC 7009	Saturn	Aquarius	$21^h\ 4.2^m$	–11° 22′	8.3	44″ × 23″
NGC 7293	Helix	Aquarius	$22^h\ 29.6^m$	–20° 50′	7.3	18′ × 14′
NGC 7662	Blue Snowball	Andromeda	$23^h\ 25.9^m$	+42° 32′	8.3	32″ × 28″

Most planetary nebulae display extended outer halos beyond the diameters stated above when imaged from a dark site.

render some images sharper than others. Analyze each frame critically, and discard up to half of them to keep them from degrading the sharpness of the final picture.

If you're shooting through color filters, try to keep at least five of the sharpest images in each color channel. When shooting with a DSLR or one-shot color (OSC) camera, triple that amount.

Once you've calibrated and aligned all of your images, combine (stack) the images using one of the advanced methods that reject "outlier" pixels, such as standard-deviation mask or sigma-reject methods (*S&T:* September 2011, page 72). These produce the sharpest, smoothest results, particularly when many individual images are combined. Rather than eliminating an entire image that has a satellite trail or some other blemish, the advanced combine algorithms will only reject the area in the frame with deviant levels as compared with the others in the group. Do this for each individual group of filtered images, or all your OSC data.

After stacking the red, green, and blue channels, combine the channels in two ways. First, add the color-filtered results together into a color image and save the

Although the Dumbbell Nebula (M27) can be imaged with excellent results from less-than-ideal locations near the city without special filters (*left*), long exposures through a narrowband hydrogen-alpha filter reveal an extended outer halo of nebulosity (*right*).

The Helix Nebula (NGC 7293) is one of the biggest planetary nebula in the night sky, offering plenty of small-scale details for imagers using small telescopes.

result. Next, take the same stacked results and stack those together in your favorite image-processing program to make a monochrome luminance image. This is often referred to as a "synthetic luminance." I usually sum the color channels and save the result as an IEEE float FIT file (meaning the image has more than 16-bit depth). This yields a high-resolution synthetic luminance that can then be sharpened using advanced deconvolution to reveal hidden details. Later, this synthetic luminance can be combined with the color channels in *Photoshop* or other image-processing software, where you can apply additional steps to enhance color and tease out sharp details.

Going Deep

Those of you who have the benefit of dark skies can try to capture additional surprises in planetary nebulae. The first is the many faint targets that are impossible to capture under the glow of suburban skies. These include the lovely but elusive Helix Nebula (NGC 7293), Abell 39 (a ghostly bluish bubble), and the obscure but rewarding PK 164+31.1. These objects respond best to the same methods that you utilize for imaging faint galaxies and nebulae: long exposures, and many of them.

The other surprise that planetary nebulae offer imagers under dark skies is that most of them are surrounded by extensive, faint halos of material shed by the progenitor star in the distant past. Lying beyond the inner rim and outer shell of more than half of well-studied planetary nebulae is an extended ionized halo, with surface brightness often 1,000 times dimmer than the main nebula. These faint halos require a combination of two imaging techniques to achieve the best result.

First, acquire your high-resolution images of the central regions, as described earlier. Next, obtain long exposures of the outer halo. Because these outer structures usually present fewer details and lower contrast than the central bright regions, consider binning your CCD 2×2 or 3×3 (if this feature is available) during the acquisition of the outer halo using your clear filter, to capture as many photons as possible. Later, when processing in *Photoshop*, apply the outer halo image to the sharp core photo as a new layer. Next, create a layer mask to conceal the central overexposed region while allowing the faint halo to contribute to your color image (*S&T:* May 2010, page 72). This approach enhances the scale of small planetary nebulae such as the Blinking Planetary (NGC 6826) and enriches the appeal of even larger planetary nebulae, including the Dumbbell (M27).

If you're looking for new challenging targets to add to your imaging repertoire, consider spending some time on planetary nebulae. These little stellar ghosts offer an exciting challenge to novice and experienced astrophotographers alike. Few objects in the night sky present such diversity to amateurs using modest equipment. ✦

Connecticut-based physician ***Ruben Kier*** *is the author of* The 100 Best Astrophotography Targets: A Monthly Guide for CCD Imaging with Amateur Telescopes.

