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SKY & TELESCOPE

JUNE 2012

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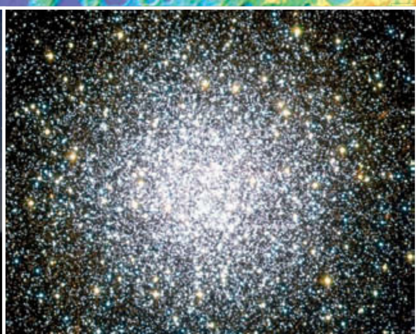

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SKY & TELESCOPE

June 2012

VOL. 123, NO. 6

On the cover: New LRO views such as this topographic far-side map unveil the Moon in striking detail.

MOON: NASA GSFC / DLR / ASU

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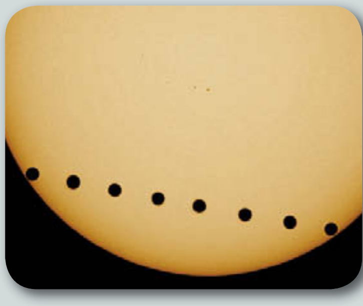

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Tarantula Nebula in Hα
ProLine PL16803 | John Gleason

Our New Moon Globe

S&T: DENNIS DI CICCO

Sean, Kelly, Gregg, and Bob look over the proofs for *S&T*'s new Moon globe.

AT *S&T*, WE DO A LOT more than publish a monthly magazine. In addition to our website, we also produce a variety of new products. Two years ago, our biggest project was the 70th anniversary DVD collection. Last year, we worked with Southern Stars to produce our *SkyWeek* app and partnered with Firefly Books on Sue French's *Deep-Sky Wonders*. And now we're particularly excited to announce our new Moon globe.

"But wait a minute," you might be thinking, "Moon globes have been around for decades."

That's true, but there's never been a Moon globe quite like ours. Previous Moon globes have used artistic renderings of the lunar surface. *S&T*'s new globe is based on actual images from cameras on NASA's Lunar Reconnaissance Orbiter (LRO) taken under nearly consistent lighting conditions. In other words, our globe is the first one that shows the Moon *as it really is*.

Creating this globe in partnership with Replogle was a team effort. Imaging editor Sean Walker and senior contributing editor Kelly Beatty came up with the idea for an LRO-based Moon globe nearly simultaneously. Kelly then obtained the actual imaging data from the LRO camera team and worked with the U.S. Geological Survey to determine the proper format for the digital image file.

Next, Kelly supplied our illustration director Gregg Dinderman with a list of hundreds of lunar features (craters, valleys, Apollo landing sites, etc.) that merited a label. Gregg manually entered them one by one into the image file, using Antonín Rükl's *Atlas of the Moon* and other sources to make sure each label was properly placed. The *S&T* editorial staff suggested additional labels, and the list eventually reached 850 named features. We checked each label multiple times to make sure every single one was spelled and positioned correctly. This process certainly deepened our knowledge of lunar nomenclature!

S&T production manager Mike Rueckwald coordinated the project with Replogle. When he obtained proofs, Sean and Gregg fine-tuned the contrast to make the globe as natural and visually attractive as possible. After several months of effort, we finished the job in mid-February.

This project involved a lot of work (especially for Gregg and Kelly), but seeing this stunning and true-to-life Moon globe proves that our effort has paid off. See page 75 for more details.

Robert Naeye
Editor in Chief

SKY & TELESCOPE

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

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Light, Revisited

In his article "Chasing Light Speed" (*S&T*: February 2012, page 34), Tom Gale mentions Louis Essen as one of the scientists who helped determine the exact speed of light. It's worth adding that Essen argued vehemently against the idea of absolute light speed, put forth in Albert Einstein's special theory of relativity. If the speed of light is absolute, time is relative. Essen, who invented the cesium clock, thought instead that the speed of light, not time, is relative.

Daniel L. Haulman
Montgomery, Alabama

In Gale's article there's a sidebar describing how to measure the speed of light in a microwave oven. I had the opportunity to judge a science fair project a few years ago in which a student did that same experiment — except he used a Hershey's chocolate bar instead of butter sticks. The student measured the burned spots on the chocolate bar to get the wavelength and derive the speed of light. The project was actually done by the student's whole science class, and needless to say they all enjoyed it.

Richard Nugent
Houston, Texas

I appreciated Tom Gale's article on ingenious experiments to determine the speed of light, although I thought that the description of Bradley's measurements of stellar aberration raised unnecessary complications. I consider Bradley's 1728 paper the very model of the scientific method. He explicitly estimated his uncertainty as 1-2%, hence his result is consistent with modern measurements. He also carefully established the apparent universality of the speed of light, showing it to be independent of a star's direction and distance and to be the same for emitted starlight as for reflected sunlight from Io. We so take these for granted that it doesn't occur to us that the first accurate experiments could not assume them.

Larry Molnar
Grand Rapids, Michigan

S&T: LEAH TISCIONE

I found it difficult to follow the explanation of James Bradley's discovery of Earth's orbital speed affecting a star's parallax. Wouldn't the starlight actually appear to arrive *behind* the real location of the star because of its journey? For example, if a ball is dropped from a height and you move, it will fall behind you. The illustration implies the starlight appears to come ahead of its actual position.

Christian Foy
Guilford, Connecticut

Editor's Note: *It is indeed a matter of appearances: think of the rain hitting the windshield of a moving car. Even if the rain is falling straight down, it appears to come from in front of the moving car.*

Lemaître's Expanding Universe Not So Obscure

Well, Lemaître's 1927 paper cannot have been very obscure (*S&T*: February 2012, page 16): I cited it in a 1996 paper, though I did miss two earlier 1916 precursors (O.H. Truman in *Observatory* and Reynold K. Young and W.E. Harper in the *Journal of the Royal Astronomical Society of Canada*). Major credit goes to Mario Livio for finding the Lemaître letter that explains he did his own censoring. Translation nuances might give another layer to the story, too: Lemaître's note claiming his "provisional discussion" was of "no actual interest" should be interpreted keeping in mind that the French apparent equivalent, "*actuelle*," means "current."

The question of credit grows dicier. While the X-axes in Lemaître's and Hubble's graphs do represent their own work, the Y-axis data for both their results (and those of others before them) came from Vesto Melvin Slipher at Lowell.

As for a Lemaître Space Telescope, I cannot resist quoting the late Jesse L. Greenstein when the flaw in the HST mirror was first recognized: "Well, Edwin Hubble finally got the telescope he deserved."

Virginia Trimble
Irvine, California

Music of the Spheres

I've always loved stargazing and have been a keen amateur astronomer and astrophotographer for the past 12 years. I've also been a keen guitar player, so recently I combined the two and wrote a song about my passion for stargazing. I invite you to listen to it on YouTube: it plays beneath a collection of raw astrophotos that I've taken over the years.

Jarlath Quinn
Godalming, Surrey, England
YouTube video: http://bit.ly/wXKnDy

Request for Partnership

We are in a unique time in history when more people reside in light-polluted cities than in the darker rural areas. As a result, most people are now effectively cut off from the night sky even in their own backyard. Like so many readers of *Sky & Telescope*, we of the International Dark-Sky Association want more people to know the wonders of the night sky, the joy of learning the constellations, and the fun, not fright, of the night.

The IDA recognizes that more needs to be done to bring back the stars where people live and that education is the key to effective change. Education will best foster a public understanding of the environmental consequences of too much artificial light at night and the ease of adopting solutions to reduce it. Through our new Suburban Outreach Sites (SOS) program, we hope to bring both this dark-sky education and the wonders of the night sky to the general public on a regular, widely accessible basis.

The IDA is seeking to partner with astronomy clubs or other interested groups that have experience with public outreach that are also willing to educate people about the important benefits of fighting light pollution. IDA will provide educational materials and techniques to help integrate these materials into star parties and other events to make this new program a success. If your group is interested, please contact me to help launch this new venture so that together we may all enjoy darker nights.

Scott Kardel
International Dark-Sky Association
wskardel@darksky.org
www.darksky.org/sos

For the Record

✷ *The image of Mars on page 43 of the March 2012 issue was taken in June 2001, not 2003 as the caption indicated. Hats off to Rodger Gordon for pointing out the error.*

✷ *The sidebar "Uniting the Stargazers" on page 26 of the March 2012 issue incorrectly stated that Epsilon Aurigae's light curve has been plotted around 14,000 times in the last year at the AAVSO site. This number is the total number of light curves plotted through AAVSO; the number for Epsilon Aurigae is 1,200.*

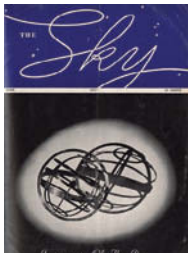
For a list of past errata, please go to ***SkyandTelescope.com/Errata****.*

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

75, 50 & 25 Years Ago

Roger W. Sinnott

June 1937



Women as Astronomers "Harvard University today finds that some of its most important advances in astronomy are the independent contributions of women.

"Women at Harvard have established the intricate physical standards by which observatories all over the world determine the spectroscopic classifications of stars. They have discovered more than three-quarters of all the 7,000 known variable stars, practically taking over this field. . . . And theirs is the groundwork providing astronomers with the yardsticks now used for measuring the tremendous distances of remote objects in the universe."

Authorship is credited to the New York Times.

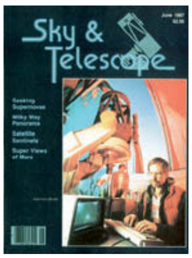
June 1962

Smallest Known Star? "'The star can hardly be much larger than half the diameter of our moon — or one-seventh that of the earth — and must have a density of about 200 million times that of water.'

"With these words, University of Minnesota astronomer Willem J. Luyten announced his discovery of a white dwarf that may be the smallest star known. He described it as probably 25,000 times fainter than the sun and very blue, its color like that of a B-type star. . . . [The] low luminosity of so hot a star can be explained only by an extremely small size."

The high proper motion of the 18th-magnitude star in Taurus, LP 357-186, persuaded Luyten it was as near as 100 light-years. More recent studies put it somewhat farther out and hence not so tiny, but the jury's still out.

June 1987



Volcanism on Mars "In images from the Viking orbiters, windblown deposits of dark material often appear inside craters. But dark patches have also turned up inside the vast Valles Marineris canyon complex. . . . Baerbel K. Lucchitta of the U.S. Geological Survey believes these areas represent volcanic vents, the first signs of such activity found in this rift system. And she thinks they may be no more than a few million years old — still fresh on a geologic time scale."

Subsequent work confirmed that Mars hasn't been volcanically active in the last 10 million years or so (see page 15).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M31 Image Courtesy Martin Pugh

New Fuel for Supernova Debate

NASA GSFC / DANA BERRY

Binary white dwarfs take billions of years to merge, slowly spiraling inward as they lose orbital energy by gravitational radiation. Their eventual mergers may produce the cataclysmic explosions seen by astronomers as Type Ia supernovae.

A SPREE OF recent studies are adding to the ongoing debate about what's behind a Type Ia supernova's boom.

Type Ia's are crucial "standard candles" for measuring large cosmic distances independently of redshifts. They leaped into astronomical fame in 1998 when they enabled astronomers to discover that the universe is expanding at an accelerating rate. But the origin of these key explosions remains hotly debated. Astronomers agree that the blast marks the total self-destruction of at least one white dwarf, but they've argued for 40-odd years over what turns the dwarf into a thermonuclear bomb.

One camp holds that the white dwarf explodes when it collects too much gas from a normal companion star closely orbiting it. The extra mass tips the white dwarf past the Chandrasekhar limit, the point at which the pressure between electrons deep inside can no longer support the dwarf's weight, causing it to collapse. The shrinkage sets off a runaway nuclear fusion reaction that races through the star within seconds, consuming it entirely.

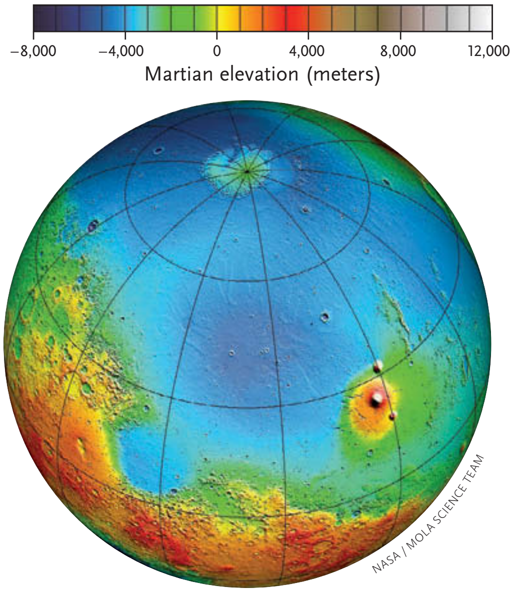
The second camp, which has been gaining traction in recent years, argues that the kaboom happens when two white dwarfs in a tight binary finally spiral together and merge. This theory usually also assumes the Chandrasekhar limit must be breached to trigger dwarf death.

To see if the double-dwarf theory could account for the known rate of explosions, Carlos Badenes (University of Pittsburgh) and Dan Maoz (Tel Aviv University, Israel) looked for extreme Doppler signatures in 4,000 Milky Way white dwarfs from the Sloan Digital Sky Survey. Fifteen proved to be whirling around an unseen companion faster than 250 km/s (560,000 mph), implying a tight orbit around another white dwarf, destined to end in merger.

Badenes and Maoz then compared this expected merger rate to the rate of Type Ia supernovae in Milky Way-type galaxies. The rates are almost exactly the same: one per century for each galaxy. This agreement doesn't prove that white-dwarf mergers produce Type Ia supernovae, but it shows they happen in sufficient numbers.

Other recent work also argues for a small companion. Observations with the Swift satellite found a dearth of X-ray and ultraviolet emission from Type Ia explosions, emissions expected if the companion star is evolved or massive. That leaves smaller hydrogen-burning stars and dwarfs, including white dwarfs, as options.

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



A color-coded globe of Martian topography, centered on Utopia Planitia, shows the vast, mostly flat northern lowlands (blue). The high peak lower right of center is Elysium Mons.

Mars's Long-Gone Ocean . . .

Planetary scientists have long suspected that the vast, low plain spanning much of Mars's northern hemisphere is the bed of an ancient ocean. River channels run down to it, impact craters within it show lobes of mud-like splats, and there are hints of terraced, wave-eroded shorelines around its edges at consistent "sea levels."

The case for an ancient Oceanus Borealis covering a third of the planet has now grown stronger. A radar instrument on the European Space Agency's Mars Express orbiter found that near-surface layers surrounding the north and south poles are most likely highly porous, chock full of ice, or both. The probe's deep-penetrating radar can't distinguish between these options, but both are reasonable outcomes if the northern plains had been waterlogged in the past.

. . . And Recent Marsquakes

Meanwhile, images from the HiRISE camera aboard NASA's Mars Reconnaissance Orbiter have surprised geologists. A close-up of Cerberus Fossae, a set of fractures that cuts across a lava flow just a few million years old, revealed a field of boulders that fell from a nearby scarp. As reported in February 23rd's *Journal of Geophysical Research: Planets*, the boulders couldn't have popped free as ice retreated. Instead, all evidence points to shaking of the ground — marsquakes — as the cause. And because weathering hasn't erased all of the boulders' trails from when they rolled and bounced downslope, the quakes must have happened recently.

Although Mars researchers have caught dusty avalanches falling from the planet's north polar cap (*S&T*: June 2008, page 15), they haven't found boulder cascades anywhere else, so the situation in Cerberus Fossae could be unique. The site is near a huge volcano, Elysium Mons, so perhaps the ground is still shifting above a pocket of subsurface magma.

Blacks Holes: It's How You Spin It — Maybe

Astronomers know that fast-spinning black holes spit more powerful jets into space than slower spinners, but whether the spin's direction with respect to infalling matter affects the jets' power is still debated. A recent study by Alexander Tchekhovskoy (Princeton University) and Jonathan McKinney (Stanford University) suggests that a slightly more powerful jet arises when the black hole spins in the same direction as its accretion disk.

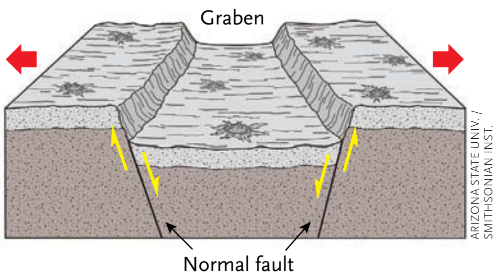
Like previous such work, the new study depends on sophisticated computer models of accreting black holes that take Einstein's relativity fully into account. But the new project looked at extremes previous simulations had not reached, "observing" puffed-up disks laced with intense, hard-to-model magnetic fields that may be closer to black holes' actual environments.

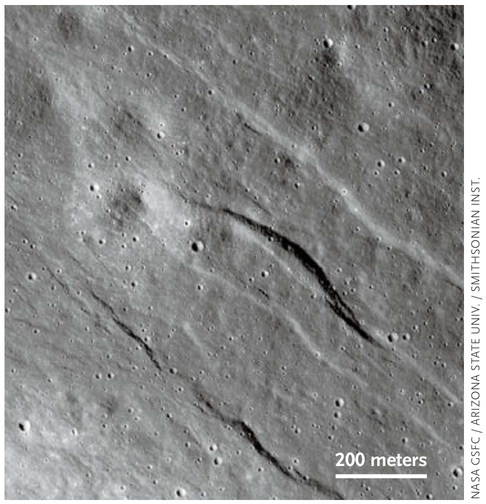
"When you are figuring out which car is fastest, you push the accelerator pedal all the way to the floor," Tchekhovskoy says. In this case, the pedal is the amount of magnetic field concentrated in the system. A higher concentration spawns a stronger jet. So the researchers stuffed the black hole as full of magnetism as they could, creating something like an olive threaded with many strands of spaghetti. They found that a stuffed, forward-spinning black hole produced a jet a few times more powerful than a backward-spinning one. That's not much difference astronomically speaking, and probably isn't enough to allow astronomers to easily distinguish between two such systems in real life. But it's a solid step forward in one of the most difficult modeling projects in astronomy.

Moon Might Still Be Kicking

Yet another hint that the Moon still has a little geologic life in it turned up recently in super-high-resolution close-ups from the Lunar Reconnaissance Orbiter Camera (LROC, see page 18).

The evidence is a series of small, narrow valleys called *graben*, which result when crust on the Moon (or Earth) pulls apart. Backyard observers are familiar with large lunar graben, the ancient linear rilles seen especially around the edges of maria. The new features are smaller and much younger, stretching at most just a few miles long, researchers report in the March *Nature Geoscience*. They're scat-





Top: **A graben forms when crust pulls apart (red arrows). Stretching causes the crust to break along parallel normal faults; the terrain between drops down (yellow arrows), forming a flat-floored valley.** ***Bottom:*** **The largest of the newly detected graben is in the highlands of the lunar farside. It's about 1,600 feet (500 meters) wide and almost 70 feet (20 m) deep.**

tered widely across the lunar landscape and are probably less than 50 million years old — just yesterday by lunar standards.

The narrow graben suggest that the Moon's outer crust recently expanded slightly here and there, even though overall the Moon should have shrunk slightly as its interior cooled and solidified. (LROC images indeed show small lobate scarps created by global shrinking.) Along with a recent reanalysis of 40-year-old Apollo seismic data, the new study buoys the notion that the Moon hasn't completely solidified after all.

Loose Planets Abound Between the Stars

The most common life forms in the universe might exist deep inside eternal-night worlds far from any star, adrift in the frigid dark of interstellar space.

Researchers at Oxford University and Stanford University's Kavli Institute for Particle Astrophysics and Cosmology (KIPAC) estimate that "nomad" planets, ejected early from their home stellar system and now free-floating through the Milky Way, could outnumber stars by as many as 100,000 to 1. The statistics remain so weak, however, that the team's lower limit is still 1 to 1.

Earlier estimates were more like a handful of loose planets per Milky Way star, though those only counted giant planets (*S&T*: August 2011, page 17). The new estimate includes those down to Pluto's size, 0.2% the mass of Earth.

Louis Strigari (KIPAC) and his colleagues extrapolated from the small number of planet-mass objects that have been detected far from their stars or in interstellar space by direct imaging or by *gravitational microlensing*. When a massive object passes nearly in front of a distant star, its gravity slightly bends (or lenses) the light of the background star, causing a characteristic brightening and fading. So far, 24 planet-mass objects have been detected by such microlensing, and 10 of them don't seem to be star-tied.

Despite the chill of interstellar space, life on a wandering world could still eke out an existence. The surface of such a planet must be just a few degrees above absolute zero. But microbial life could thrive for billions of years under a thick atmosphere or ice crust, benefiting from heat flowing from the planet's interior.

Exoplanet specialists think that some 80% of planetary systems go through an early period of gravitational chaos that flings some of their worlds into interstellar space. Still, skeptics have a hard time imagining how tens of thousands of objects at least as large as Pluto could originate for each star, regardless of whether they stay with it or get flung off. Our solar system has only 17 known objects that qualify — the 8 planets, 7 large moons, and the two largest Kuiper Belt objects — even though the solar system never went through serious planet-flinging chaos.

Better statistics for unbound planets may come from NASA's Wide-Field Infrared Survey Telescope (WFIRST) and the ground-based Large Synoptic Survey Telescope (LSST), two gigantic sky-survey projects that, if fully funded, may begin work within a decade or so.

NASA / JPL-CALTECH

CELESTRON

Tom Johnson, 1923–2012

Thomas J. Johnson, the creator of the modern Schmidt-Cassegrain telescope and the founder of Celestron, died on March 13th at the age of 89.

Celestron began in 1960 as the "Astro-Optical" division of Johnson's company, Valor Electronics, but quickly grew to be an independent contender in amateur astronomy. Johnson's formidable telescope-making talent spurred much of the company's success. His own highly unconventional and transportable 18¾-inch Cassegrain so impressed fellow telescope makers that it became the cover story of *S&T*'s March 1963 issue. By the end of 1964 Celestron was producing 4-, 6-, 10-, and 22-inch Schmidt-Cassegrain telescopes, a design Johnson adopted after reading Donald Willey's analysis in the April 1962 issue of this magazine.

In 1970 Johnson and his colleagues introduced the "classic C8," a compact, quality 8-inch portable Schmidt-Cassegrain designed to be photography-friendly. The overnight hit set the pattern for all the amateur Schmidt-Cassegrains that would follow in the coming decades from Celestron, Meade Instruments, and others (*S&T:* June 2010, page 36).