◀ GALACTIC SPRAWL

Fabian Neyer

This exceedingly deep photograph of M101 in Ursa Major reveals the farthest extent of this showpiece galaxy's spiral arms, as well as numerous background galaxies.

Details: *TEC 140 APO refractor with SBIG STL-11000M CCD camera. Total exposure was 45⅗ hours through color and hydrogen-alpha filters.*

◀ ▼ NORTHERN EXPOSURE

Howard Eskildsen

Using custom contrast enhancement, Florida amateur Howard Eskildsen highlights the bright rays in the lunar north that emanate from the large crater Anaxagoras.

Details: *Explore Scientific 152-mm f/8 refractor with Imaging Source DMK 41AU02.AS video camera. Stack of multiple frames recorded February 20th from Ocala, Florida.*

▼ CAPE COD VIEW

Chris Cook

The central bulge of the Milky Way reaches across the sky as seen from Red River Beach in Harwich Port, Massachusetts.

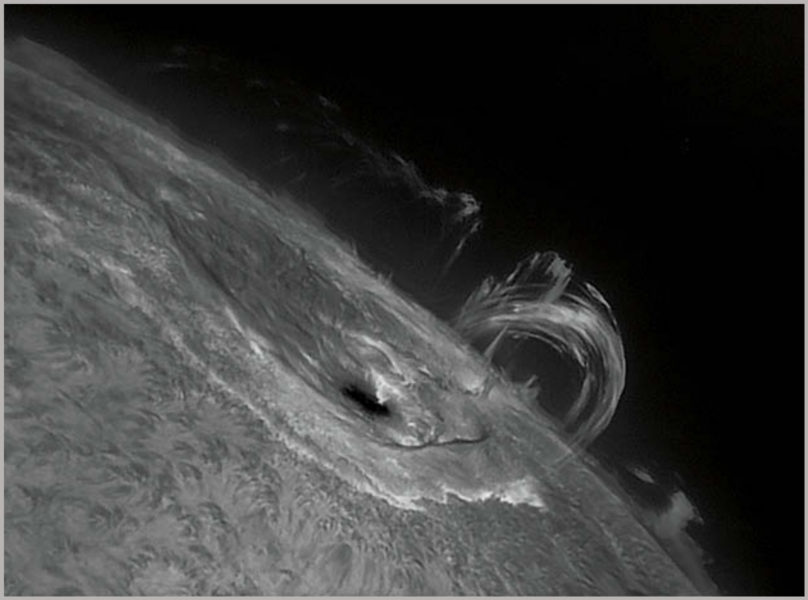
Details: *Canon EOS 5D DSLR camera with 15-mm f/2.8 fisheye lens. Total exposure was 1 minute.*

▲ BARRED SPIRAL

Howard Trottier

Spiral galaxy M109 in Ursa Major sports one of the most distinct central bars of any galaxy in the Messier catalog.

Details: *PlaneWave Instruments CDK17 Corrected Dall-Kirkham telescope with SBIG STL-4020M CCD camera. Total exposure was 8 hours through color filters.*



◄ SOLAR TANGO

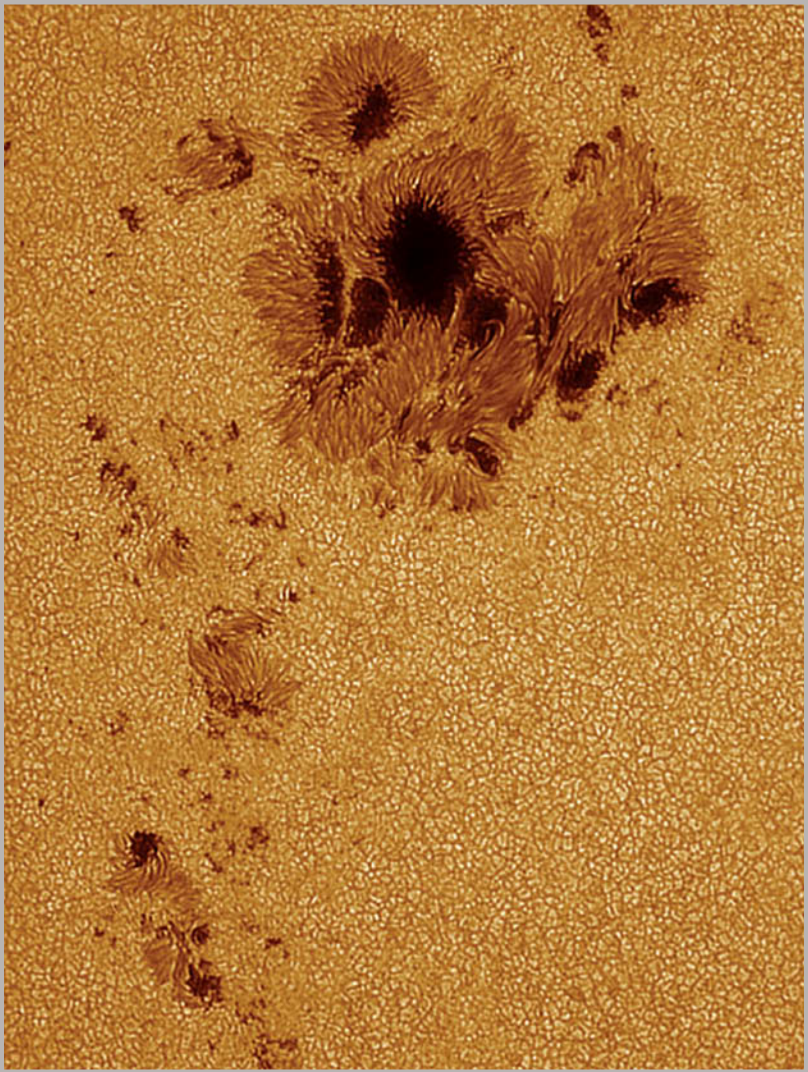
David Cortner

After producing multiple strong flares, sunspot AR1520 displayed these graceful arching prominences as it neared the solar limb on July 17th.
Details: *90-mm f/10 refractor with Lunt Solar Systems 60THa solar hydrogen-alpha filter and a Point Grey Research Chameleon video camera. Stack of 50 video frames.*

◄ ▼ CHURNING SPOTS

Eduard Garcia-Ribera

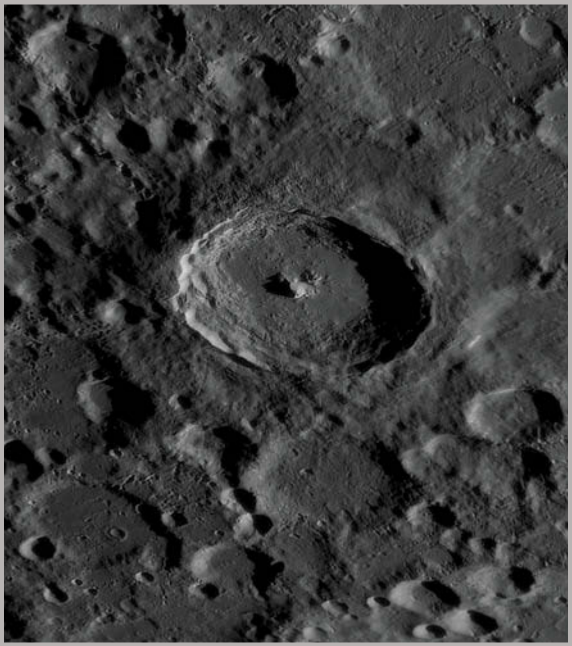
The large sunspot group AR1476 put on a wonderful show for solar observers in early May.
Details: *Takahashi FS-152 refractor with a Baader Herschel Safety Wedge Solar Prism and Imaging Source DMK 31AU03.AS video camera. Stack of multiple video frames.*



▼ SOUTHERN HIGHLANDS

Mike Wirths

Tycho is easily counted among the most prominent craters on the Moon. With its sharply defined rim, it stands out from the older, weathered craters of the southern highlands.
Details: *18-inch Starmaster Dobsonian telescope with a Lumenera Infinity2-2M video camera. Stack of hundreds of frames recorded through a True Technology red filter.* ✦