To read the full obituary, please visit **skypub.com/JohnsonObit**. ✦

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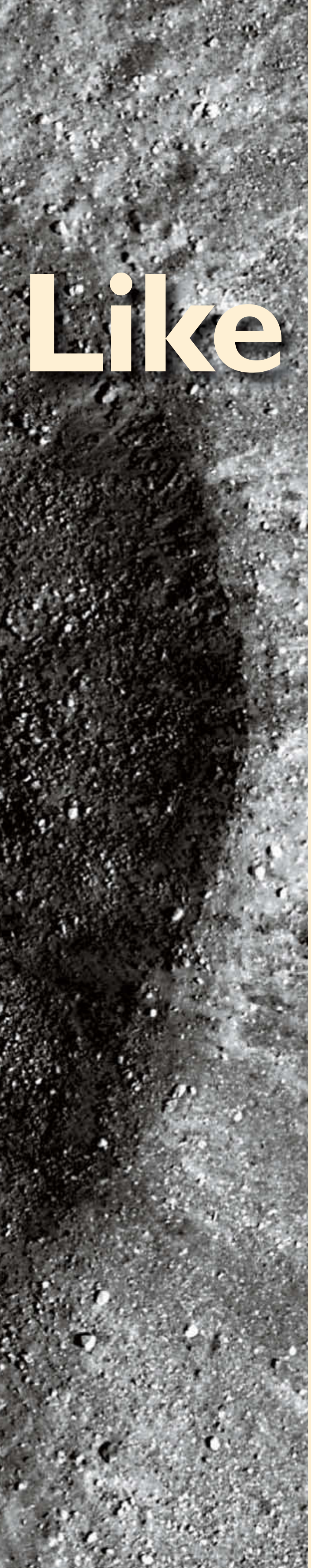
Seeing the Moon



Like Never Before

NASA's Lunar Reconnaissance Orbiter reveals spectacular landforms on our deceptively familiar satellite.

JIM BELL

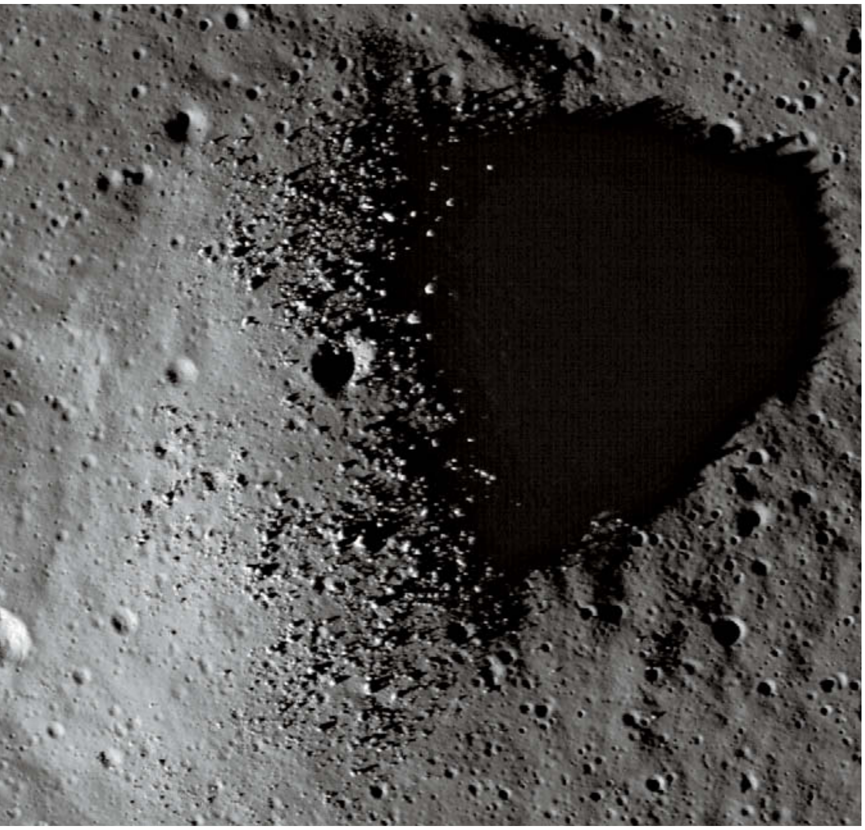
BULL'S-EYE Sometime in the last billion years a meteoroid gouged this unnamed football-field-sized crater in Oceanus Procellarum. The fury of the impact ejected light-colored boulders from deep underground, which rained down on the surrounding terrain. Over time, space weathering will darken the whitish ejecta. Molten rock from the impact trickled down the crater slopes to form the smooth, dark floor.

A COMMON MISCONCEPTION is that we know everything there is to know about the Moon. After all, NASA and other space agencies have sent probes there since the 1950s, and astronauts have explored the surface and returned samples that have been studied in labs for more than 40 years. What more could we learn?

Well, based on spectacular results continually streaming in from the latest robotic emissary, NASA's Lunar Reconnaissance Orbiter (LRO), the answer is "Lots!" From creating the first detailed global maps of the Moon, both topographic and infrared, to finding evidence that there are unique kinds of rocks and minerals that are not represented in the Apollo samples, LRO scientists have made breakthrough discoveries that clearly show that we still have much to learn about our neighbor in space.

LRO has orbited and mapped the Moon since the summer of 2009. A joint project between NASA's human and robotic exploration divisions, LRO is equipped with an impressive set of scientific instruments that include spectrometers to measure the Moon's ultraviolet and infrared properties, a laser altimeter to measure the surface topography, radar-emitting and neutron-detecting instruments to search for subsurface water, a radiation detector to assess potential astronaut health hazards, and of course, cameras to take pictures of the surface (*S&T:* June 2009, page 20).

Indeed, the Lunar Reconnaissance Orbiter Cameras (LROC) have taken some of the most beautiful, highest-resolution, and scientifically comprehensive images ever obtained of the Moon's surface. LROC is actually a 3-camera system: a Wide-Angle Camera (WAC) and two Narrow-Angle Cameras (NACs). From LRO's normal orbital altitude of 50 km (30 miles), the WAC takes color pictures of the Moon with a resolution of about 100



FARSIDE DOMES ***Above left:*** **The 500-meter hole near the peak of this volcanic dome is actually a well-placed impact crater, not a vent.** ***Above right:*** **Flowing magma deposited mounds like this one before solidifying. The boulders clustered on top are likely eroding out of the mound itself and are about 10 to 30 meters across.**

meters per pixel at visible wavelengths, and the NACs take monochrome images of adjacent 2.5-km-wide strips with a resolution of just 50 cm/pixel.

Scientists have used WAC images to create spectacular global Moon maps under different lighting conditions, revealing new features and geologic relationships that had never been seen before. For example, WAC color images are enabling scientists to create the most detailed maps yet of the mineral ilmenite ($FeTiO_3$) — an important resource for metals and oxygen that will be needed by future lunar explorers and settlers.

High-resolution NAC pictures are revealing unprecedented details on the lunar surface, such as millions of tiny impact craters (including some new ones formed since the Apollo era), individual boulders, and other landforms that are revealing new details about cratering processes, erosion, tectonics, and volcanism. For example, NAC images have exposed a global network of small-scale ridges called *lobate scarps* that formed from vertical tectonic movement that indicate that the Moon has been shrinking and contracting slightly since its formation. Some of these thrust faults cut across seemingly young impact craters, suggesting that the Moon may be tectonically active today (see page 15).

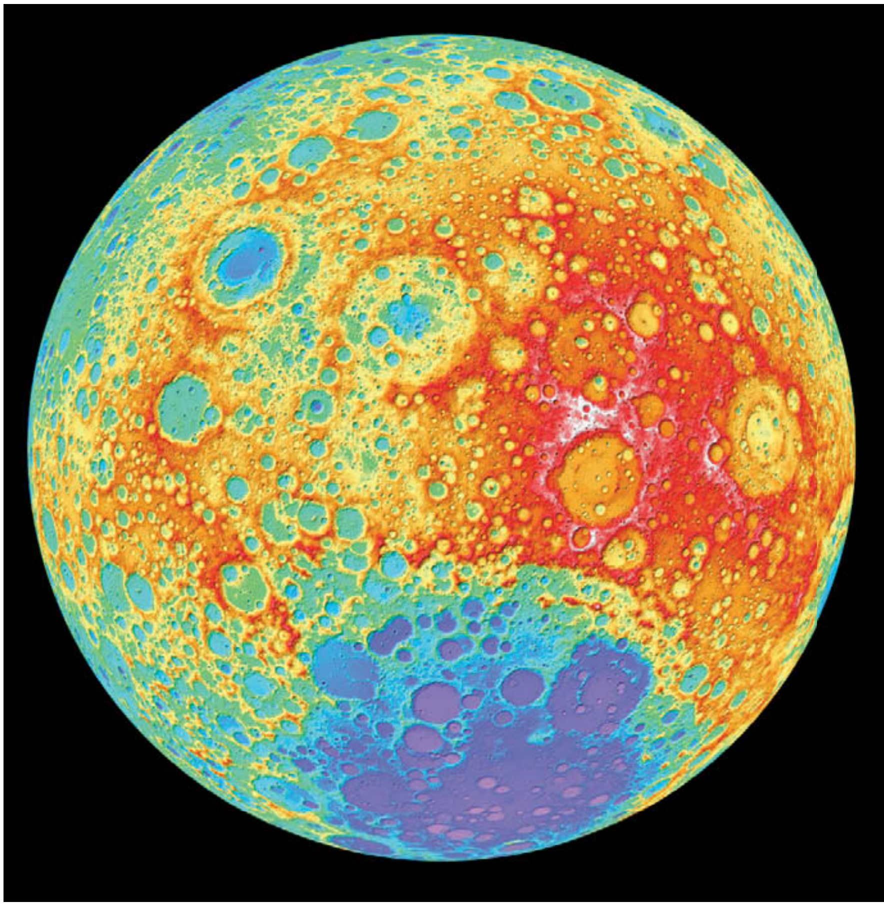
The LRO science team has also used the NACs to take spy-satellite-like photos of equipment and surface disturbances left by the Apollo astronauts more than 40 years ago. Indeed, some of the most popular images show the old Apollo lunar module descent stages, tracks left by astronauts walking or driving the Lunar Roving Vehicles, and Soviet Luna landers and Lunokhod rovers. In certain cases, these pictures have enabled scientists to more accurately reconstruct the locations and geologic context for some of the lunar samples brought back to Earth.

Other instruments on LRO are yielding new scientific results as well. A thermal (heat-detecting) instrument called Diviner has made the first infrared maps of the entire lunar surface, confirming the extremely cold temperatures of the permanently shadowed regions near the lunar poles — including some areas with temperatures of only 25 Kelvins (–415°F) — barely above absolute zero!

LRO also played a critical role in the Lunar Crater Observation and Sensing Satellite (LCROSS) experiment, which in October 2009 impacted the upper stage of LRO's launch rocket into a permanently shadowed region in Cabeus Crater, near the Moon's south pole (*S&T:* February 2010, page 28). LCROSS measurements of the impact plume revealed evidence for small amounts of water ice, plus other surprising volatile chemicals that get trapped in such extremely cold locations. These include the element mercury, which is relatively easy to detect and that could point to regions that have high concentrations of other volatiles. LRO neutron spectrometer measurements of the polar regions are yielding surprising and not yet completely understood results, such as evidence for buried ice in sunlit as well as permanently shadowed polar regions.

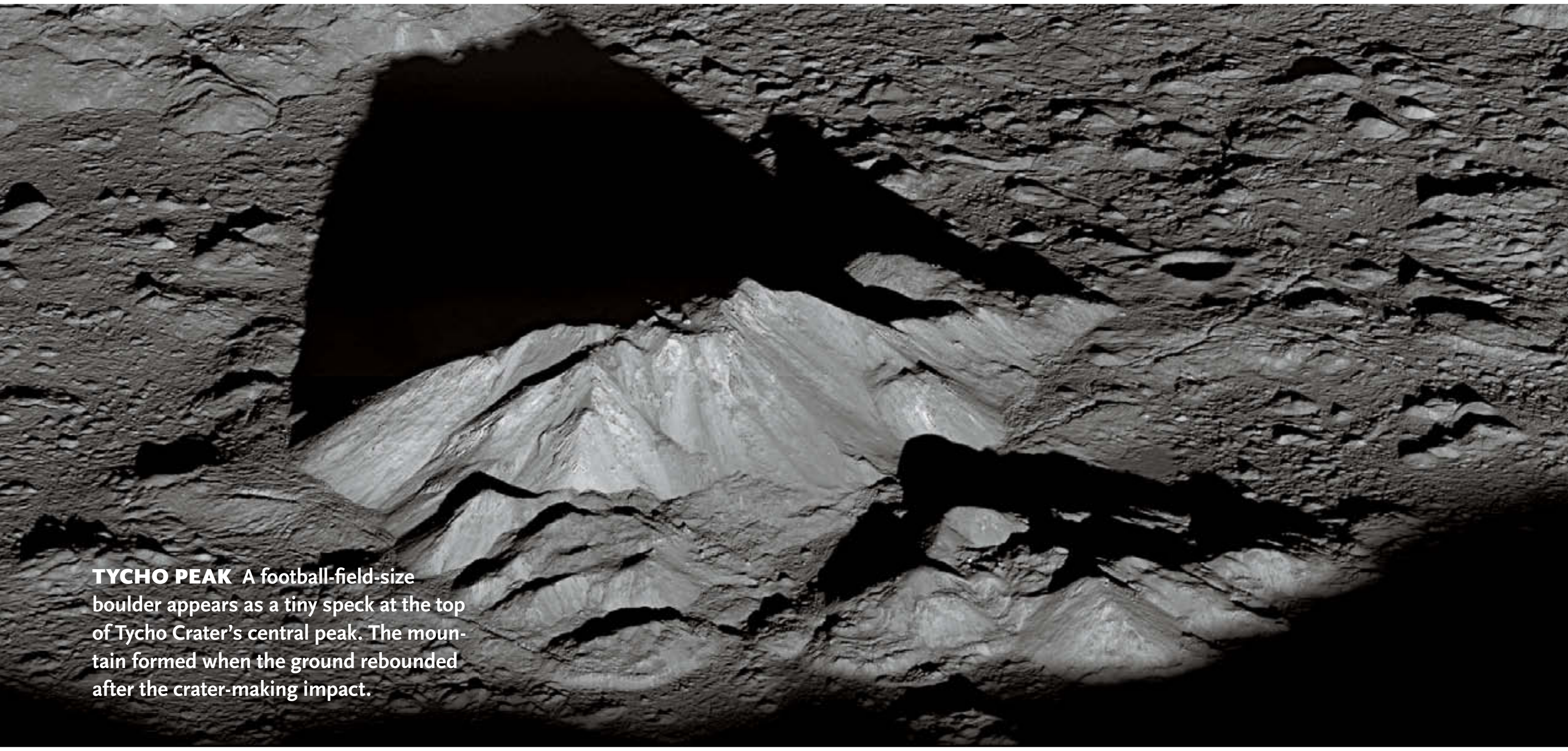
Combined with LRO images and previous data from Lunar Prospector, the Diviner data also allowed scientists to discover a new region of high-silica volcanic domes on the lunar farside — volcanic deposits dramatically different from the runny, flood-basalt lavas seen prominently in the dark, circular mare deposits on the nearside. These domes provide evidence that lunar volcanism has been more global and more diverse than originally thought.

LRO's laser altimeter data, combined with stereo images from the LROC WAC and NACs, has resulted in the most accurate and detailed topographic maps ever made of the lunar surface. These maps finally provide the detailed profiles of elevations and slopes needed for modeling the formation and evolution of lunar impact craters along with tectonic and volcanic features.

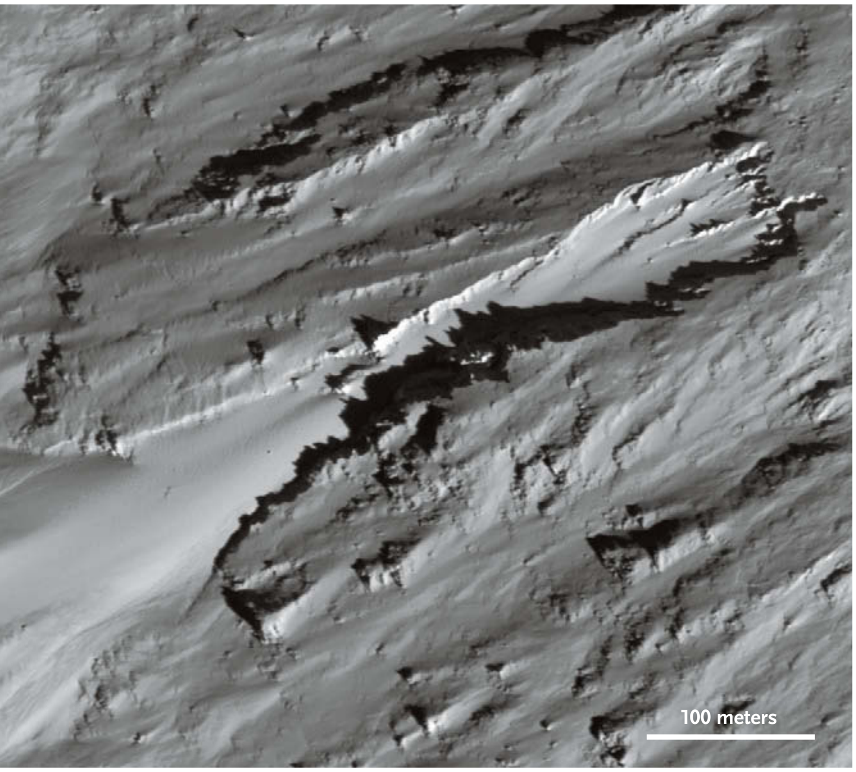


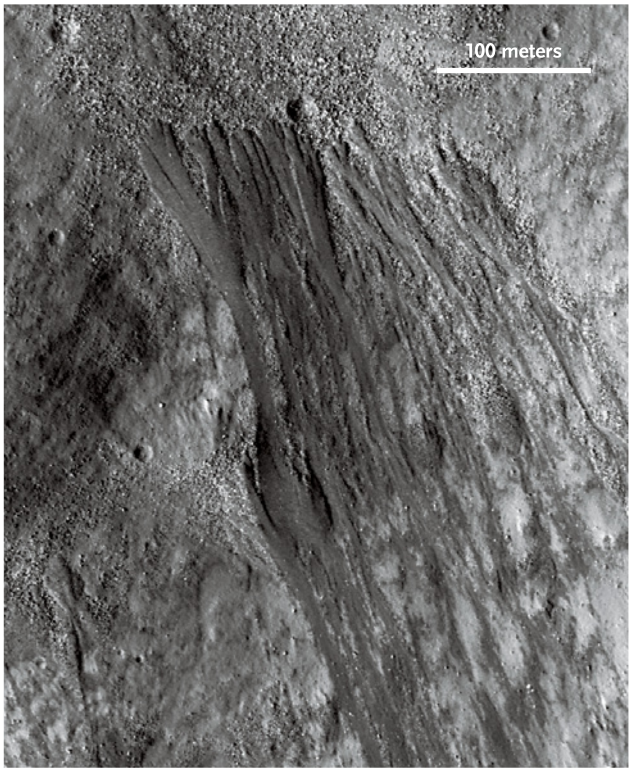
NASA GSFC / DLR / ASU

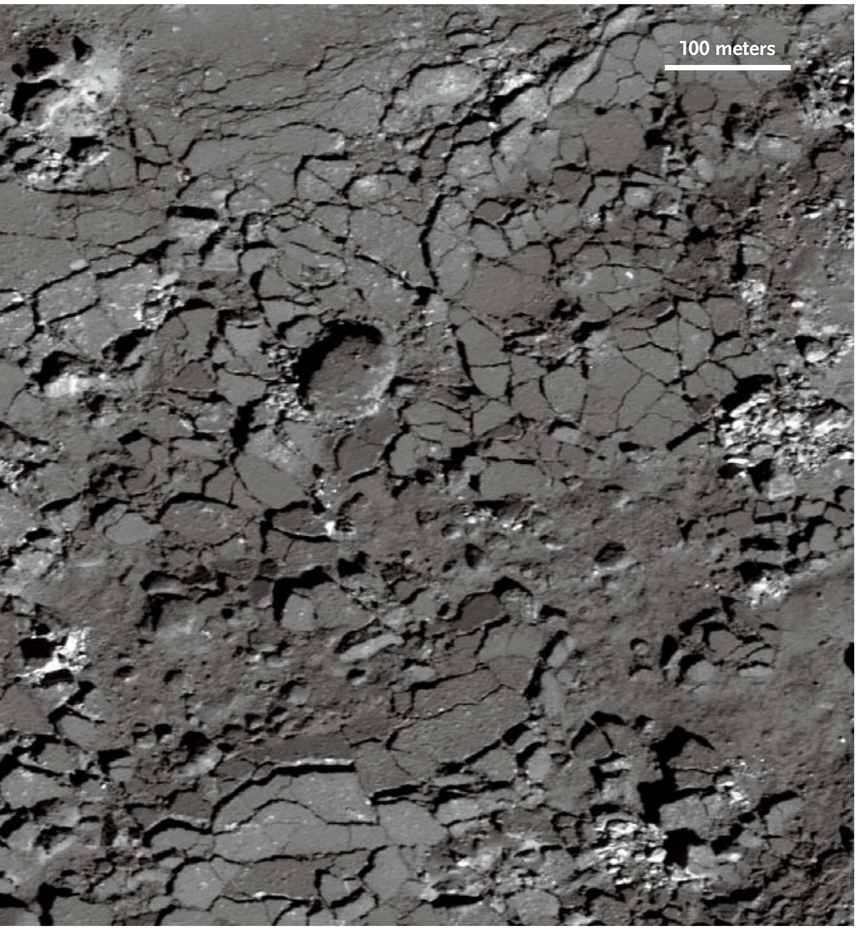
RUGGED FARSIDE ***Right:*** **Scientists constructed this topographic map of the lunar farside from stereo images taken by LRO's Wide-Angle Camera. The South Pole–Aitken Basin (colored blue) dominates the far southern hemisphere. High elevations are red.**



TYCHO PEAK **A football-field-size boulder appears as a tiny speck at the top of Tycho Crater's central peak. The mountain formed when the ground rebounded after the crater-making impact.**







ERODING SURFACES Erosion has reshaped the lunar surface in striking ways. Fine, dry debris streaming down crater walls created smooth troughs in the relatively young farside crater Moore F *(upper left)* and dark rivulets in the older, nearside crater Reiner *(above)*. Molten rock seeped up from below and hardened to form the floor of Giordano Bruno Crater *(left)*. The rock cracked like parched desert ground on Earth does when the spring rain drains away. Clusters of boulders later rolled down the steep crater walls.

The spacecraft's radiation instrument has collected important information on the total dose of radiation that astronauts will experience during long-duration lunar orbit or surface stays, obtaining new information on radiation levels during solar-minimum conditions like those of the past few years, and helping scientists gauge how much the Moon itself could shield future lunar colonists from cosmic rays. These kinds of measurements help to constrain designs needed for effective radiation shielding on future spacecraft.

LRO has been a spectacular mission — one that continues today to map and characterize the Moon in more detail. A particular point of pride among LRO team members is the way that the mission has brought NASA's

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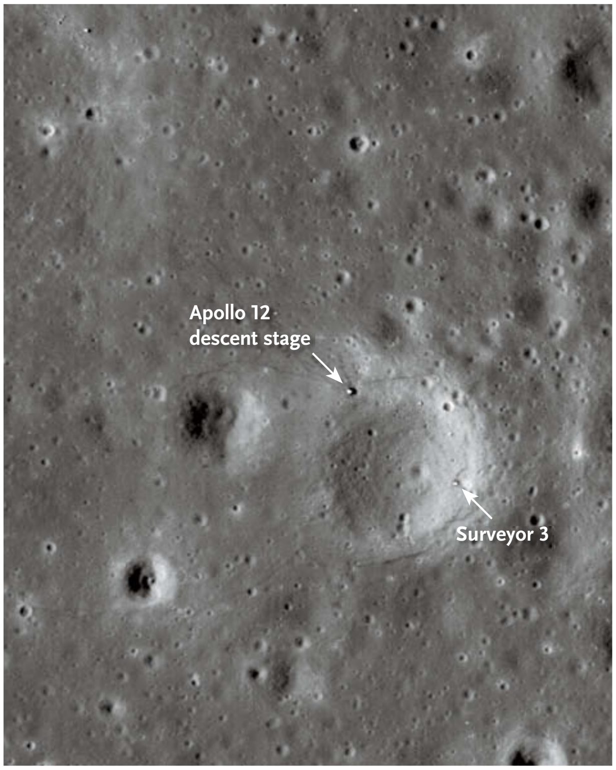
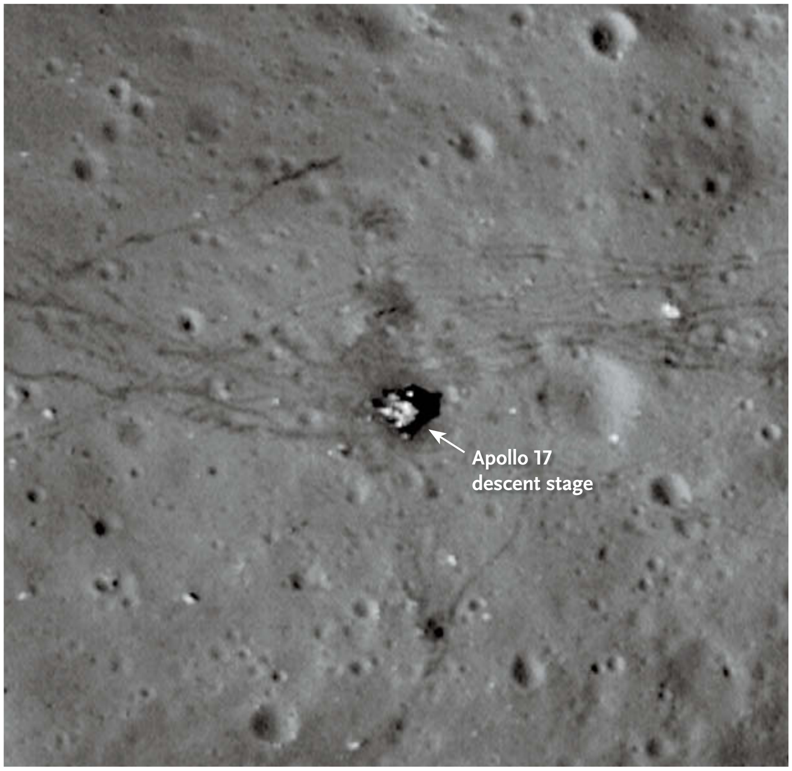
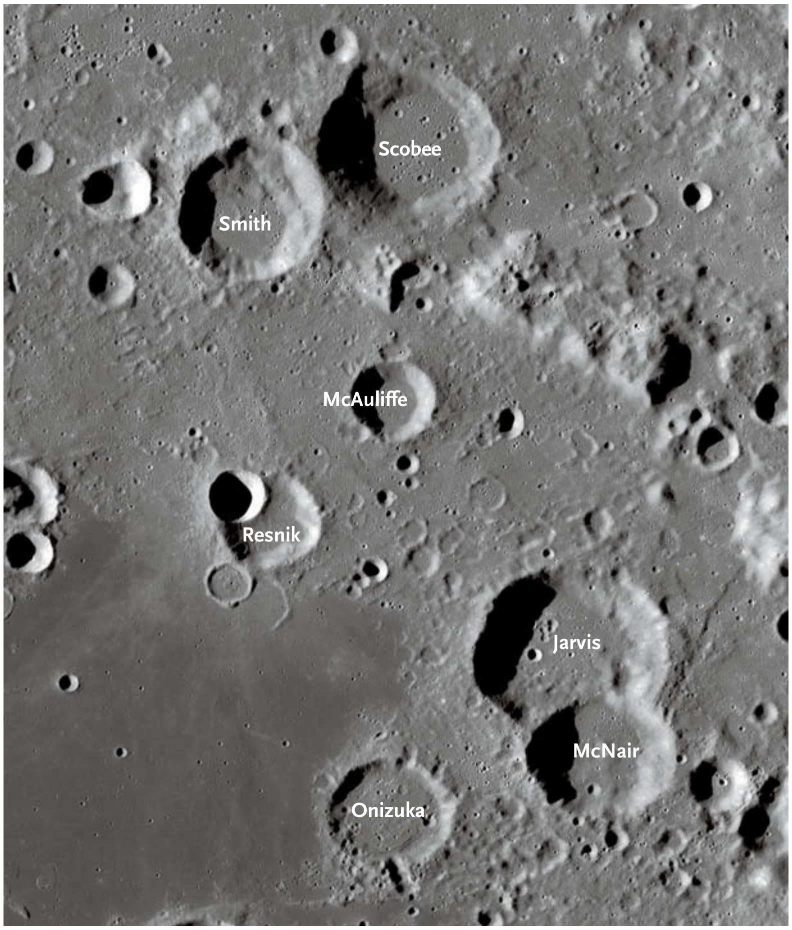
Listen to an interview with author Jim Bell and view more spectacular images from LRO by visiting skypub.com/lro.





LEAVING FOOTPRINTS Discarded lunar module descent stages mark the Apollo 12 *(left)* and Apollo 17 *(right)* landing sites. Human presence is recorded in dark trails of footprints at both sites and Lunar Roving Vehicle tire tracks at the Apollo 17 site.



IN MEMORIAM Seven craters on the floor of the Apollo impact basin's eastern rim (on the lunar farside) were named in honor of the seven lost crew members of the Space Shuttle *Challenger.*

human and robotic exploration sides together in a truly complementary effort to characterize the lunar surface and environment for future human exploration missions. The mission is also making key scientific discoveries that will help motivate and justify those missions. I have no doubt that humans will return to the Moon one day to live and work as scientists and engineers, and even to explore and frolic as tourists. Even though it's hard to predict when that time will come, much of the information needed to successfully begin that new era of human adventure will have come from the men, women, and instrumentation on NASA's LRO mission. ✦

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*Contributing editor **Jim Bell** is an astronomer and planetary scientist at Arizona State University. He is the President of The Planetary Society, the world's largest public space advocacy organization. He is the lead scientist for the Pancam color stereo cameras on NASA's Mars rovers Spirit and Opportunity, and is also a Participating Scientist on the Lunar Reconnaissance Orbiter. He has authored several books, including* Postcards from Mars, Mars 3-D, *and* Moon 3-D.

ALAN HALE & His 500 Comets

DAVID H. LEVY

Along the way to achieving his goal of viewing 500 comet apparitions, this New Mexico astronomer discovered one of the 20th century's finest comets.

On the evening of February 2, 1970, humanity had already made two successful manned landings on the Moon, the first mass-marketed Schmidt-Cassegrain telescopes were on the verge of becoming a reality, and an 11-year-old amateur astronomer named Alan Hale was setting up a 4½-inch reflector for his first look at a comet. His target was Comet Tago-Sato-Kosaka (1969g), and he found it near the bright star Hamal in Aries.

At the time, Hale was interested in viewing all types of celestial objects, but the beautiful structure of Comet Tago-Sato-Kosaka helped spark a fascination with comets that has continued for more than four decades. While that first comet excited Hale, it was the brilliant Comet Bennett that appeared in the morning sky two months later that really ignited his passion.

Of all observing activities, the visual study of comets is among the least predictable. Deep-sky objects have catalogued characteristics that typically allow observers to know in advance if the targets will be visible in their telescopes. But comets fly by their own rules. A comet

Below: **New Mexico native Alan Hale has devoted most of his observing career to comets, so it's especially fitting that his sole comet discovery (and his 199th comet sighting) became one of the most spectacular comets of the 20th century.** ***Above:*** **Contributing editor Johnny Horne captured the view of his son Adam looking at Comet Hale-Bopp in the evening sky of March 31, 1997, from the snow-covered slopes of Grandfather Mountain in western North Carolina.**

COURTESY ALAN HALE

predicted to be 9th magnitude may be bright through an 8-inch reflector, or it might be completely invisible. We just don't know in advance.

With this uncertainty, Hale's 40-plus years spent hunting down as many comets as possible becomes even more impressive. Some have been easy, but others have pushed the limits of his observing experience.

A Long Journey

Hale's voyage to astronomy began as a sixth-grade student in Alamogordo, New Mexico, when he began pestering his father to buy him a telescope. Knowing that his son wouldn't leave him in peace until he received a suitable telescope, the elder Hale purchased a 4½-inch reflector from Sears. Since his father was an early riser, Hale got to see some of the beautiful predawn events that the 1960s offered, particularly the 1966 Leonid meteor shower during which some 40 meteors per second spilled out of the sky. This period was an exciting one for young American amateur astronomers because the United States was headed to the Moon. But instead of lunar observing, Hale was headed to more comets.

"Of course, early on I was intrigued by the idea of discovering a comet," Hale told me. It wasn't until high school, however, that he deliberately began hunting them, but the search was never a serious endeavor. Hale preferred studying known comets as well as newly discovered ones found by other observers. By 1987 he had upgraded to the 16-inch Newtonian reflector that he still uses.

It was the July 22–23, 1995, observations of two known comets — 71P/Clark and 6P/d'Arrest — that was a defining moment in Hale's career. Hale, who was living in Cloudcroft, New Mexico at the time, began the night by viewing Comet Clark, but he had to wait several hours for Comet d'Arrest to rise high enough to observe. Deciding to pass the time by staying outdoors and enjoying the sparkling clear sky, Hale began exploring globular clusters in Sagittarius, near our galactic center.

One of his targets was Messier 70, a cluster estimated to be about 30,000 light-years away. When he looked into the eyepiece he immediately noticed a fainter, diffuse object in the same field of view as the cluster. Although Hale considered a comet discovery unlikely, he began working through a basic checklist. First he verified that the object didn't appear on any of his star charts and that nothing was listed for the object's position in any of his deep-sky catalogs. "When I logged into my e-mail account and found a new message," Hale recalls, "I was sure it would be an announcement for the discovery of the comet I had just seen, but that wasn't the case."

Hale then logged on to the computers at the Central Bureau for Astronomical Telegrams (CBAT) in Cambridge, Massachusetts, where he found no mention of a comet in the vicinity of M70. "By this time I was reasonably sure that I had found a new comet," Hale says, "so I

S&T ARCHIVE

Like most beginning observers, Hale started out viewing all types of celestial objects. But comets became his focus following his initial sighting of Comet Tago-Sato-Kosaka (1969g) with a 4½-inch reflector. The comet was best seen from the Southern Hemisphere, where this photograph was taken with the University of Michigan's 24-inch Schmidt telescope on December 28, 1969.

sent an e-mail to CBAT's Brian Marsden and Dan Green informing them of my probable comet discovery."

That same night, at a star party near Stanfield, Arizona, veteran deep-sky observer Thomas Bopp was using his friend James Stevens's 17½-inch Dobsonian reflector. Like Hale, Bopp was caught off-guard by the unexpected object in the same field of view as M70, and he also quickly reported the object as a possible new comet.

In the days following the comet's discovery, Hale was hoping that the object might turn out to be periodic, returning every few years. The comet is indeed periodic, but it returns every few thousand years rather than every few dozen. But more importantly, it's part of a group of truly big comets that includes the Great Comet of 1811, and it was headed to become one of the truly great comets of the 20th century. By February 1997 the comet was a bright naked-eye object in the morning sky, and a month later it swung into the evening sky as a spectacular sight. Hale, along with thousands of observers around the world, made frequent observations of the fans and jets pouring out of his beautiful comet's nucleus.

On the Way to 500

At the end of 2011, when I interviewed Hale for this story, he had observed 497 comet apparitions (which includes some comets seen in different years) and was anticipating his 500th sighting sometime in early 2012. His program — Countdown to 500 Comets — is a part of his not-for-profit Earthrise Institute (**www.earthriseinstitute.org**). "Once I get to 500," Hale said at the time, "I plan to continue the program in some way. I have no intention of 'retiring' from comet observing in the near future, but I suspect there will come a time when I will no longer feel like trying to chase down every 14th-magnitude comet that comes along. Furthermore, I promised my girlfriend that I would show her Halley when it reruns in 2061, since she missed it in 1986."

Hale reached his goal of viewing 500 comet apparitions when he glimpsed the extraordinarily diffuse remnant of Comet Lovejoy late last January. A month earlier the comet had put on a spectacular show in the Southern Hemisphere, where this picture was snapped in the morning sky by New Zealand photographer James Tse.

Hale reached the 500 milestone even earlier than expected, and by mid-March 2012 he was at 502. But it was his 500th sighting that was memorable, and for more reasons than just achieving his long-sought goal: the comet itself was particularly noteworthy.

At the end of November 2011, Australian amateur Terry Lovejoy made the first ground-based discovery of a sungrazing comet in 41 years (see last month's issue, page 36). By Christmas, Comet Lovejoy was one of the most stunning naked-eye comets in recent memory, with a tail stretching more than 30°. But it was only visible in the Southern Hemisphere pre-dawn sky.

As the New Year opened, Comet Lovejoy became essentially all tail with no distinct coma, and it was fading rapidly. "By the latter part of January," Hale writes, "the comet had traveled far enough north for me to attempt [an observation]. On the evening of the 22nd, with the 41-cm [16-inch] telescope I seemed to detect an extremely pale and vague 'something' with about the same surface brightness as the gegenschein, that nevertheless moved with the expected rate in the expected direction during the 1½ hours that I followed it." Three nights later Hale made a similar sighting, noting the proper rate and direction of motion over a two-hour period. It was enough for him to confirm his 500th comet.

Why is observing so many comets so important? In Hale's case, one of the reasons is that each comet is unique and has something special to offer. Depending on its orbit and intrinsic brightness, each comet provides an opportunity to learn something new about comets and the way they behave. Hale's high-altitude observing site provides excellent conditions for this work, especially for the faint comets.

As a professional astronomer (he earned his Ph.D. in astronomy from New Mexico State University in 1992), Hale's major effort now lies in teaching classes for the American Public University System. These courses range from introductory astronomy to graduate courses in space policy. As an amateur astronomer, and the discoverer of a major comet, Hale is also one of the best-known comet observers of our time. With a 16-inch telescope (small by professional standards), Hale proves that visual observers can still do valuable work, as is evident from his amazing achievement of sighting 500+ comets. His lifetime of work sets an example of what amateur astronomers can accomplish when they are determined. ✦

A longtime contributor to the pages of S&T, ***David H. Levy*** *is no stranger to observing and discovering comets.*

PERILOUS JOURNEYS:

The 1761 Transit of Venus

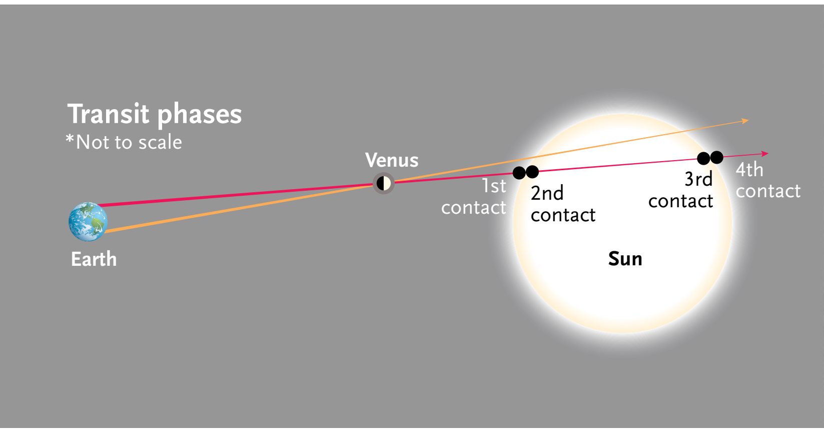
Braving warfare, storms, and disease, astronomers ventured across the globe to measure

Eli Maor

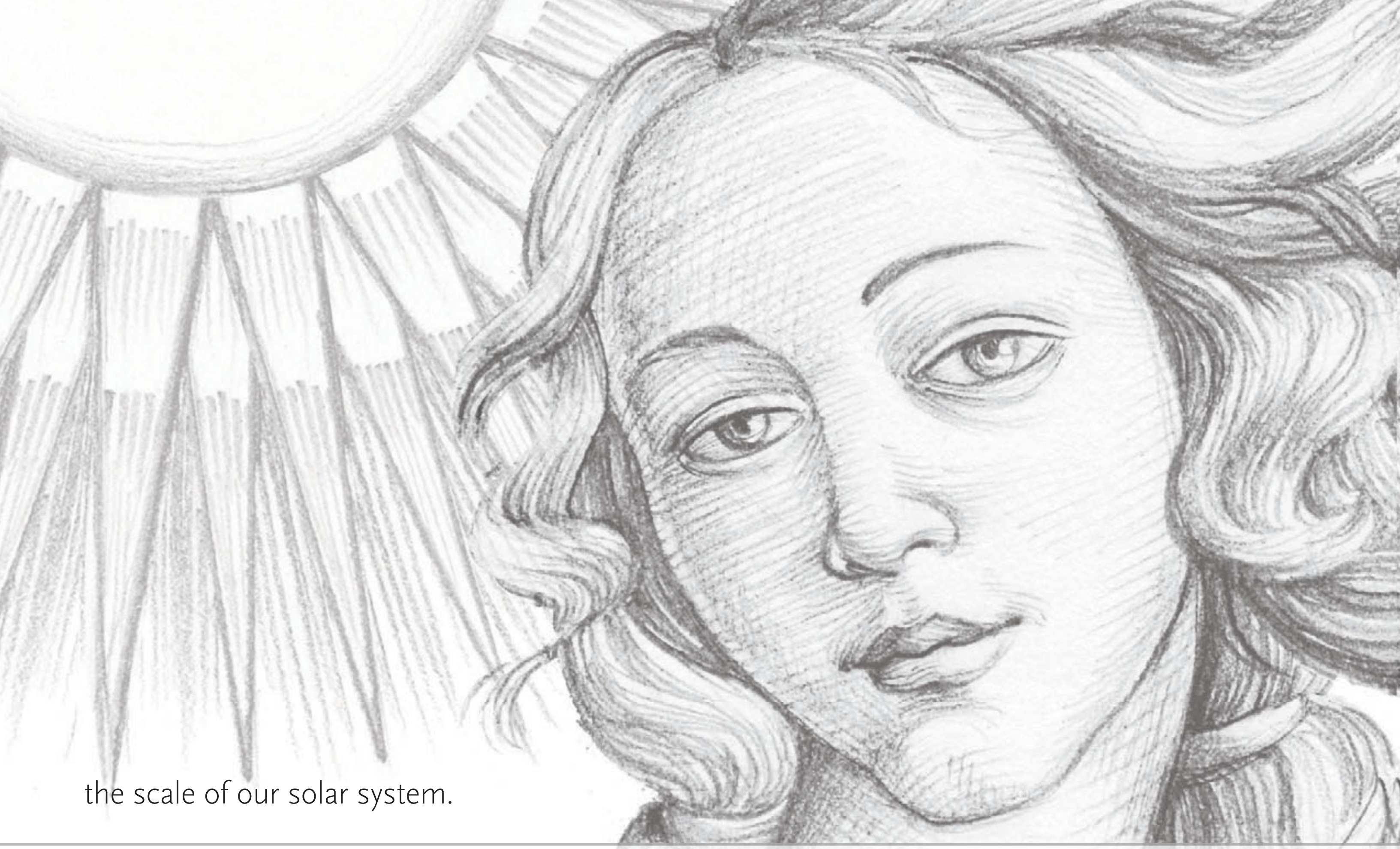
As far as we know, the 1639 transit of Venus was observed by just two humans: Jeremiah Horrocks in the small hamlet of Hoole, near Liverpool, England, and his friend William Crabtree, from his home in Manchester. But when Venus again crossed the Sun's disk in 1761, hundreds of astronomers fanned across the globe to greet her.

This sudden surge in interest was sparked by Edmond Halley (1656–1742). Halley excelled in many areas of study, but he is best known for his successful prediction of the return of the comet of 1682, later to bear his name. But it was a paper he submitted in 1716 to the Royal Society in London that was the catalyst of the transit mania.

On November 7, 1677, Halley observed a transit of Mercury while stationed on the Atlantic island of St. Helena. This was only the fourth transit of the innermost planet ever observed, and the first to be watched from beginning to end. During this event he got the idea of timing the duration of future transits of Venus and using the data to determine the astronomical unit (a.u.), the mean Earth–Sun distance. A rare opportunity was coming up: Venus would once again cross the Sun's face on June 6, 1761, after a hiatus of 121½ years.



HALLEY'S METHOD Edmond Halley conceived a geometric method for using transits of Venus to measure the Earth–Sun distance. Observers could measure a transit's duration by timing second and third contacts, which would yield the length of Venus's track across the Sun. Astronomers could calculate Venus's apparent shift (parallax) as seen by observers at widely separated locations and then triangulate the distance to Venus. From Kepler's third law, astronomers knew that Venus was 72.3% as far from the Sun as Earth.



the scale of our solar system.