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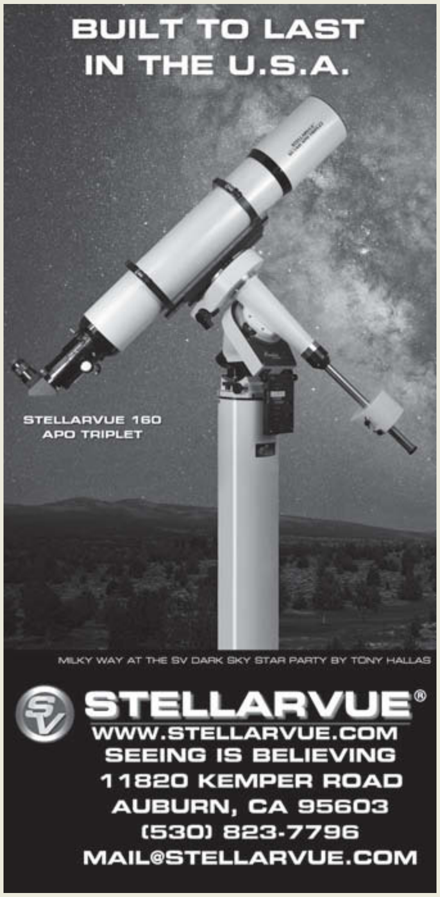

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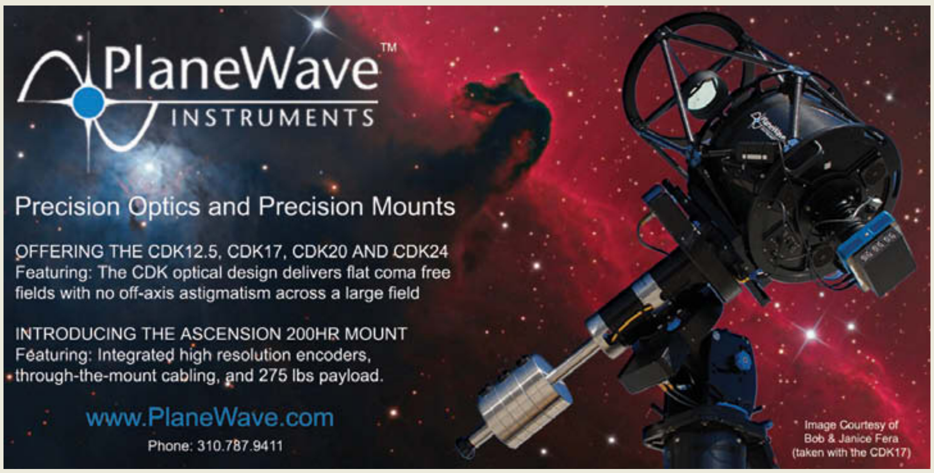

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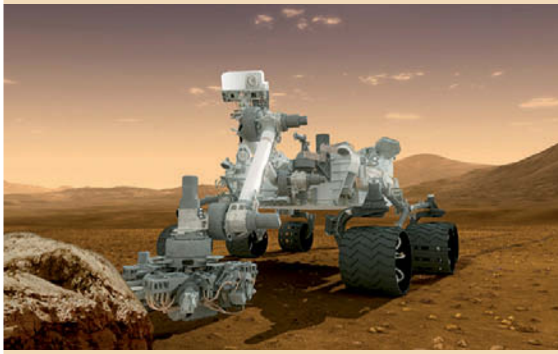

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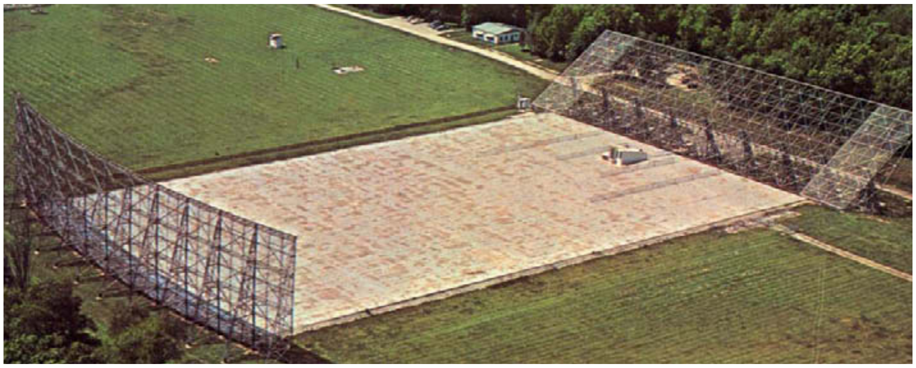

NORTH AMERICAN ASTROPHYSICAL OBSERVATORY

The football-field-size "Big Ear" radio telescope, operated by the Ohio State University, conducted SETI from 1973 to 1995. It was disassembled in 1998 to make room for a golf course.