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Rousing Words

In Halley's day, the dimensions of our solar system were still very much in doubt. Kepler's third law enabled astronomers to determine the relative distances of the planets from the Sun, but their *absolute* distances were another matter. One had to know at least one planet's true distance to the Sun, and the most natural candidate was Earth. Thus, determining the a.u. became one of the most urgent tasks of 18th-century astronomy.

Halley's plan, later refined by French astronomer Joseph-Nicolas Delisle, was to station observers at widely separated locations around the globe. Each observer would time the moment when Venus's silhouette completely made its entrance on the Sun's face, and again when it was about to leave the Sun (second and third contacts, respectively) to the best possible accuracy. Because of the parallax effect, different observers would record slightly different durations between second and third contacts, and Venus's track across the Sun would also vary slightly.

Transits of Mercury occur much more frequently — 13.4 times per century on average. Venus, however, is closer to Earth, giving it a larger apparent shift in position against the fixed stars — a larger parallax angle — when observed from different locations on Earth. In principle, astronomers could measure the parallax angle on every clear night when Venus is visible, but the planet's intense glare makes such measurements practically impossible. During a transit, however, Venus's black silhouette would stand out with razor-sharp clarity against the solar disk.

The success of Halley's plan depended critically on two factors: a precise knowledge of the geographical position of each observer, and a precise timing of second and third contacts. Geographical location presented relatively few difficulties and could be determined with standard navigational equipment, either before or after the transit. Transit timing, however, was an all-or-nothing affair: it had to be accomplished in real time while the transit was in progress. Halley estimated that if second and third contact could be timed to the nearest second, the a.u. could be determined with an accuracy of 1 part in 500.

When Halley published his proposal at age 60, he was keenly aware that he would not live to witness the 1761 transit, due to occur 45 years hence. Nevertheless, he urged his fellow astronomers to launch an all-out effort to observe the transit from as many widely dispersed stations as possible. This would require the cooperation of many governments, the allocation of adequate funds, and the organization of oceanic and overland expeditions staffed by competent scientists and equipped with telescopes and navigational instruments. It would be the first full-scale international scientific endeavor in history. Halley concluded his paper with these rousing words:

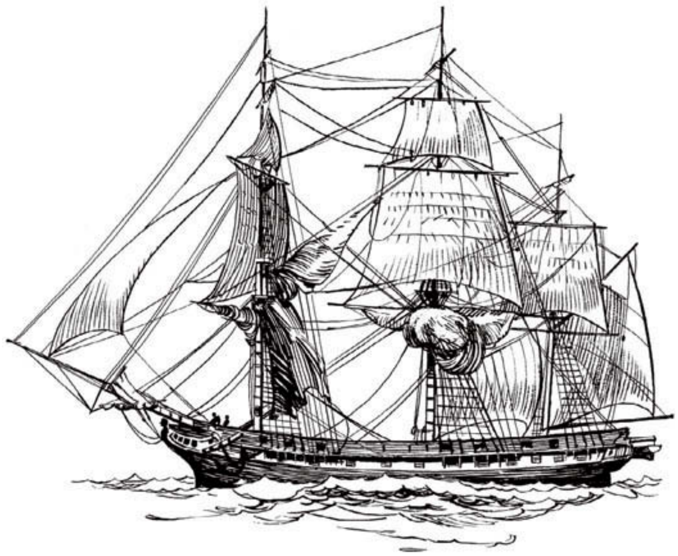
> I recommend it therefore again and again to those curious astronomers who, when I am dead, will have an opportunity of observing these things, that they will remember this my admonition, and diligently apply themselves with all their might in making this observation, and I earnestly wish them all imaginable success: in the first place, that they may not by the unreasonable obscurity of a cloudy sky be deprived of this most desirable sight, and then, that having ascertained with more exactness the magnitudes of the planetary orbits, it may redound to their immortal fame and glory.

Halley died on January 14, 1742, at age 85. His long life was marked by one scientific achievement after another, yet he did not live to witness the two events that made him world famous: his comet returned in 1758–59, and Venus would appear on the Sun's face three years later.

War Intervenes

As the transit approached, several nations organized expeditions, including two by the British and four by the French. But Halley's hope for international cooperation was dashed — Britain and France, and their respective allies, were now at the height of the Seven Years' War (known in the U.S. as the French and Indian War).

One British expedition, headed for Bencoolen, Sumatra (Bengkulu, Indonesia today), was under the command of astronomer Charles Mason (1728–1786), who was assisted by surveyor Jeremiah Dixon (1733–1779) — the pair who later became famous for marking the Mason-Dixon Line between Pennsylvania and Maryland. Just a day after



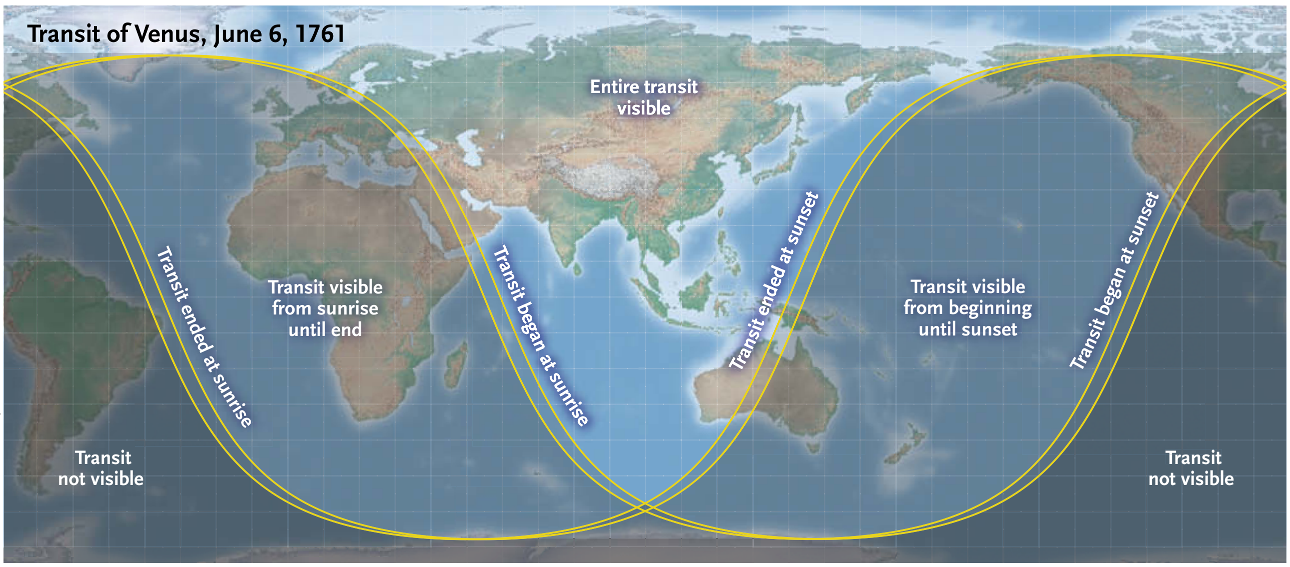
PEARSON SCOTT FORESMAN / WIKIMEDIA FOUNDATION

departing Portsmouth on January 8, 1761, the French frigate *L'Grand* intercepted their warship, the *HMS Seahorse*. In the ensuing battle, 11 British sailors were killed. The seriously damaged ship was forced to return to Plymouth.

Badly shaken, Mason informed the Royal Society that "We will not proceed thither, let the Consequence be what it will." The Society issued a stern rebuke: "Their refusal to proceed upon this Voyage, after their having so publickly and notoriously ingaged in it... [would] be a reproach to the Nation in general, to the Royal Society in particular, and more Especially to themselves." It could not "fail to bring an incredible scandal upon their character, and probably end in their utter ruin."

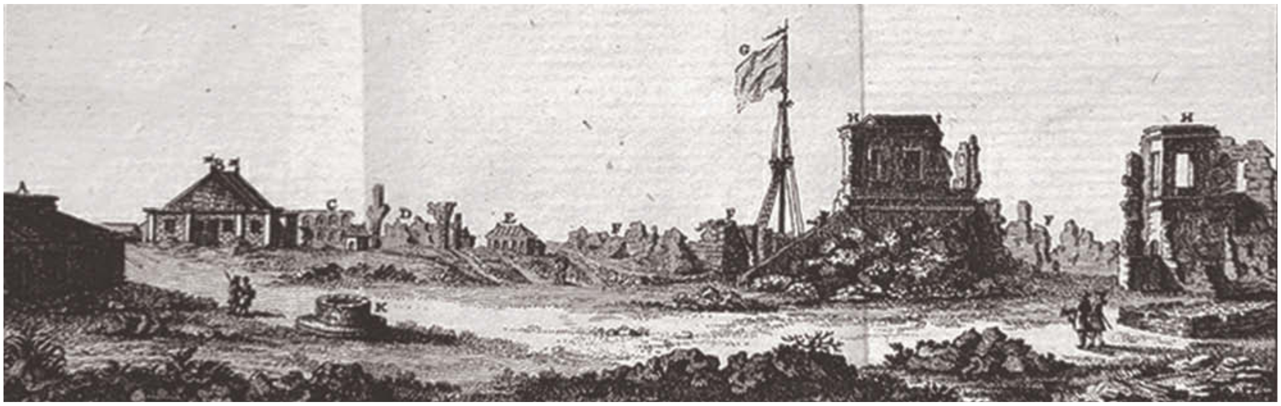
The harsh reprimand had its intended effect. With the *Seahorse* repaired, Mason and Dixon sailed again for

1761 TRANSIT OF VENUS As this map shows, observers in much of Asia and the East Indies could view the June 6, 1761 transit in its entirety. This forced European astronomers to travel to far-flung locations, many of which were hotly contested by the British and French (and their allies) during their bitter Seven Years' War — the first truly global war.



SOURCE: MICHAEL ZEILER / WWW.ECLIPSE-MAPS.COM

DANGEROUS WATERS British astronomer Charles Mason sailed with surveyor Jeremiah Dixon from Portsmouth to observe the transit from Sumatra. Their ship was the 24-gun frigate *HMS Seahorse*, which may have resembled the ship pictured on the facing page. A 34-gun French frigate attacked and damaged the *Seahorse* just a day after its departure. Forced to return to port, the future surveyors of the Mason-Dixon Line eventually sailed again and observed the transit from Cape Town. French astronomer Guillaume Le Gentil endured one hardship after another in an effort to record the transits of 1761 and 1769.



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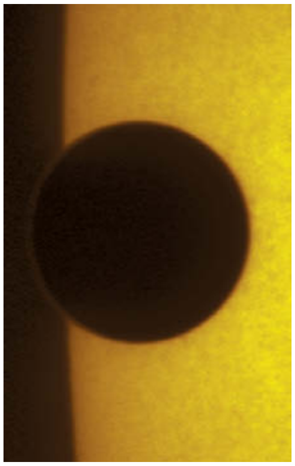
TRIALS AND TRIBULATIONS Sailing from Mauritius in March 1761, Guillaume Le Gentil planned to observe the transit from Pondicherry on the east coast of India. But the French colony was besieged and then captured by the British. Le Gentil ended up seeing the transit from a rolling ship in the Indian Ocean. In 1766 he sailed to Manila to observe the 1769 transit, but was ordered back to Pondicherry, which had reverted to French control. Unfortunately, clouds rolled in on the day of the transit. The image above shows the town in ruins in 1769. Le Gentil returned to Paris in 1771 after an 11½-year absence, and learned that he had been presumed dead.

Sumatra on February 3rd. But the ship's captain realized en route that they could not reach Bencoolen in time for the transit. Upon reaching Cape Town (then known as Kaapstad), South Africa in late April, they were granted permission by the Dutch colonial authorities to disembark. After spending several weeks setting up their equipment, Mason and Dixon observed the second half of the transit through breaks in the clouds. It was the only successful observation in the Southern Hemisphere.

An Incredible Journey

Of the four French expeditions, one in particular made history because of the incredible misfortunes of its leader. Headed by an astronomer with the impossibly long name Guillaume Joseph Hyacinthe Jean-Baptiste Le Gentil de la Galaisière (1725–1792) — commonly known as Le Gentil — its destination was the town of Pondicherry (now Puducherry) on India's southeast coast. The group left France on March 26, 1760, more than a year before the transit. On July 10th it reached the island of Mauritius (then known as the Isle de France) in the Indian Ocean, where Le Gentil heard bad news: Pondicherry was under siege by the British. After recovering from a bout of dysentery, he learned that the French frigate *La Sylphide* would attempt to relieve Pondicherry. The ship sailed on March 11, 1761, but monsoon winds blew it off course for weeks. When the winds subsided, the ship was beset by persistent calms. Then on May 24th, off the coast of India, the captain heard that Pondicherry had fallen to the British, so the ship headed back to Mauritius.

Unfortunately, there wasn't enough time to make it to the island. Le Gentil enjoyed clear skies for the transit and was able to time both ingress and egress at sea. But with his ship bobbing on waves in the Indian Ocean, and without the means to determine his longitude precisely, his observations were scientifically useless.



S&T ARCHIVE

ATMOSPHERE DISCOVERY From his home in St. Petersburg, Russian scientist Mikhail Lomonosov reported seeing a thin arc of light around Venus at ingress and egress. He presciently interpreted the arc as being due to sunlight refracting through a thick Venusian atmosphere. Other observers also saw the arc, but they were so preoccupied with timing Venus's ingress and egress that they failed to grasp its significance. The image from the 2004 transit shows a luminous arc that may be fairly close to what Lomonosov saw.

Rather than sailing home to France, Le Gentil resolved to make the best of a bad situation. While waiting the eight years to the next transit, due on June 3, 1769, he explored the flora, fauna, and geology of Mauritius and nearby Madagascar.

Le Gentil eventually decided that Manila, capital of the Philippines, offered better prospects for clear skies.

OBSERVING SITES Astronomers ventured all over the world to view the 1761 transit. This map shows locations mentioned in the article. But astronomers went to many other places as well, including Siberia, Norway, and Newfoundland.

Learning that a Spanish warship was about to sail to Manila, he talked the captain into taking him aboard, and he reached his destination on August 10, 1766. But 11 months later he received orders from the French Academy of Sciences to sail to Pondicherry (now back in French hands), though only Venus's egress would be seen from there. He arrived in March 1768, still more than a year before the transit, and spent the remaining time taking preliminary measurements.

Le Gentil's sky had been crystal clear for a full month before the transit. Simon Newcomb explained what happened next in his book *Popular Astronomy* (1880):

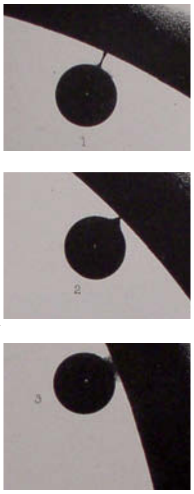
> On June 3, 1769, at the moment when this indefatigable observer was preparing to observe the transit, a vexatious cloud covered the sun and caused the unhappy Le Gentil to lose the fruit of his patience and of his efforts. He had missed the planet's egress, the moment when Venus was leaving the Sun, not to return for a hundred and five years. To add insult to injury, he later learned that in Manila, his original destination, the sky on that day was perfectly clear. It was two weeks before the ill-fated astronomer could hold the pen that was to tell his friends in Paris the story of his disappointment.

But Le Gentil's troubles were far from over. After another bout of dysentery, he finally left Pondicherry on March 1, 1770, and sailed to Mauritius. While returning to France in December, his ship lost a mast in a storm off the Cape of Good Hope, forcing it back to Mauritius. He then boarded a Spanish warship in late March 1771 and finally reached the port of Cadiz on August 1st. After resting for a month in Cadiz, Le Gentil completed the last leg of his journey on foot across the Pyrenees.

After being away 11½ years, Le Gentil arrived in Paris in October 1771. He had been assumed dead and his heirs were dividing up his estate. The Royal Academy of Sciences demoted him to the rank of a "veteran" (retiree), convinced that he had neglected his official duties in order to make some personal gains. Fortunately, Le Gentil's story has a happy ending. He was eventually given back his rank and position at the Paris Observatory, but he had to take legal action to win back his personal property. He then married and prospered, and spent the remaining 20 years of his life raising a daughter and writing his papers. He died in October 1792 at age 67.

Discovering Venus's Atmosphere

Russian astronomers also observed the 1761 transit, and one of them made a historic discovery, though it took the world nearly two centuries to give him due credit. Mikhail Vasilyevich Lomonosov (1711–1765) was born near the arctic port of Archangel, the son of an illiterate fisherman. Desiring a quality education, he ran away at age 19 and made his way to Moscow, where he was admitted to school by declaring himself the son of a nobleman. He rounded off his education in Germany.



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BLACK DROP EFFECT In principle, Halley's parallax method was quite capable of producing a highly accurate value of the astronomical unit. But astronomers all over the world reported seeing a dark, narrow bridge connecting Venus's silhouette to the Sun's limb during second and third contact. Due to this black drop effect, even observers at the same location would record contact times that differed by a minute or longer — meaning other methods would ultimately be needed to pin down the value of the a.u. Australian watchmaker Friederich Allerding recorded the effect in this illustration made during the egress of the December 9, 1874 transit.

Lomonosov was an early advocate of the idea that matter consisted of individual corpuscules (molecules), that heat is a form of mechanical energy, and that light propagated as waves — years before these views became part of mainstream physics. He was elected to the St. Petersburg Academy of Sciences, and was instrumental in founding Moscow State University in 1755, later named after Lomonosov. The Russian scientist's rags-to-riches life story shares many similarities with his American contemporary, Benjamin Franklin (who witnessed the 1769 transit from Lewes, Delaware). Though the two men never met, they admired each other's scientific work from afar.

Observing the transit from St. Petersburg with a 4½-inch refractor, Lomonosov saw a faint arc of light around Venus's black image at the end of second contact and again at third contact. He interpreted this arc as light refracting through a Venusian atmosphere. Lomonosov reported his findings in a paper and reached this conclusion: "Planet Venus is surrounded by a significant air atmosphere, similar to (if not even greater than) that which bathes near our terrestrial globe."

Other observers also reported an arc, but they were focused on transit timings, not on physical effects. Lomonosov's paper was quickly translated into German, and some 200 copies were circulated in Europe. But it wasn't until the mid-20th century that his paper became widely known in the West, and Lomonosov given credit for discovering Venus's atmosphere. Before then the discovery of Venus's atmosphere had been attributed to Johann Schröter or William Herschel. Lomonosov preceded them by some 30 years.

For more about the upcoming June 2012 transit of Venus, visit skypub.com/tov.

The Aftermath

The 1761 transit was observed from some 70 stations around the globe. But when the many observations were compared and analyzed — a long process that took years — the results were disappointing: the value of the a.u. was estimated to range between 77,846,110 and 96,162,840 miles — far short of the precision Halley had hoped for.

The culprit was a ghostly black filament that seemed to connect Venus's trailing edge to the Sun's limb at the moments of second and third contact, lingering there for a few seconds like a drop about to separate from a leaking faucet (January issue, page 73).

This *black drop effect*, recorded by nearly all observers regardless of their location, would become the bane of the entire endeavor: it would hamper all efforts to time the transit's crucial moments. Attempts to estimate the duration of the effect were just as difficult, varying from a few seconds to a full minute. This setback was repeated during the transits of 1769, 1874, and 1882. Although transit observations improved the value of the a.u. and can thus be deemed a partial success, the black drop effect convinced astronomers that they would have to determine it by other means. Despite the enormous effort and lavish sums of money, the endeavor had a rather unglamorous ending. ✦

***Eli Maor** is the author of* e: the Story of a Number *and several other books on the history of mathematics. This article is based on his 2004 book* Venus in Transit.

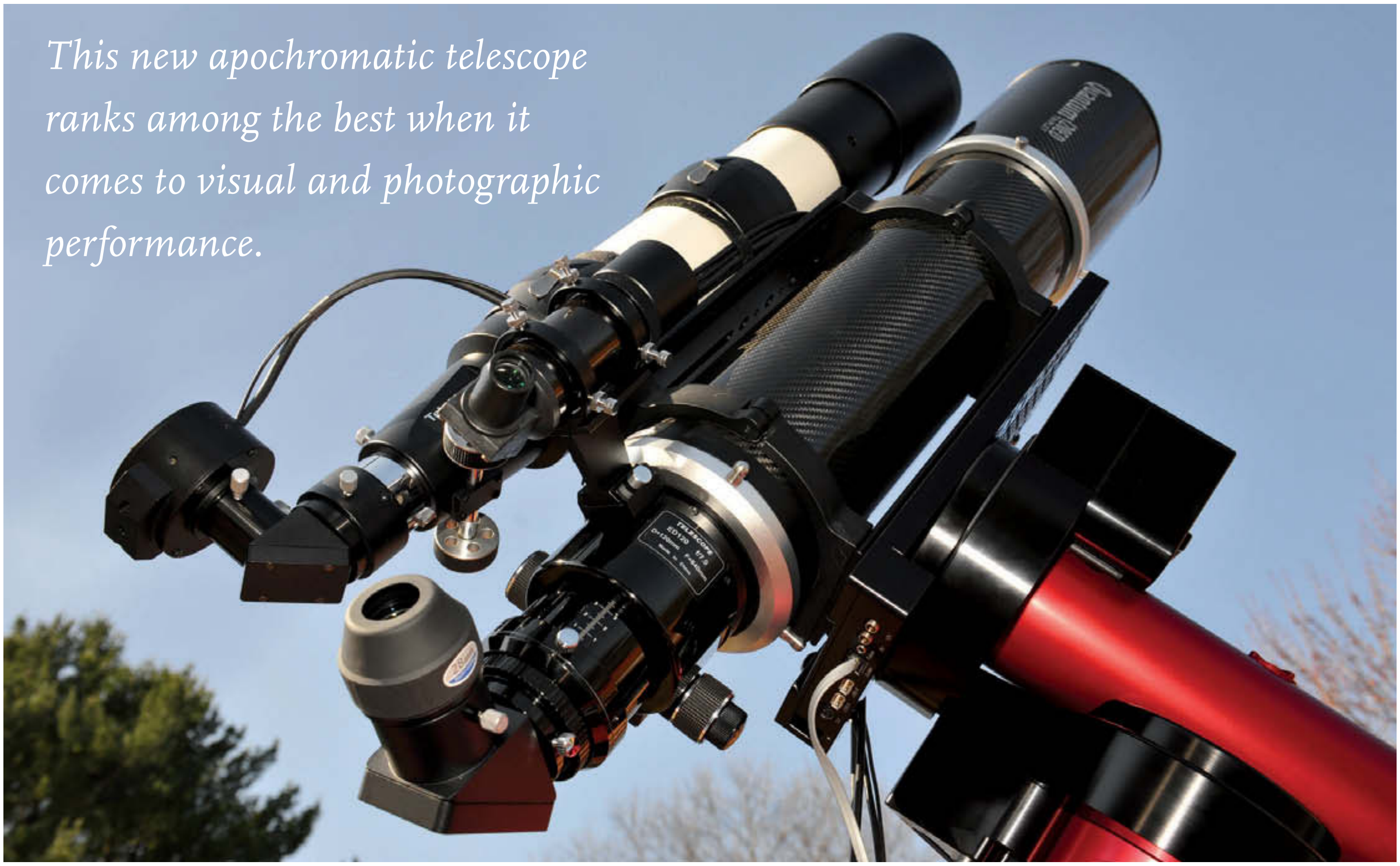
How the A.U. Was Ultimately Determined

After the 1874 transit, astronomers realized that Halley's parallax method would not nail down the value of the astronomical unit as precisely as they had hoped. Scottish astronomer David Gill (1843–1914), who observed the 1874 transit from Mauritius, built an observatory on Ascension Island in the mid-Atlantic. His photographic measurements of Mars's parallax during its 1877 opposition allowed him to determine the a.u. to be 93,110,000 miles — within 0.17% of the modern value of 92,955,807 miles. Astronomers later refined this by measuring the parallax of certain asteroids. More recently, they timed the return of radar waves bounced off Venus and measured the time for radio signals to reach Earth from the Viking Mars landers.

Dennis di Cicco

The Sky-Watcher Quantum 120 Refractor

This new apochromatic telescope ranks among the best when it comes to visual and photographic performance.



ALL PHOTOGRAPHS BY THE AUTHOR

Sky-Watcher Quantum 120 Refractor

U.S. price: $3,799

Available from Celestron dealers in the U.S. only (see text for details)

celestron.com; 310-328-9560

Top: **The Sky-Watcher Quantum 120 (4.7-inch) f/7 apo refractor is sold as a notably complete package, including tube rings and a dovetail mounting bar. It's shown here set up in the author's suburban Boston observatory, along with a piggyback guide scope used for astrophotography.** ***Above:*** **The heart of the Quantum 120 is a triplet objective with one lens element made from Ohara's premium FPL-53 extra-low-dispersion glass. The cell has a push/pull mounting in the unlikely event that the scope should ever require collimation.**

THERE IS NO DOUBT about it. I had strong opinions — no, let's make that "very strong" opinions — about the Sky-Watcher Quantum 120 refractor before I started testing it. For a product reviewer, that's generally a bad thing to admit. But in this case, well, read on.

The Quantum 120 is a premium-class apo built around a 120-mm (4.7-inch) f/7 triplet objective with two lens elements made from Schott glass and the third made from Ohara FPL-53 extra-low-dispersion glass. The latter is the ED glass that advertisers love bragging about. The scope has an attractive carbon-fiber tube with a matching retractable dew cap, and there are four internal light baffles that are very effective at suppressing light scattered from the inside walls of the tube.

The large, dual-speed focuser has several nice features complementing the overall quality of its fit and finish. In addition to a 360°-rotation adapter at the business end of

What we liked:

Excellent optical performance

Multi-featured focuser

Dedicated field flattener included

What we didn't like:

Focuser's friction drive slips with heavy loads

the drawtube, the entire focuser body can rotate 360° relative to the telescope tube, making it easy to position the large focusing knobs in any orientation you want. The 11:1 speed reduction is smooth and precise over the full 100 mm (4 inches) of drawtube travel, and there's a nice engraved millimeter scale on the drawtube. A conventional 2-inch adapter with a compression ring and two locking thumbscrews can be removed from the drawtube to reveal a maximum accessible opening 2¾ inches across.

A stainless-steel bar on the bottom of the drawtube serves as the track for the focuser's friction drive as well as the only mechanical support for the drawtube, since the focuser's ball bearings ride exclusively against this bar. Astrophotographers will appreciate the exceptionally strong lock on the drawtube, which you can engage without shifting the image or upsetting the focus. Nice!

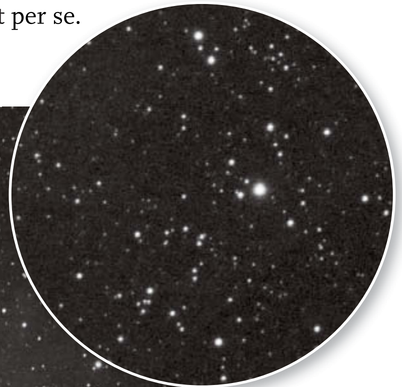
The Quantum literature does not specify the focuser's load capacity, but a little poking around on the internet shows the same focuser rated for 5 kg (11 pounds) when focusing and up to twice that weight when locked. While I agree that the lock will hold a lot of weight, the 5-kg load for focusing seems, shall we say, generous. My focuser would barely lift 4 pounds when the scope was pointed at the zenith before the friction drive slipped.

Rounding out the Quantum 120's unusually complete package is a good 9×50 right-angle, erect-image finder, a 2-inch mirror diagonal, a decent-quality 28-mm 2-inch eyepiece, a set of tube rings with a large dovetail mounting bar, and a hard-sided storage case. This scope, however, is only available from Sky-Watcher U.S.A. through Celestron dealers in the United States. But swapping the carbon-fiber tube for one made of painted aluminum lets you buy this setup throughout the rest of the world as the Sky-Watcher Esprit 120ED. The aluminum tube adds about a pound to the Quantum's already substantial 22-pound weight.

Just Observing

Winter began with a flurry of products we requested for review showing up at about the same time, including a telescope mount, the Quantum 120, and a variety of accessories and CCD cameras. I set up the Quantum and mount as a basic platform for testing the other items, and thus almost all of my initial use of the Quantum was for observing rather than testing it per se.

Nevertheless, each time I looked



The author took this view of the Rosette Nebula with the setup shown on page 36. His colleague Sean Walker stacked and processed seventeen 10-minute exposures taken through a Baader hydrogen-alpha filter. The inset is an enlargement showing the high quality of star images produced by the included field flattener near the corners of the large-format CCD.

While the 10½-pound load imposed by this setup involving an FLI ProLine 16803 CCD camera caused the focuser to slip when the scope was pointed at high elevations, the focuser's lock always held securely once the camera was focused. The field flattener (with gray band) is attached to the camera with the author's homemade adapter.

through the scope I was struck with the quality of the images it delivered. Stars were tack sharp and snapped into focus with a precision that only comes with superb optics. There was no light scatter around even the brightest stars. I was particularly impressed by the lack of color fringing around bright objects and the purity of star colors seen through the scope.

One unusually cold January night while making notes on the mount's Go To performance, I slewed the Quantum to the double star Almach (γ Andromedae). I was so taken by the intensity of its gold and blue hues that I abandoned my testing plans for the mount and just started observing double stars. The scope's resolution is excellent, distinctly splitting the challenging double Eta Orionis (separation less than 1½ arcseconds) at 280×, and there was even a hint of color difference between the component stars.

The Moon and Jupiter were very enjoyable sights in the Quantum, and later in the season Venus and Mars were added to the nightly roster of objects I'd check out with the scope. For deep-sky observing, the Quantum provided memorable views of star clusters and planetary nebulae, and it had no problems showing brighter nebulae and galaxies (think "Messier catalog") in my suburban sky.

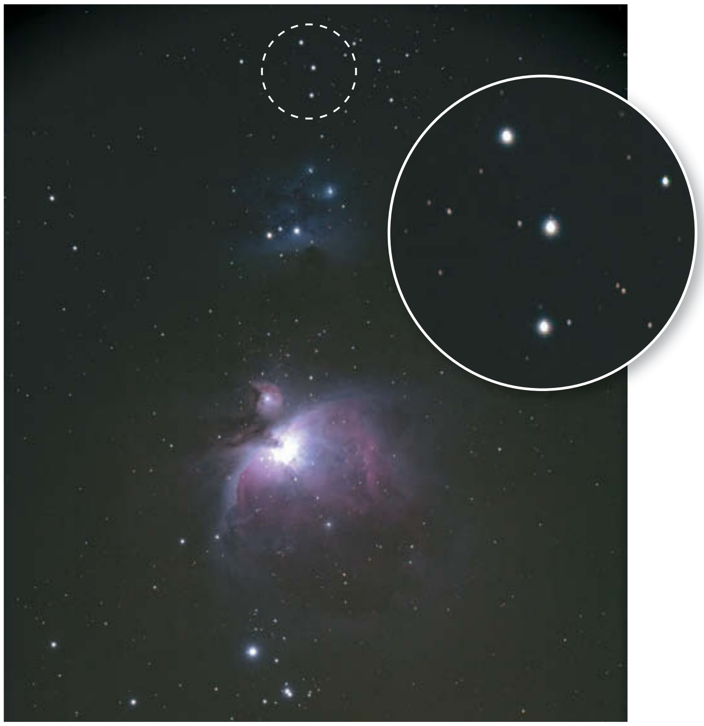
With so much observing under my belt, I came to the conclusion that the Quantum 120 is an excellent telescope *before* I started testing it. For the record, I measured the aperture as 120 mm and the effective focal length as 833 mm. The telescope experiences a very slight focus shift as the ambient temperature drops. Because this shift is in the opposite direction from what would occur with thermal contraction of the tube assembly, I attribute it to thermal changes within the objective — something I've encountered with other triplets as well.

The Quantum 120 comes with a dedicated field flattener, which performed remarkably well. Without the flattener, stars at the long end of a full-frame DSLR are distinctly elongated. (DSLRs with smaller APS-size chips will record fine star images almost corner to corner without the flattener.) With the flattener, even the very corners of my full-frame camera have sharp, round stars. There was, however, a modest amount of vignetting due to the restrictions imposed by the standard T ring I was using to mount my camera to the flattener. Anyone planning to do deep-sky shooting with a full-frame DSLR should consider acquiring one of the special camera adapters that have large openings.

The flattener has an optical backfocus of 75 mm, which should be maintained for optimum performance. The mechanical dimensions of the flattener's cell eat up 3 mm of this distance, but the remaining 72 mm is more than enough for most astronomical CCD cameras and filter wheels. The picture at left shows the adapter I machined to mate the flattener to an FLI ProLine 16803 CCD camera and filter wheel. As the shot of the Rosette Nebula on page 35 shows, this setup produced very good star images even at the corners of the frame, implying a usable imaging circle about 50 mm in diameter.

After several months of using and testing the Quantum 120, I'm confident that this scope ranks right up there with today's premium-class apo refractors even though it's still a bit of a sleeper in the marketplace. And while it's also among the more costly refractors in its aperture class, given all the items that come standard with the scope, including the excellent field flattener, it's an exceptional value for a photography-ready apo. ✦

S&T *senior editor* ***Dennis di Cicco*** *doesn't consider himself among the refractor cognoscenti, but he's beginning to think that being one isn't such a bad idea.*



Without the field flattener, star images are elongated (inset) at the edge of the field recorded by a full-frame DSLR. This 5-minute exposure of the Orion Nebula was with a Nikon D700 at ISO 400.

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

New Product Showcase

SOUTHERN STARS

◄ **SKYFI WIRELESS** The world is becoming an increasingly wireless place, and that trend is spilling over to telescope control. Initially there were Bluetooth adapters for connecting scopes to hand controls and computers without a tangle of cables. But now there are systems based on WiFi with its longer-range transmitting capabilities. One of the latest WiFi setups is the SkyFi wireless adapter from Southern Stars, which works with mounts that have USB support. SkyFi USB ($149.95) is a wireless receiver that plugs into your telescope mount's USB port. When switched on, SkyFi creates its own 802.11 open wireless network, allowing you to connect your iPhone, iPad, iPod Touch, or computer operating *SkySafari* to control your telescope. SkyFi USB is also compatible with Orion Telescope & Binoculars' *StarSeek* iPhone app, and Carina Software's *Voyager* program for Mac and PC computers. SkyFi requires four AA batteries for up to 12 hours of continuous operation. An AC wall adapter and a cigarette-lighter DC power cable are also available as options.

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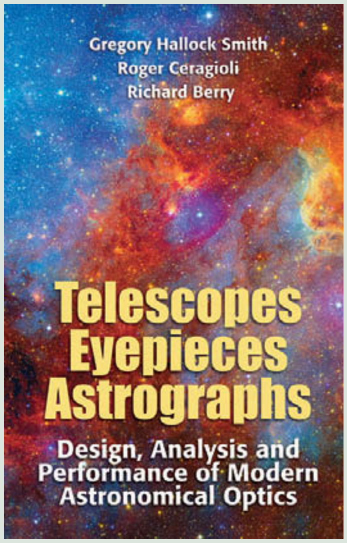

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OPTICAL TELL-ALL There's now a book that takes the mystery out of modern telescope and eyepiece designs. *Telescopes Eyepieces Astrographs: Design, Analysis, and Performance of Modern Astronomical Optics* by Gregory Hallock Smith, Roger Ceragioli, and Richard Berry examines myriad optical systems inside and out to help prospective buyers make informed purchasing decisions. The book cuts through sales jargon to assist the reader in understanding the strengths and weaknesses of particular designs. How will a particular telescope's field curvature affect images that you shoot through it? What is spherochromatism? These are just a few of the questions addressed in *Telescopes Eyepieces Astrographs* to help you determine what telescope best suits your needs.

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.

Our Closest Neighbor

The Moon is by far the most rewarding celestial object for a small telescope. Such an instrument will reveal our satellite's bleak, impact-blasted landscape. Even binoculars will show many features.

The terminator is the line separating day and night. Here is where you can see the most surface detail. Near the terminator the Sun is low on the lunar horizon, so that even gently rounded hills cast long, spire-like shadows.

Away from the terminator the shadows shrink, so the terrain appears flatter, and differences in albedo (light and dark) dominate the view instead.

Image by *S&T:* Dennis di Cicco and Sean Walker.

SKY & TELESCOPE
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Numerical Index

The map is oriented to match the Moon as it appears to the unaided eye or in binoculars from mid-northern latitudes.

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4 Epigenes
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6 W. Bond
7 Barrow
8 Meton
9 Pythagoras
10 South
11 J. Herschel
12 Fontenelle
13 Archytas
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16 Strabo
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20 Alpine Valley
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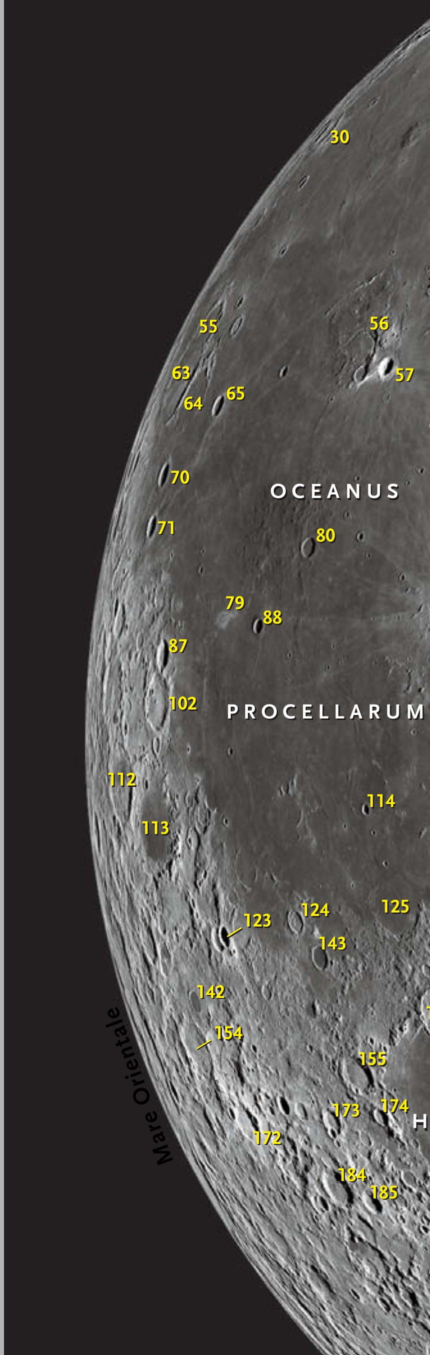
275 Curtius
276 Simpelius
277 Schomberger
278 Manzinus
279 Boguslawsky
280 Boussingault

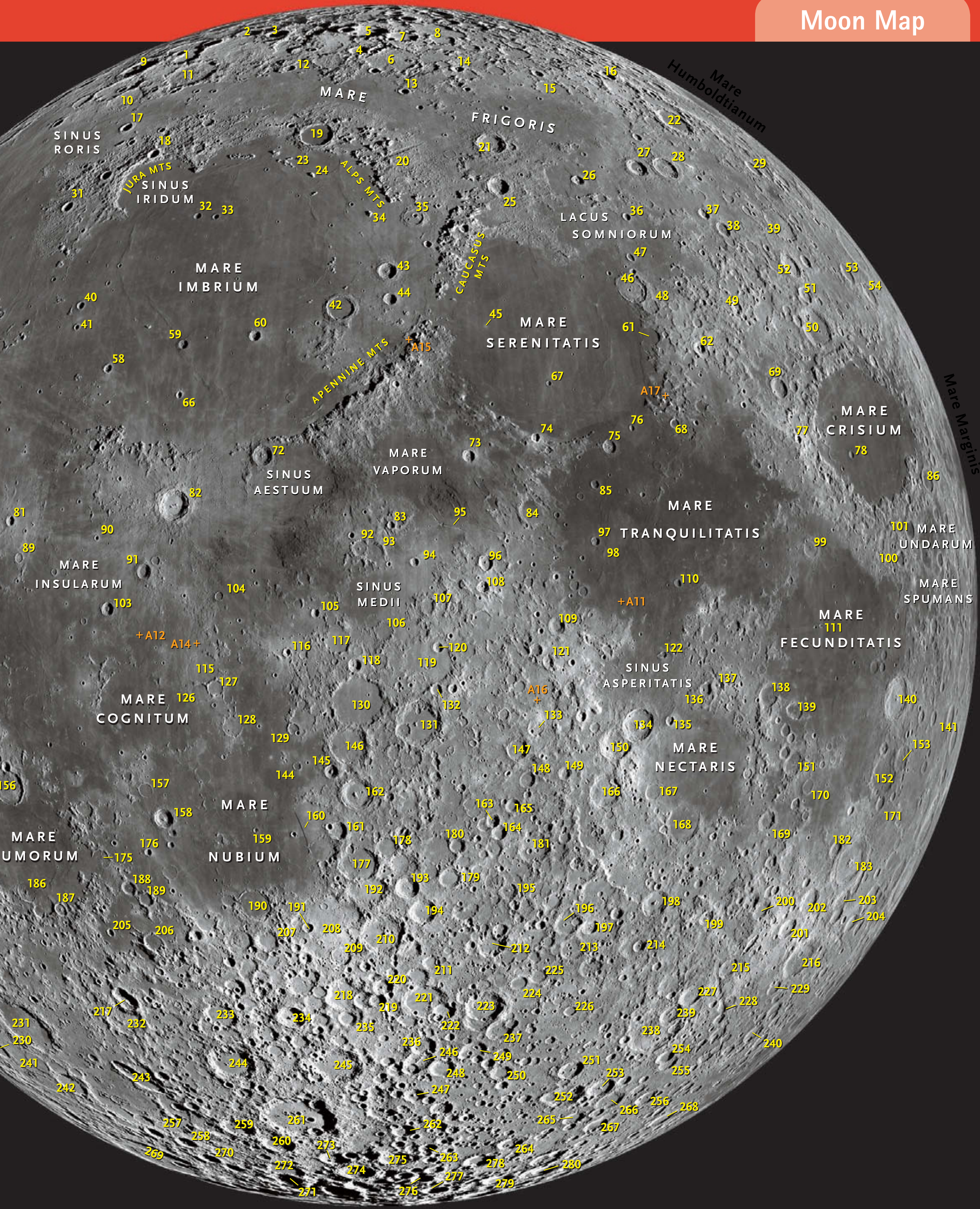
Apollo Landing Sites

A11 Apollo 11
A12 Apollo 12
A14 Apollo 14
A15 Apollo 15
A16 Apollo 16
A17 Apollo 17



To identify a feature you see in your telescope, find its reference number on the map, then check the numerical index.

For ease of use, the reference numbers generally read lunar west to east (left to right), then move north to south (top to bottom). For example, features 1 through 8 are found near the Moon's northern limb (edge), while the highest-numbered craters cling to the southern limb.


Mare Humboldtianum
Mare Marginis
SINUS RORIS
MARE FRIGORIS
JURA MTS
SINUS IRIDUM
ALPS MTS
LACUS SOMNIORUM
CAUCASUS MTS
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A11
MARE FECUNDITATIS
A12
A14
SINUS ASPERITATIS
A16
MARE COGNITUM
MARE NECTARIS
MARE NUBIUM
MARE UMORUM

Sky at a Glance

3 Evening: The nearly full Moon is 4° upper left of Antares.

4 Dawn: A partial eclipse of the full Moon is visible from most of the Americas; see page 53.

5 Afternoon and evening: North Americans can watch Venus's dark disk cross the Sun. The transit is also visible in Europe, Asia, and Australia, where it's June 6th. See page 50.

14–30 Dusk: Mercury is more than 9° above the west-northwest horizon a half hour after sunset for observers at mid-northern latitudes.

16 Dawn: The waning crescent Moon forms a long triangle with Jupiter and the Pleiades to its lower left; see page 48.

17 Dawn: The very thin Moon shines near Jupiter low in the east-northeast a half hour or more before sunrise. Look for Venus to their lower left.

20 The longest day of the year in the Northern Hemisphere. Summer begins at the solstice, 7:09 p.m. EDT.

21 Dusk: The waxing crescent Moon forms a wavy line with Mercury, Pollux, and Castor to its right or upper right.

25–27 Evening: The waxing Moon passes below Mars on the 25th and 26th, and it's below Spica and Saturn on the 27th.