In the April 1985 issue of *S&T*, I described my amateur search for radio signals from the stars — searching especially for a repeat of the "Wow! signal" recorded by the football-field-sized Ohio State University radio telescope in 1977. The Wow remains the best candidate for a signal from E.T. ever recorded. My search has continued, illustrating what a motivated amateur can accomplish in the search for extraterrestrial intelligence (SETI).

I built a radio telescope in 1983 to search for interstellar signals, at a time when Ohio State's program was the only full-time SETI project. My system used a 12-foot steerable dish antenna and a 256-channel receiver listening at 1420 megahertz. It was quite advanced (I got help from professionals), and could easily detect the hydrogen in the galactic plane. But after several years of searching, I found no talkative aliens.

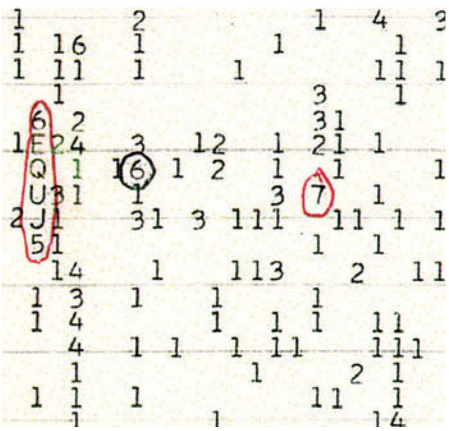
Harvard University physicist Paul Horowitz let me use his 8-million-channel receiver system and 84-foot dish to look for the Wow signal for several four-hour sessions in the mid-1980s. That search failed to find any of the ultra-narrowband signals his system was designed to detect, but I managed not to break anything.

Suspecting that a weak constant source might lurk where the strong but apparently intermittent Wow had been seen, I applied for observing time at the Very Large Array — the most powerful radio eye on the sky at the time. Surprisingly, the gates of Big Science opened and in the mid-1990s I found some weak natural sources during a few hours of observing, but no artificial signals.

The VLA probably would have missed intermittent signals, so in the late 1990s I linked up with Simon Ellingsen at the University of Tasmania to use an 84-foot radio telescope in Australia that could listen for a longer period than is possible from the Northern Hemisphere. Despite 14-hour stretches observing in 1,024 channels, we saw lots of hydrogen but no E.T.

How could the Wow signal be so elusive? It might have been local interference due to a secret satellite or some other red herring. But it was the best candidate seen by the Ohio State survey over many years. Such tugs on the cosmic fishing line seem to be worth more follow-up than the roughly one day I've spent at each of several positions needed to cover uncertainties in coordinates. Maybe it was a signal that blinks "on" very rarely, something like a lighthouse on a rotating planet. Maybe it was a signal sweeping in frequency.

Nobody has found artificial signals from the stars after 50 years of sporadic searching, but most searches have been modest — viewing small spots of sky for a few minutes and listening on small slivers of spectrum. The sky could be blaring with radio super-stations at places on the radio dial that we have not yet tuned to, or flickering with laser flashes that our few optical searches have yet to spot. If we can muster an ambitious search with an instrument such as the currently underfunded Allen Telescope Array, we may yet find broadcasts revealing minds something like our own. ✦


J. EHMAN / B. DIXON / NORTH AMERICAN ASTROPHYSICAL OBS.

Jerry Ehman scribbled "Wow!" (see the title above) next to this computer printout to highlight the strength of a narrowband radio signal (6EQUJ5) picked up on August 15, 1977.

***Robert Gray** is the author of the new book* The Elusive Wow: Searching for Extraterrestrial Intelligence. *He lives in Chicago and analyzes data for a living.*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