29 All night: Pluto is at opposition to the Sun, rising around sunset and setting around sunrise; see page 52.

Planet Visibility

	◀ SUNSET	MIDNIGHT	SUNRISE ▶
Mercury	NW	Visible June 4 through July 7	
Venus		Visible starting June 13	NE
Mars	SW	W	
Jupiter		Visible starting June 3	NE
Saturn	S	W	

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

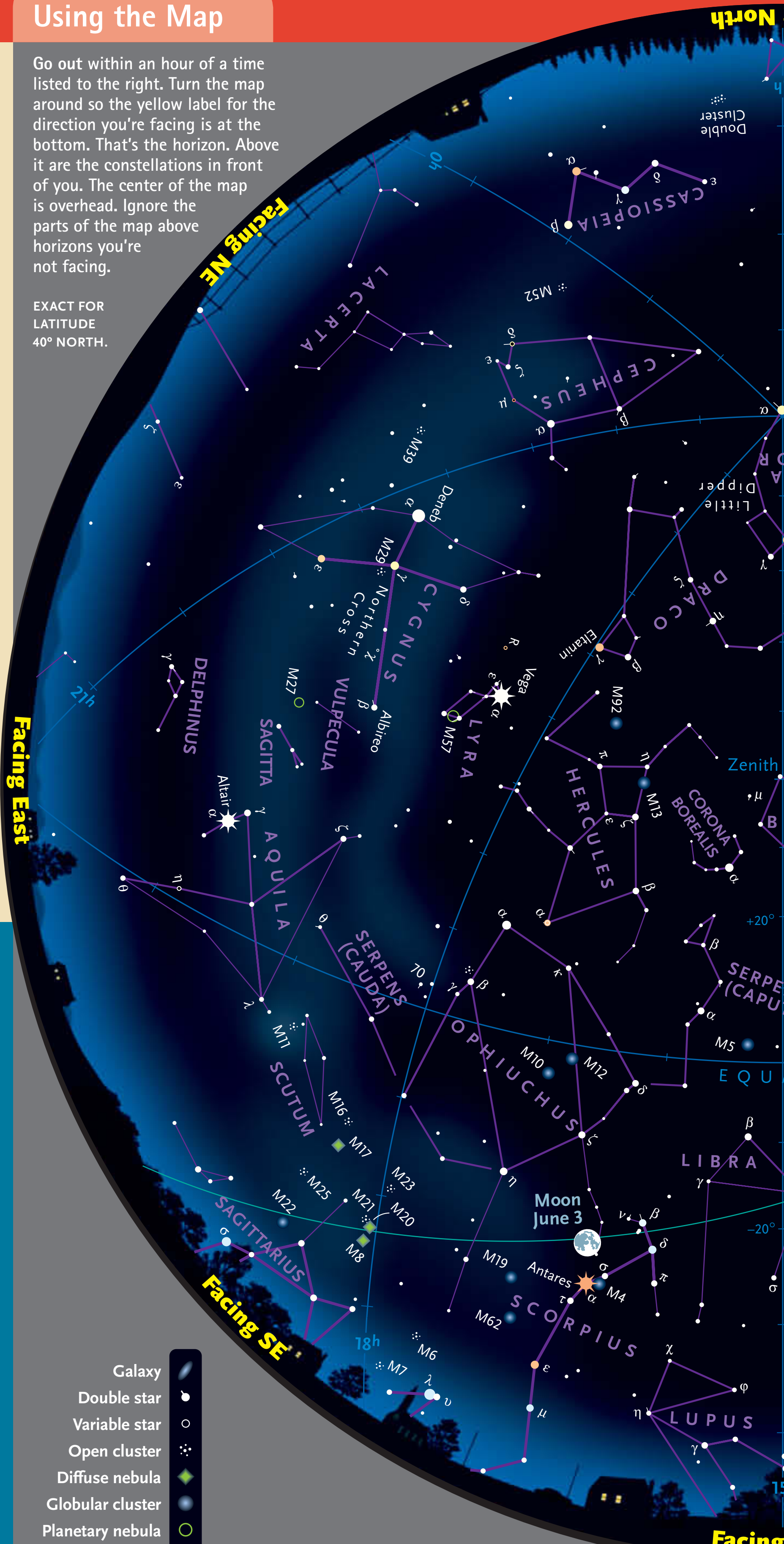
Moon Phases

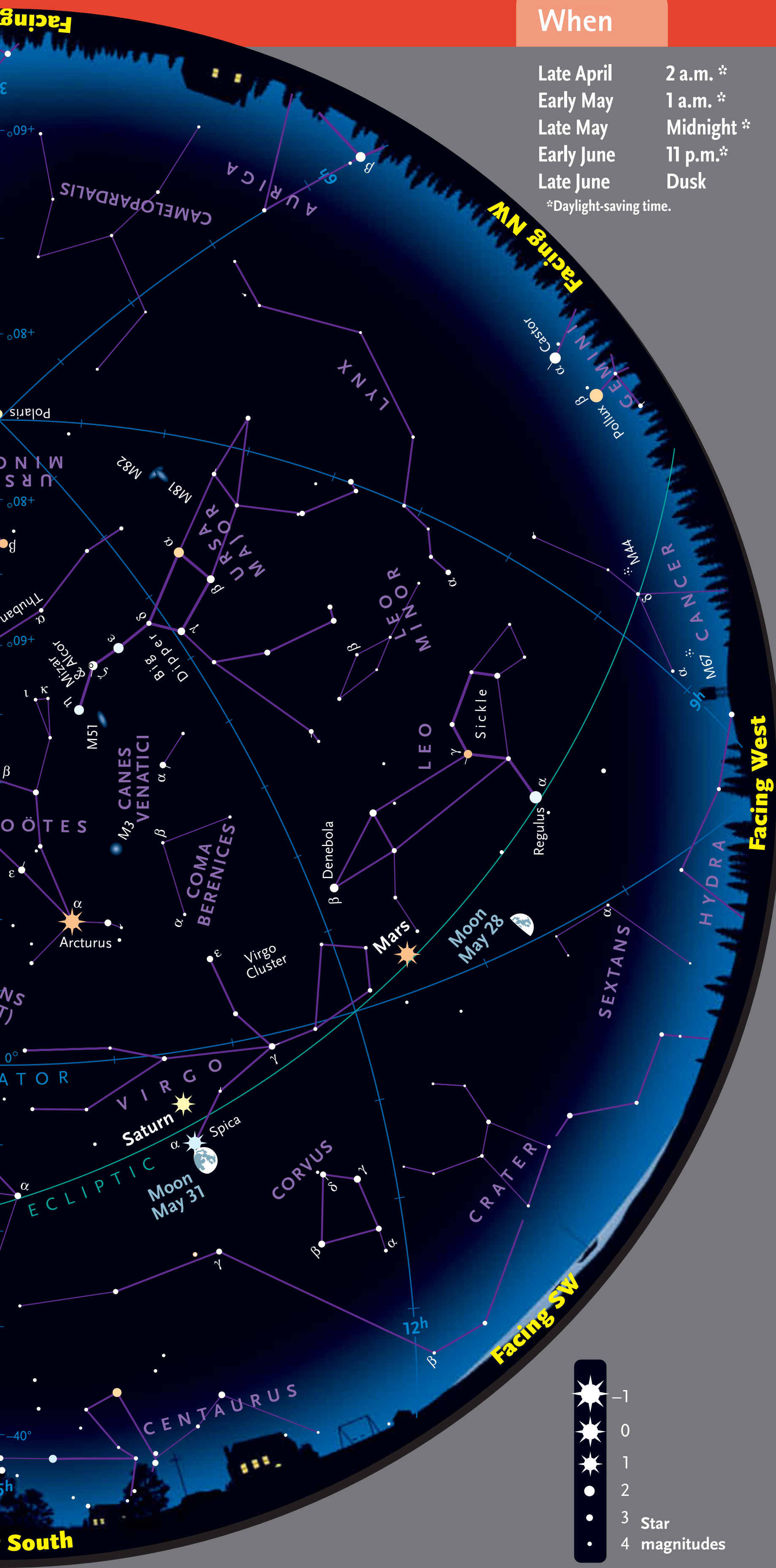
SUN	MON	TUE	WED	THU	FRI	SAT
					1	2
3	4	5	6	7	8	9
10	11	12	13	14	15	16
17	18	19	20	21	22	23
24	35	26	27	28	29	30

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

Late April	2 a.m.*
Early May	1 a.m.*
Late May	Midnight*
Early June	11 p.m.*
Late June	Dusk

*Daylight-saving time.

Binocular Highlight

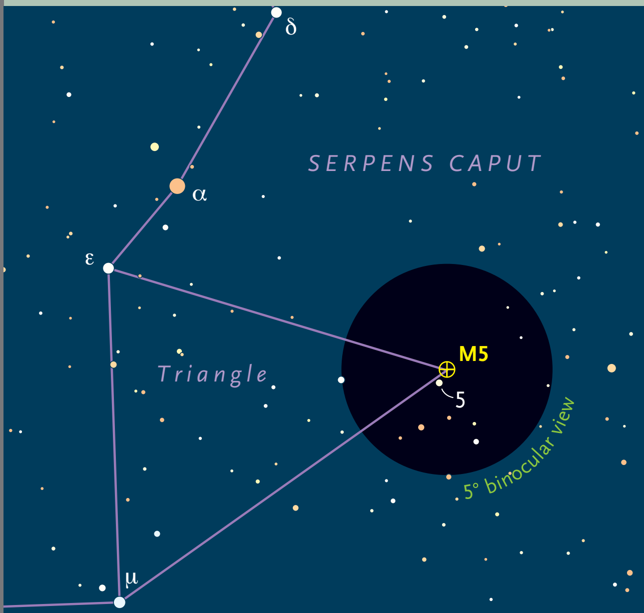
M5: An Easy Globular

Of all the various types of deep-sky objects, globular clusters routinely give beginning binocular observers the most unexpected difficulty. Although none of the Messier list's examples are especially dim, many appear quite small at typical binocular magnifications, and that makes identifying them tricky. Most look like slightly out-of-focus stars, but with experience they get easier to spot. A good way to begin globular hunting is to start with one of the biggest and brightest examples, **M5** in Serpens Caput.

Although it's not as famous as M13 in Hercules, M5 is actually a touch brighter, shining at magnitude 5.7, compared with 5.8 for M13. Where M5 falls short is that it's not conveniently located near a distinctive grouping of moderately bright stars. I usually find M5 by picturing it as the westernmost point on an equilateral triangle that includes Epsilon (ε) and Mu (μ) Serpentis. Sweeping near the missing tip of the triangle brings the cluster's field into view.

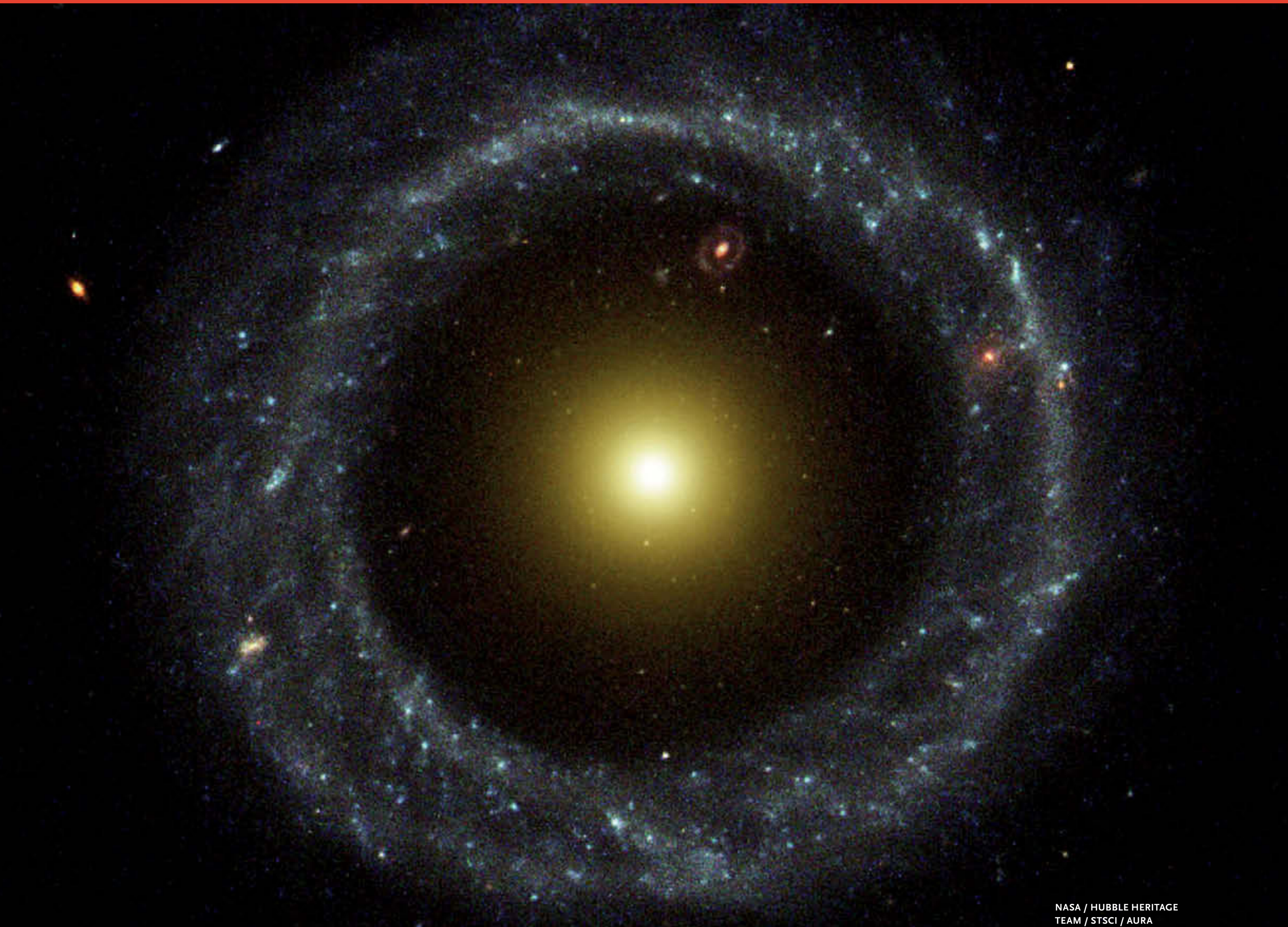
As if to make it easier to build your globular-hunting skills, M5 is nicely situated just north-northwest of a similarly bright star, 5.1-magnitude 5 Serpentis. As a result, even in 7× binoculars, the fuzziness of M5 is obvious when compared with its pinpoint stellar neighbor. All binocular globulars display the same telltale lack of sharpness to one extent or another. And when you know what to look for, bagging other, less conspicuous examples becomes easier.

Once you're confident in your sighting of M5, journey east into globular-rich Ophiuchus and try your luck with the Messier clusters found there. Seek out M9, 10, 12, and 14. Then, if you're successful, move on to little M107 — a real skill-testing challenge. ✦ — *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.



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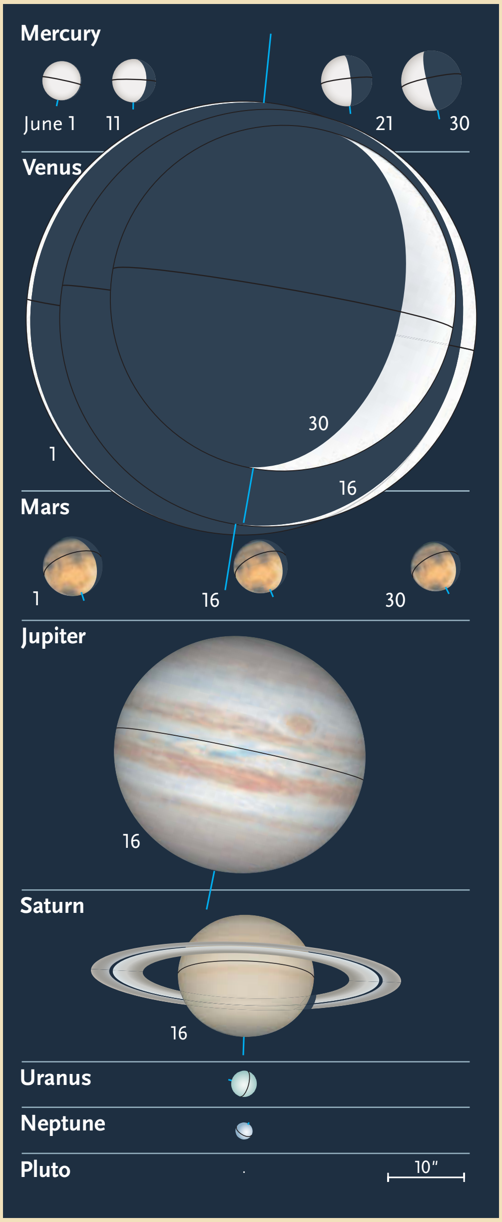
In This Section

Additional Observing Article:

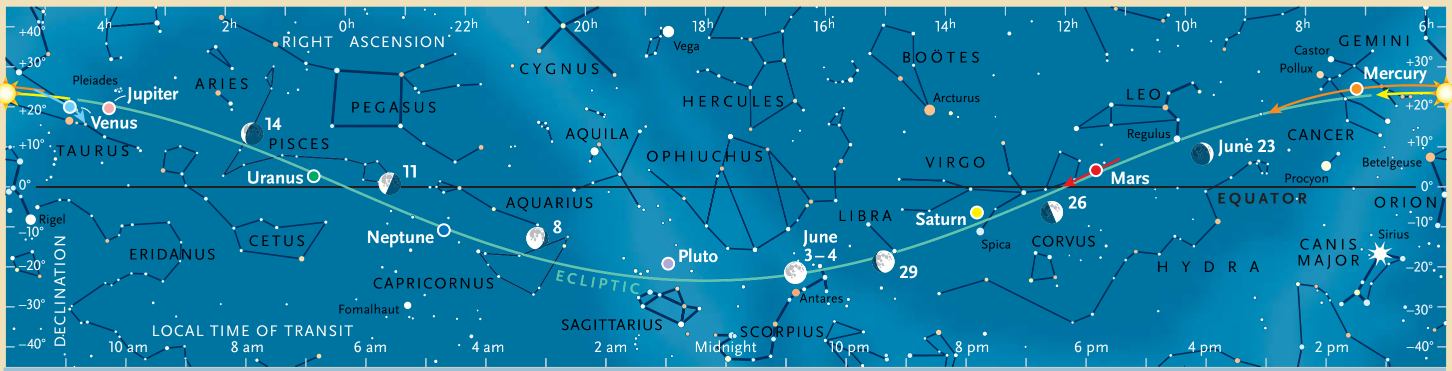


Sun and Planets, June 2012

	June	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	4^h 36.6^m	+22° 03′	—	–26.8	31′ 33″	—	1.014
	30	6^h 36.8^m	+23° 10′	—	–26.8	31′ 28″	—	1.017
Mercury	1	5^h 00.0^m	+23° 56′	6° Ev	–1.8	5.2″	97%	1.302
	11	6^h 29.2^m	+25° 18′	16° Ev	–0.8	5.7″	79%	1.175
	21	7^h 40.8^m	+23° 04′	23° Ev	–0.1	6.7″	58%	1.001
	30	8^h 26.3^m	+19° 33′	26° Ev	+0.4	7.9″	42%	0.848
Venus	1	5^h 10.2^m	+24° 17′	8° Ev	–4.1	57.0″	1%	0.293
	11	4^h 44.9^m	+21° 18′	8° Mo	–4.1	57.0″	1%	0.293
	21	4^h 27.7^m	+18° 45′	22° Mo	–4.4	51.8″	7%	0.322
	30	4^h 25.3^m	+17° 33′	31° Mo	–4.6	45.4″	16%	0.367
Mars	1	11^h 04.8^m	+7° 06′	94° Ev	+0.5	7.9″	89%	1.188
	16	11^h 28.4^m	+4° 12′	86° Ev	+0.7	7.2″	89%	1.305
	30	11^h 53.3^m	+1° 12′	80° Ev	+0.8	6.6″	89%	1.410
Jupiter	1	3^h 41.0^m	+18° 48′	13° Mo	–2.0	32.9″	100%	5.984
	30	4^h 08.1^m	+20° 10′	35° Mo	–2.0	33.9″	100%	5.814
Saturn	1	13^h 29.3^m	–6° 29′	132° Ev	+0.5	18.4″	100%	9.024
	30	13^h 27.4^m	–6° 25′	104° Ev	+0.7	17.6″	100%	9.444
Uranus	16	0^h 30.7^m	+2° 33′	77° Mo	+5.9	3.5″	100%	20.272
Neptune	16	22^h 20.4^m	–10° 59′	112° Mo	+7.9	2.3″	100%	29.599
Pluto	16	18^h 35.6^m	–19° 18′	166° Mo	+14.0	0.1″	100%	31.260

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

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

Fred Schaaf

The Beacon in the Sky

The Pole Star remains in the same spot, night and day.

Few sights in astronomy have been discussed as much as Polaris and the Dippers. But I think we can come up with a way to see Polaris that's fresh for almost everyone.

Dippers high. The all-sky map in our center foldout shows the way the sky looks during June evenings. If you turn the map upside-down so that "Facing North" is at the bottom, you'll see that the Little Dipper is at its highest. The pattern at this time looks like an acrobat doing a handstand — with Polaris, the North Star, as the acrobat's hands. Polaris is very close to the north celestial pole around which the rest of the Little Dipper circles, forever visible above the horizon for viewers from the North Pole to the tropics.

The Big Dipper at this hour is actually somewhat past its peak above the pole. But it's so bright and striking that it remains extremely prominent high in the northwest. The Little Dipper, by contrast, contains only three reasonably bright stars: Polaris and the stars on the far side of this dipper's bowl, Kochab and Pherkad.

The steadfast star. Polaris is less than 1° from the north celestial pole. So to the naked eye from any given location in Earth's Northern Hemisphere, Polaris essentially remains always at the same altitude and the same direction — due north.

From your favorite observing spot, whether at home or somewhere else, Polaris is always just above a particular tree, building, or other landmark. As the night passes, this star stays fixed. But did you ever stop and think that even in broad daylight Polaris is still there? At noon today go out to where you stargaze. Consider that Polaris is even then where you see it at night — seemingly a part of the landscape. By day Polaris is an invisible but still ever-watchful, friendly presence. A whole sky of stars is up there by day too, of course. But only Polaris is up there in a known, unchanging spot.

A fresh challenge. Knowing precisely where 2.0-magnitude Polaris is from your observing site helps you spot it as early in evening twilight as possible. In the February 1969 *Sky & Telescope*, editor Joseph Ashbrook challenged the magazine's readers to determine how early they could make that sighting with the naked eye. His own average was when the Sun was 4.8° below the horizon (*S&T*: August 1969, page 129). Try this observation yourself and write to me about what you find.

More planets by day. Back in my March column I discussed seeing Venus and Sirius naked-eye when the Sun was still above the horizon. In September 2010 all two-dozen students in my college class were able to glimpse Venus with their unaided eyes several hours before sunset.

I've seen Jupiter naked-eye up to an hour after sunrise, and I know a few people who have seen it much later in the day. My most interesting observation of this sort came on an exceptionally clear morning long ago when I was able to see three planets — Venus, Jupiter, and an unusually bright Mars — with my unaided eyes some minutes after sunrise. I had to cease my observation for an errand, but Mars was getting low in the west anyway. Its ruddy color really stood out in the deep blue sky. ✦

Polaris is the tiny bright arc in the center of this 8-hour time exposure above *S&T* senior editor Dennis di Cicco's backyard.

Two at Dawn, Three at Dusk

Venus and Jupiter pair splendidly in June's predawn sky.

In the long dusks of June, Mars seems to materialize partway up in the southwestern sky with Saturn well to its left. As the month progresses, Mercury comes into plain view at dusk low in the west-northwest. And Venus, pursuing higher Jupiter, grandly leaps up to prominence in the dawn sky.

But two events steal the June show. The last **transit of Venus** in the 21st century occurs on June 5th in North America and June 6th in the Old World. Just 1½ days before the transit, on the 4th, a not particularly deep **partial eclipse of the Moon** is visible from Australia and East Asia across the Pacific to most of North and South America. These events are detailed on pages 50 and 53.

DUSK

Mercury has a fine evening apparition from mid-June to early July. It stands highest in the dusk (for observers at mid-northern latitudes) from June 20th to 26th even though its greatest elongation from the Sun is not until the end of the month. During the second half of June, Mercury sets about 1½ hours after the Sun and shines around magnitude zero.

EVENING

Mars and **Saturn** are easy to find somewhere between south and west-southwest as June's long evening twilights fade away. The two planets are remarkably similar in brightness, slightly outshining 1.0-magnitude Spica nearby. Mars dims from magnitude +0.5 to +0.7 and Saturn from +0.5 to +0.8.

Saturn halts its retrograde (westward) motion on June 26th, so it remains nearly stationary in June and July, less than 5° from Spica. Meanwhile, Mars is already speeding away from Regulus and toward Saturn and Spica. Mars leaves Leo and enters Virgo on June 20th and is just ¼° from Beta Virginis (Zavijava) on the 27th. But Virgo is a long constellation, so even at month's end Mars is still 25° lower right of Spica and Saturn.

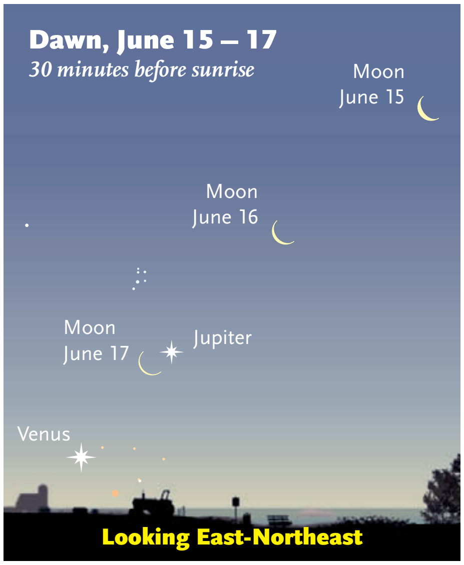
This month Saturn's rings are at a temporary minimum tilt of 12½° from edgewise. The disk of Mars shrinks from 7.9″ to 6.6″, too small to show many features in amateur telescopes.

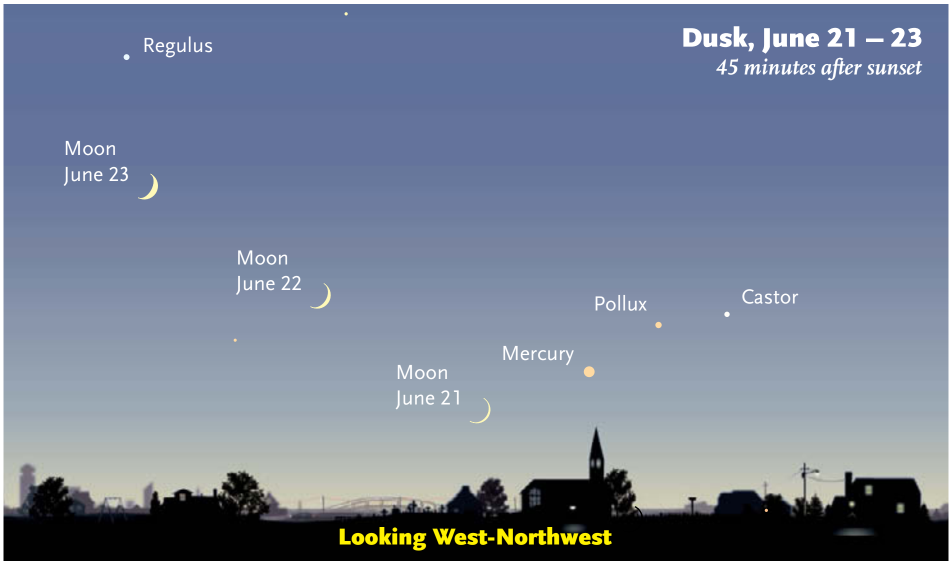
Pluto, in Sagittarius, is at opposition on June 29th, so it's best observed when highest in the south in the middle of the night. See page 52 for a finder chart.

DAWN

Jupiter begins June rising only about 45 minutes before the Sun, but by month's end that figure swells to more than 2 hours. Jupiter shines at magnitude –2.0 between Aldebaran and the Pleiades. And it's thrilling to see an even more brilliant object emerge from the Sun's glow around mid-month and then leap up in pursuit of Jupiter.

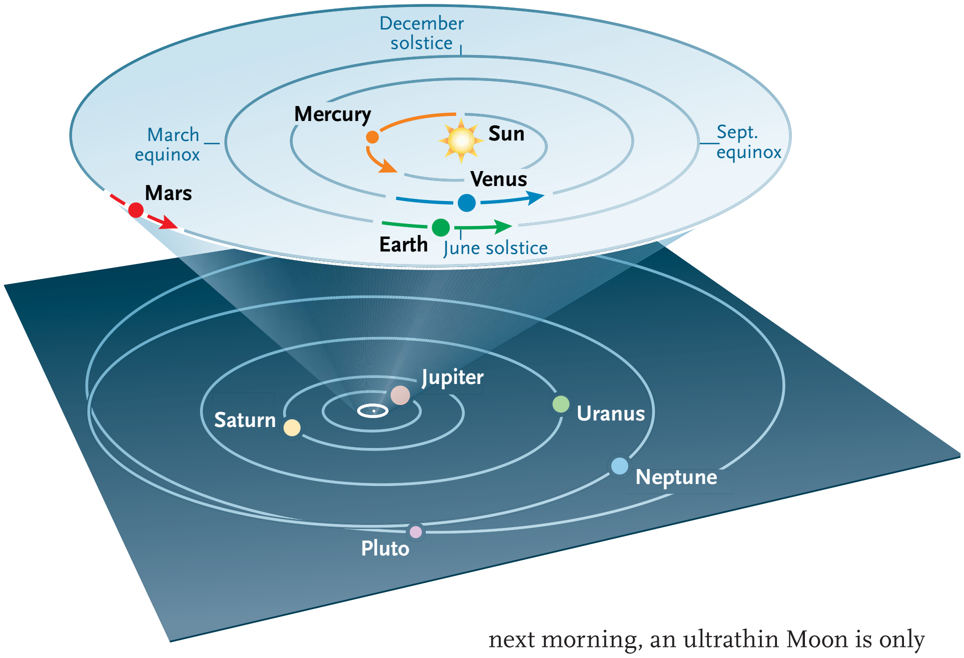
Venus is the brilliant object vaulting out of the sunrise glow to Jupiter's lower left. On June 9th, Venus, fresh from its historic transit of the Sun, rises just 15 minutes before the Sun as seen from latitude 40° north and is probably visible only in binoculars. The interval between Venus-rise and sunrise increases very





ORBITS OF THE PLANETS

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



rapidly; it's about 45 minutes by June 15th and almost 2 hours by month's end. Meanwhile, the gap between Venus and Jupiter shrinks from 15° on June 9th to less than 5° by June 30th.

An additional surprise is that Aldebaran emerges from twilight just below Venus. On what date can you first detect the star? On June 27th, when Jupiter is 5° above Venus, Aldebaran is 3° below Venus — and the line becomes even more compact in the next few days. Binoculars in early dawn may also show that Venus has entered into the midst of the Hyades star cluster.

What do Venus and Jupiter look like in telescopes this month? Jupiter is nearly at its smallest, 33″ to 34″ wide. But Venus's appearance changes dramatically. On June 15th its crescent is fully 55″ long and still only 3% lit. By month's end, the Venus crescent is 45″ long and 16% illuminated. Meanwhile the planet brightens from magnitude –4.1 to –4.6.

Uranus is in northwestern Cetus, and **Neptune** is in Aquarius. Both are reasonably high at dawn; see **skypub.com/urnep** for finder charts.

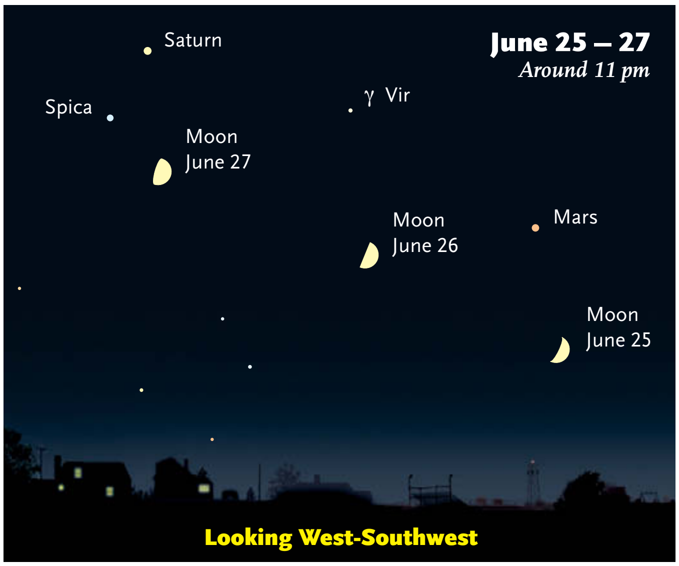
MOON AND SUN

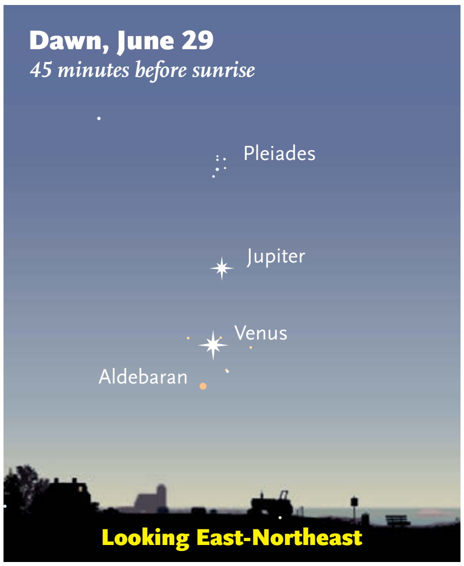
The **Moon** undergoes a partial eclipse on June 4th; see page 53 for more details.

But for some of us, June's most exciting lunar event may be the waning crescent's passage by Jupiter and Venus during dawn. The lunar crescent is well above Venus and Jupiter on the mornings of June 15th and 16th, forming an elegant line with the planets. Then on June 17th, the lunar sliver floats only about 1° lower left of Jupiter (as seen from the U.S. East Coast; farther apart farther west). The next morning, an ultrathin Moon is only 3° high 20 minutes before sunrise — about 6° lower left of Venus.

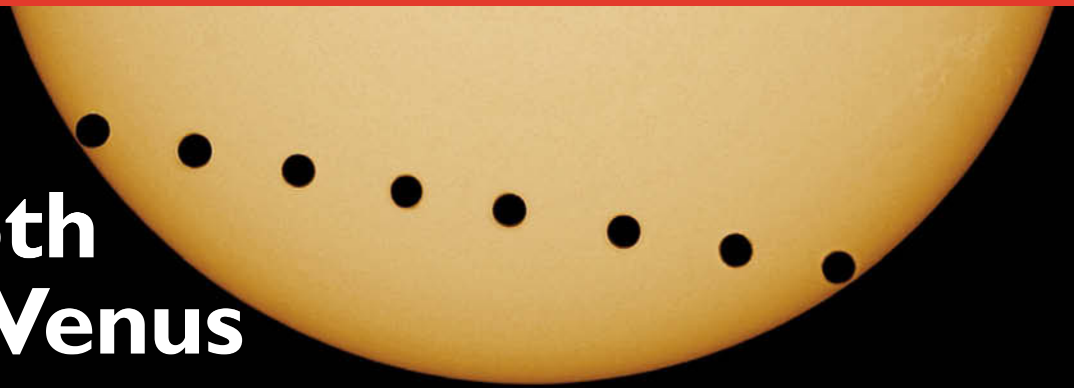
Back in the evening sky, on June 21st the thin waxing crescent forms an uneven line with Mercury, Pollux, and Castor. The Moon is a thick crescent by the time it's below Mars on June 25th and slightly gibbous when below Spica and Saturn on June 27th.

The **Sun** reaches the solstice, its northernmost point on the celestial sphere, on June 20th at 7:09 p.m. EDT. This ushers in summer in the Northern Hemisphere and winter in the Southern Hemisphere. ✦





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



The June 5th Transit of Venus

The black silhouette of Venus will cross the Sun for the last time in our lives.

When you receive this magazine, brilliant Venus will still be shining in the west every clear evening at dusk, though sinking lower every day. A telescope will reveal Venus dwindling in phase to a thinner and thinner crescent. Around the end of May it will become lost from sight deep in the glow of sunset. And normally that would be the end of the story until Venus's reappearance in the dawn.

But this year, Venus's inferior conjunction with the Sun will be very special. On the afternoon of Tuesday, June 5th for North Americans, Venus will cross the Sun's face for the first time since 2004 and the last until 2117. Venus will appear as a black disk 3% as wide as the Sun itself.

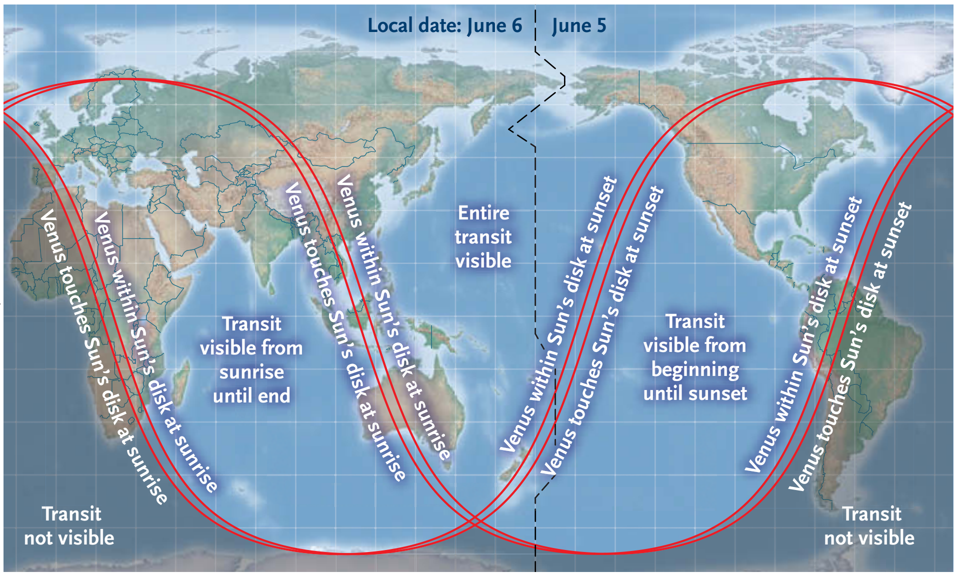
Even the smallest telescope, if safely filtered or used to project the Sun's image onto paper, will show the transiting planet easily. A much better view will be had in a 3- to 6-inch telescope with a full-aperture solar filter over its front. And with a safe solar filter, Venus's tiny black dot should be visible to the unaided eye. Of course, plan to use the same eye protection you would for viewing the Sun safely at any other time, so as not to risk permanently damaging your eyesight.

The transit will last about 6 hours and 30 minutes, but in most of North America the show will be cut short by sunset. You can watch the entire event from start to finish from Alaska, Hawaii (barely), eastern Australia, and eastern Asia. The Sun will rise with the transit already in progress on the morning of June 6th for observers in most of Europe, east Africa, and eastern and south Asia. The map on this page tells the story.

Above: **At the last transit of Venus on June 8, 2004, Johannes Schedler in Austria took this sequence of shots about 53 minutes apart.**

NAKED-EYE VISIBILITY

Will you be able to see Venus on the Sun (through a safe solar filter) with your unaided eyes? Probably! Try this test. Cut out a paper disk 66 millimeters (2.6 inches) wide; that's the Sun. Draw a dark black dot on it exactly 2 mm in diameter. In bright light, view the disk from 7 meters (23 feet) away. Can you see the dot?



S&T: LEAH TISCIONE, SOURCE: MICHAEL ZEILER / ECLIPSE-MAPS.COM

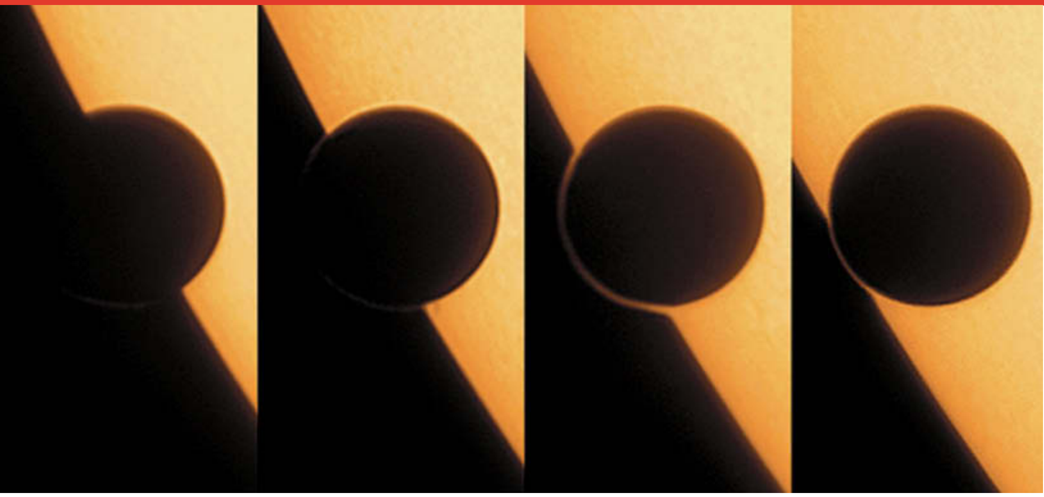
For most of North America, the transit of Venus begins on the afternoon of June 5th and is still in progress at sunset. The western Pacific, eastern Asia, and eastern Australia see the whole show from beginning to end on June 6th local date. For South Asia, the Middle East, most of Europe, and parts of Africa, the transit is already in progress when the Sun rises on the 6th.

The Sequence of Events

The transit begins with *first contact,* when Venus first touches the Sun's northeastern limb. In North America this happens within two minutes of 22:05 Universal Time June 5th (6:05 p.m. Eastern Daylight Time, 5:05 CDT, 4:05 MDT, 3:05 PDT), depending slightly on your location. It starts as late as 22:16 UT in Australia. For North Americans, Venus's entry point will be very near the top of the Sun's disk.

The planet's "ingress" ends about 18 minutes later with *second contact*, when the planet's last, outermost edge enters

Alan MacRobert



The hair-thin aureole of Venus's atmosphere showed during the June 2004 ingress in this video sequence taken by Lorenzo Comolli in Italy. He used a filtered 8-inch Schmidt-Cassegrain telescope and a Panasonic digital camcorder.

onto the Sun's bright face.

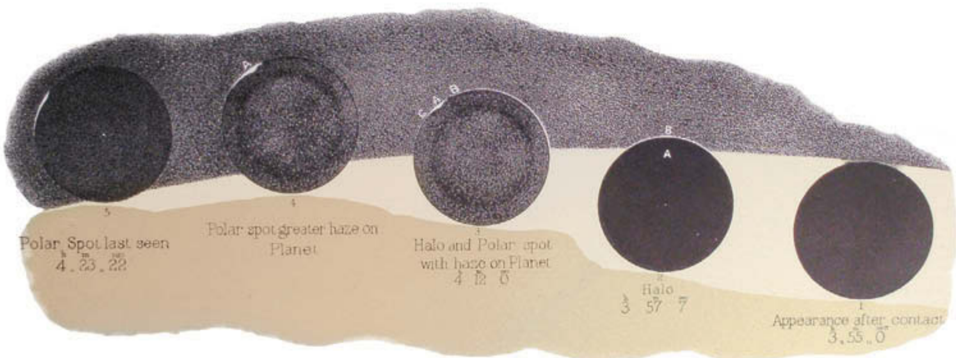
This is the time to look for two of the most interesting phenomena. The first is the faint, elusive *aureole* of Venus's illuminated atmosphere just off the Sun's limb, as shown above and below. The aureole may encircle the planet after first contact, then shrink to a thin arc as Venus moves farther onto the Sun. It may contain bright spots or zones. Since the aureole is visible through a solar filter, it must be several orders of magnitude brighter than the thin cusp extensions due to Venus's atmosphere that telescopic observers sometimes see when Venus is a crescent.

The notorious *black drop effect* occurs as the last of Venus moves just inside the limb. The black drop is caused by blurring due to Earth's atmosphere and telescopic diffraction, combined with the Sun's strong limb darkening at its extreme edge. Together these factors can cause Venus's round outline to become a slight teardrop shape around second contact, thwarting efforts to time this moment precisely (see page 33). You can see a somewhat similar effect by closing one eye, looking at a bright wall, and barely touching your thumb and forefinger together a few millimeters in front of your eye.

For the next 6 hours Venus creeps across the Sun's face. At mid-transit it will be passing a little deeper inside the solar disk than it did on June 8, 2004. If Venus passes near a sunspot, it will be much darker than even the spot's umbra.

When Venus reaches the Sun's other limb, the sequence repeats in reverse order for third and fourth contacts — for the parts of the world that can see them.

Henry Chamberlain Russell in Australia drew the aureole and black drop when observing the 1874 transit of Venus, using a refractor stopped down to an aperture of 5 inches at 100× with green and blue filters. A bright "polar spot" temporarily appeared on the aureole.



Weather Prospects

Having a clear sky for the transit of Venus will take luck, effort, or both. June in most of North America brings a roughly equal daytime mix of clouds and sunshine, but this is thunderstorm season for the late-afternoon hours when the transit takes place.

The sunniest skies are expected in parts of the American Southwest and along parts of the West Coast; see the similar prospects described for the May 20th partial/annular solar eclipse in last month's issue, page 50.

Cloudiness increases eastward, reaching a maximum over the Appalachians and along the Atlantic seaboard. Nevertheless, mobility by car will probably enable almost any determined Venus-watcher to get some view of the transit, as weather forecasts give a pretty reliable "heads up" three to five days beforehand — lots of time to drive to a more promising location. See the cloud-prospect map and links at **skypub.com/tov**. Details of weather prospects worldwide are also in the January issue, page 70.

Wherever you are, make every effort to see this remarkable event. It's your last chance — unless you live another 105 years!

Using a 6-inch refractor they carried up Hosac Mountain in Maine, Paul Howell, Kirk Rogers, and George Whitney took this hydrogen-alpha image shortly after sunrise on June 8, 2004.

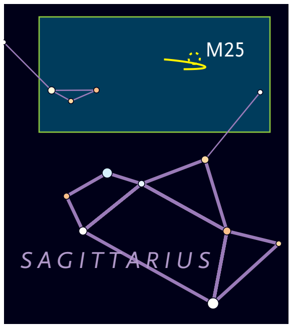
Finding Pluto in 2012

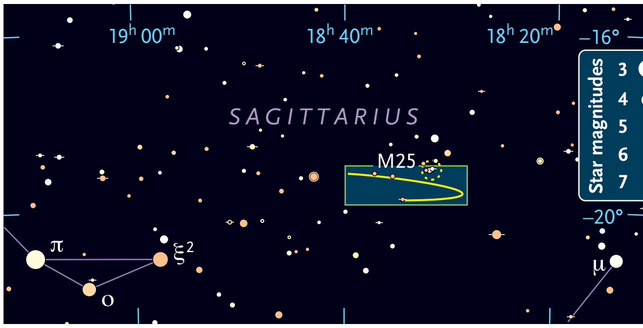
Little Pluto came closest to the Sun and Earth at perihelion in 1989; since then it has been moving farther into the distance along its moderately elliptical, 246-year orbit. So in the last couple decades, Pluto has faded from about magnitude 13.6 to 14.0 during its months around opposition. That may not seem like much of a change, but when you're working that faint with your telescope, every bit of light matters.

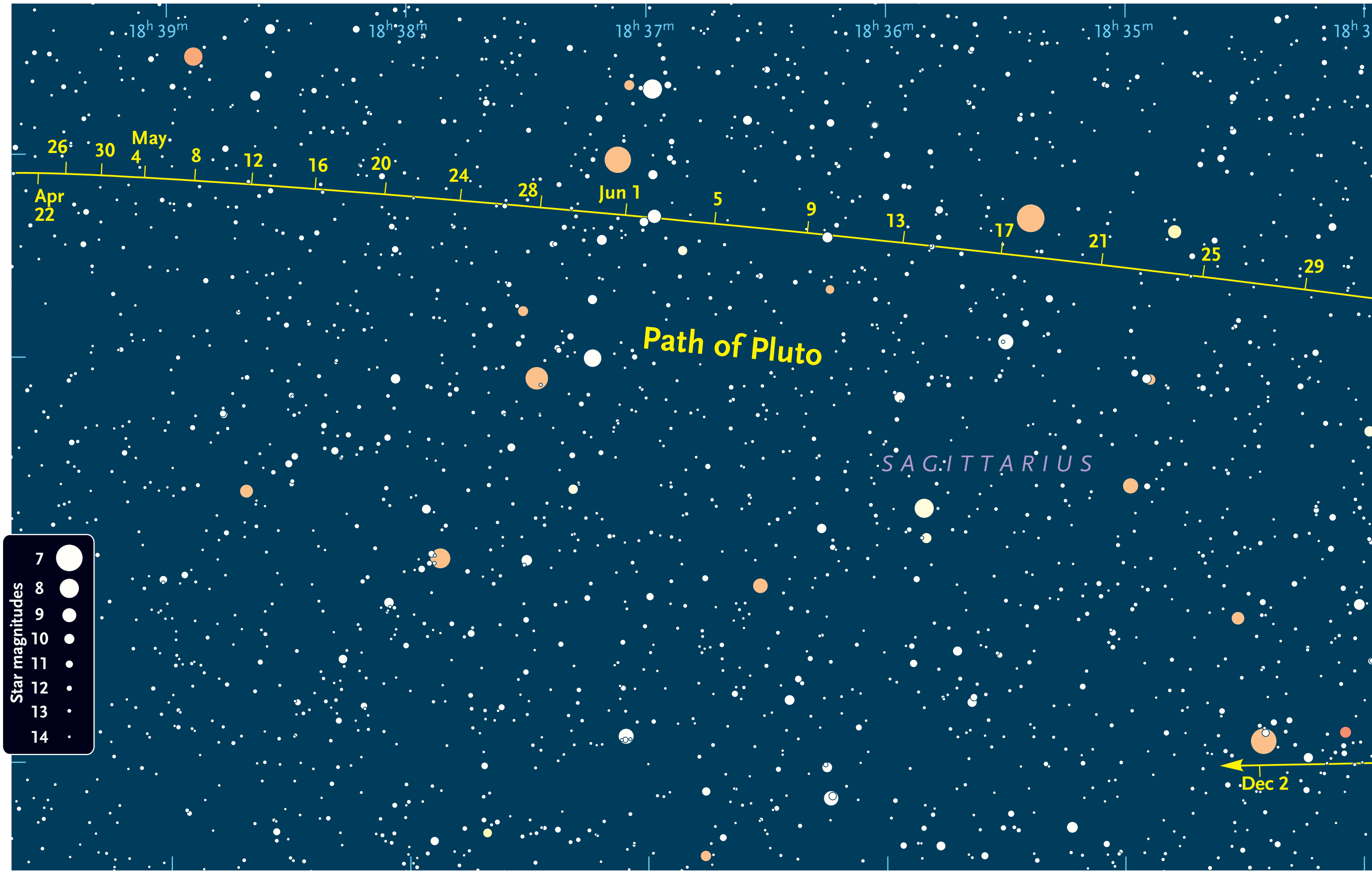
Moreover, Pluto has been moving ever farther south. This year it's in Sagittarius near declination –19°. It won't bottom out until reaching nearly –24° in 2030. So mid-northern observers never see it very high.

At least the star swarms that it's crossing are now thinning out. Pluto is currently moving out of the richest Sagittarius Milky Way, appearing 2° farther east each year.

You'll probably need at least a 10- or 12-inch telescope if your sky has any light pollution at all. On the chart at bottom, ticks are marked on Pluto's path for 0^h UT every four days. This is on the afternoon or evening of the previous date in the







For maps and full details about the lunar eclipse worldwide, see skypub.com/june2012lunareclipse.

time zones of the Americas. Interpolate between the ticks to put a pencil dot on Pluto's path for the date and time you plan to hunt it.

The chart shows stars to magnitude 14.5. Once you've star-hopped to Pluto's field with your scope, switch to your highest power to make the final steps among the extremely faint points to your pencil dot.

To be certain that you've found the correct tiny glimmer (stellar databases this deep are not always complete!), sketch its position among the stars right around it and check back the next night to see that it has moved.

Partial Lunar Eclipse June 4th

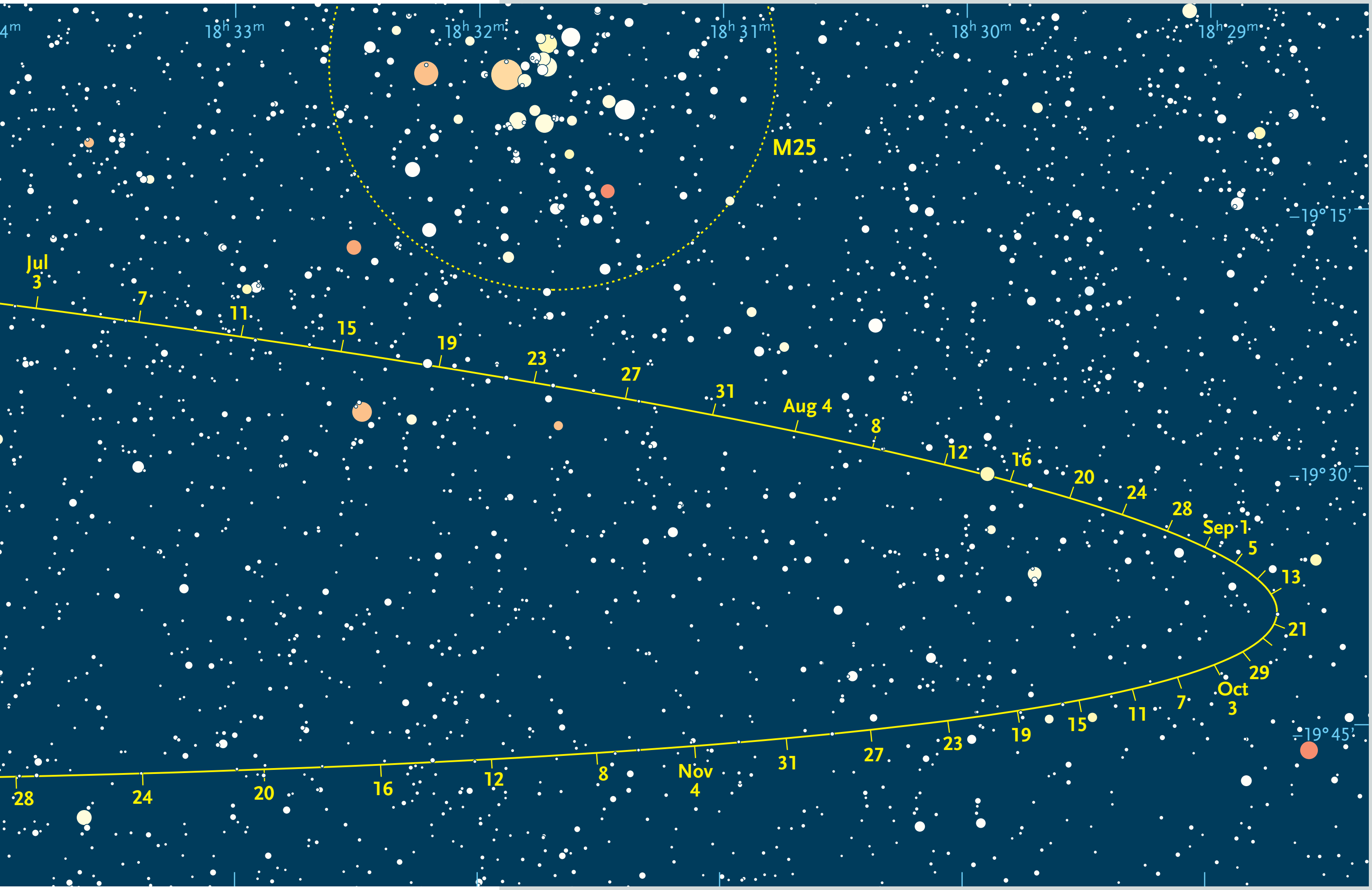
On the morning of Monday, June 4th, the day before the transit of Venus (by pure coincidence), much of the Americas, the Pacific, Australia, and East Asia will witness some very different blackout action — as the full Moon undergoes a partial eclipse.

The celestial southeastern rim of the Moon will first touch the umbra (dark central part) of Earth's shadow at 10:00 Universal Time. That's 6:00 a.m. Eastern Daylight Time, 5:00 CDT, 4:00 MDT, 3:00 PDT. The Moon will have already set and the Sun risen for the northeastern U.S. and Canada; people there miss out. West of a line from North Carolina through Ohio, you get to see at least the eclipse's beginning as the Moon is about to set and the Sun is about to rise.

The partial eclipse will be deepest, with the umbra intruding 38% of the way across the Moon from the south, more than an hour later, at 11:03 UT. By then you'll need to be west of a line from Louisiana through North Dakota. The partial eclipse ends at 12:07 UT. Far Westerners see the whole event high in a dark sky before dawn gets under way.

The penumbra (pale outer fringe) of Earth's shadow will be visible on the Moon as much as 45 minutes before the partial phase starts and after it ends. ✦


S&T ARCHIVES



The Art of Seeing

Spending time observing familiar territory can help you see new things.

We all look at the Moon, but do we actually see it? Some observers grab a small telescope to check where the terminator is located on an unexpected clear night, while others set up a bigger instrument to observe or image features of interest.

Many lunar observers are not particularly critical. They occasionally check in on Plato, Clavius, or Tycho, but they don't take advantage of unique combinations of lighting and librations — conditions that only repeat every 18 years — to look for the unexpected and unknown. What I've learned by studying the images submitted to Lunar Photo of the Day is that there are always new things to see that I had never noticed before. If you stick to just casual observing instead of active learning, you will be no wiser when it comes to the Moon.

Many times I've looked at the three big A's: **Archimedes**, **Aristillus**, and **Autolycus** along the eastern edge of Mare Imbrium. We know that Archimedes formed before the last mare lava flows. First, Imbrium lavas surrounded Archimedes. Second, these lavas rose up through the crater's fractures to partially flood its floor. Ejecta from both Aristillus and Autolycus lie on top of the mare, so these craters had to have formed after the Imbrium lavas were emplaced. Looking closely, you can also observe ejecta from Aristillus that in some places lie on top of Autolycus, establishing Aristillus as the youngest of the three craters.

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Many have casually looked at Aristillus (upper right), but few have taken the time to really see clues of the area's history.

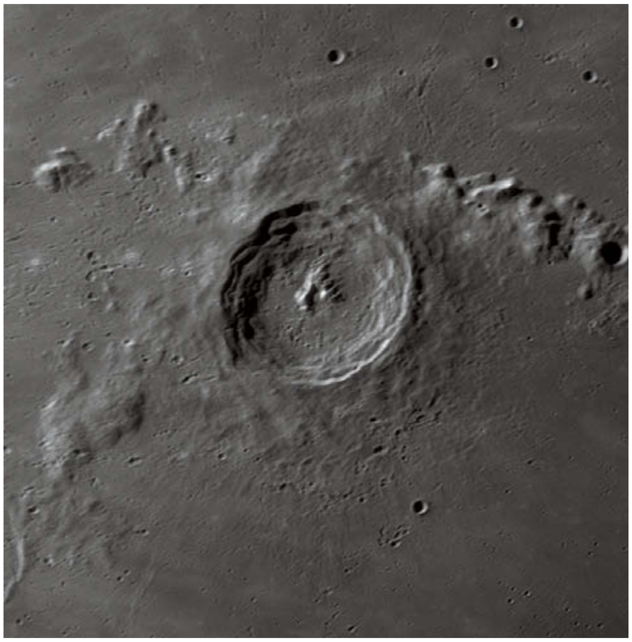
But until recently I never realized that the projectile that formed Aristillus may have hit the lunar surface from an oblique angle. The evidence is there for the discerning eye, in the distribution of ridged and furrowed material that makes up the *continuous ejecta deposit* closely surrounding the crater. Farther away the ejecta do not cover every piece of pre-existing terrain and so are called the *discontinuous ejecta deposit*; these deposits include secondary craters and rays.

When the illumination angle is low you can see that the ridged and furrowed material to either side of Aristillus is extensive, more to the west than to the east. But there is much less material in the orthogonal directions, to the north and south. Asymmetrical ejecta are a sign that the projectile approached at an angle far from the vertical, maybe even a mere 20° from the horizontal. For very low angles of impact, such as with the crater Messier, ejecta predominantly spray to the sides and downrange. Aristillus may have formed when a projectile came from the south-southwest at a low to moderate angle.

Recognizing hints of lunar history in apparently normal craters encourages us to examine other craters more closely. Another possible oblique impact formed **Eratosthenes**. This relatively fresh crater is definitely older than nearby Copernicus, whose rays and secondary craters cut across it. As we saw with Aristillus, the key to determining if a crater formed obliquely is the distribution of its rays, secondary craters, ridges, and furrows. If they extend roughly equally in all directions, the impact angle was high enough to not be considered oblique. Eratosthenes has faint rays but they are overwhelmed by rays from Copernicus and thus can't provide evidence of an impact angle. Copernicus's secondary craters are also pervasive.

But small chains of radiating secondaries extend from Eratosthenes to the north in Mare Imbrium, reaching nearly two crater diameters beyond the crater rim. To the south, the ejecta-modified surface barely extends one crater diameter. To the east of Eratosthenes the radial features don't extend far, either, and to the west confu-

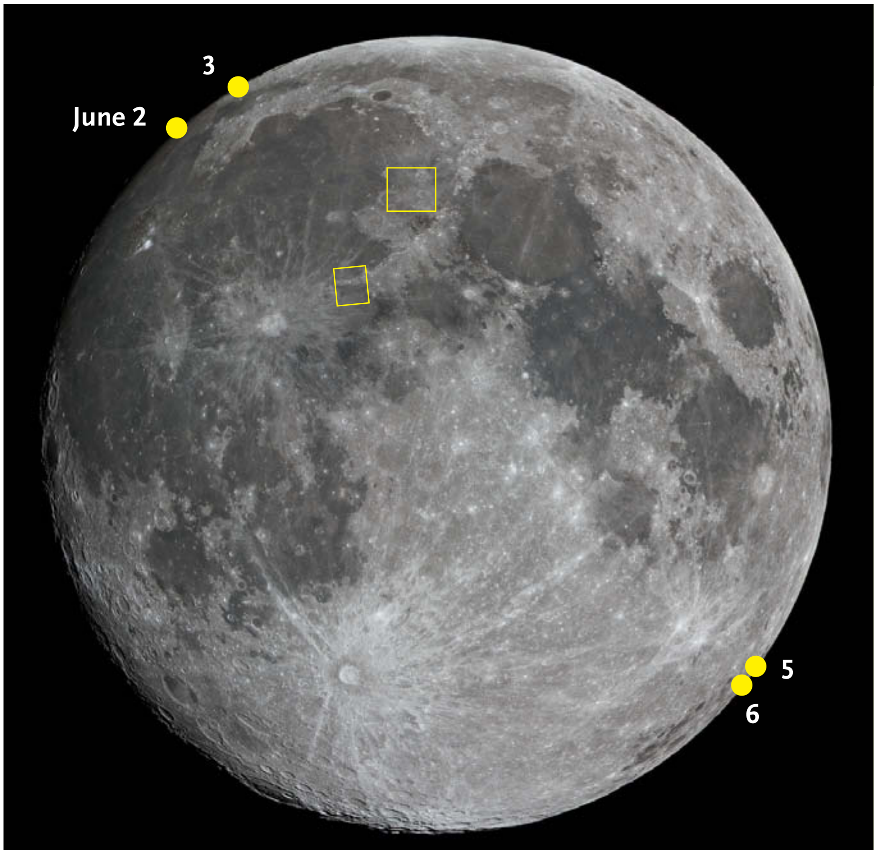
Ejecta to the north of Eratosthenes is spread farther than that to its south, hinting that the crater may have formed by a high-angle oblique impactor that approached from the south.



WES HIGGINS

sion with debris from Copernicus makes it hard to judge the extent. It's possible that later mare lavas covered the secondaries: the lava south and east of Eratosthenes lacks secondary craters and may be younger than that crater. But based on this uneven distribution we can cautiously speculate that Eratosthenes formed by an oblique impact, with the projectile coming from the south, preferentially blasting material northward. The distribution of ejecta relates to how oblique the angle of impact was. Although the crater has some ejecta in most directions, it's concentrated to the east and west, so the most likely interpretation is that Eratosthenes formed by an oblique but relatively high angle.

Though it's easy to become a complacent lunar observer, it doesn't take much effort to continually see the Moon with fresh eyes. ✦



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

S&T: DENNIS DI CICCO

The Moon • June 2012

Phases

FULL MOON	June 4	11:12 UT
LAST QTR MOON	June 11	10:41 UT
NEW MOON	June 19	15:02 UT
FIRST-QTR MOON	June 27	3:30 UT

Distances

Perigee	June 3, 13h UT
225,595 miles	diam. 32′ 55″
Apogee	June 16, 1h UT
253,798 miles	diam. 29′ 16″

Librations

Pythagoras (crater)	June 2
Mouchez (crater)	June 3
Hecataeus (crater)	June 5
Vallis Palitzsch	June 6

The Quincunx of Serpens

A remarkable galaxy group swarms around the serpent's head.

In *Round the Year with the Stars*, Garrett P. Serviss pens, "The head of Serpens, like those of Hydra and Draco, is plainly marked by a striking group of stars, in this case resembling the figure called a 'quincunx.'" This charming old term refers to an arrangement of five objects, four of them forming a rectangle with the fifth at its center.

The celestial quincunx of Serpens is a 5° asterism fashioned by Beta (β), Gamma (γ), Kappa (κ), Iota (ι), and Rho (ρ) Serpentis. Many distant galaxies are strewn around the Serpent's head, as if they were glossy scales shed during his fierce battle with Ophiuchus. Let's visit some of those belonging to the NGC 5962/5970 Group, about 90 million light-years distant.

Sprinkled west of Beta and Kappa Serpentis are nine stars that share the designation Tau (τ). **NGC 5962**, the galaxy group's brightest member, is nestled amid them just 29′ north of Tau^5. Easily visible at 37× through my 130-mm refractor, NGC 5962 is small, moderately faint, and grows much brighter toward the center. At 117× it appears 2′ long and two-thirds as wide, tipped west-northwest, and it's dominated by a relatively large core. At 164× the fleecy core barely discloses a starlike nucleus.

NGC 5962 sports a small central bulge ensconced in a broken ring from which multiple, filamentary arms unfurl. The knotty spiral arms have a high star-forming rate, turning about 6.4 solar masses of material into stars each year. Since William Herschel discovered this galaxy in 1784, it has gained thousands of new stars.

Now we'll drop in on the interacting galaxies **NGC 5953** and **NGC 5954**, found 28′ west-northwest of ruddy Tau^4 Serpentis. Tau^4 is a pulsating red-giant star that ranges between magnitude 5.9 and 7.1 in a complex manner governed by three superposed periods of variability.

With my 130-mm scope at 63×, putting Tau^4 in the field's eastern edge brings a 12′ right triangle of 9th- and 10th-magnitude stars into view. The galaxy pair is a small, faint, elongated glow just outside the triangle's longer leg. This touch of mist holds a brighter core in its west-southwestern end at 102×, and starts to resemble two galaxies with intermingled halos at 164×. NGC 5954 (east-northeast) is fainter and more uniform, with a weak concentration off center.

My 10-inch reflector at 115× shows NGC 5953 and NGC 5954 as distinct entities. The former is roundish with a small bright core, and the latter is a nearly north-south smudge. This is a pretty pair at 213×, with a tenuous glow bridging the gap between the galaxies. NGC 5954 has a very faint northern plume, while the brightness of the rest of the galaxy is slightly enhanced in the east.

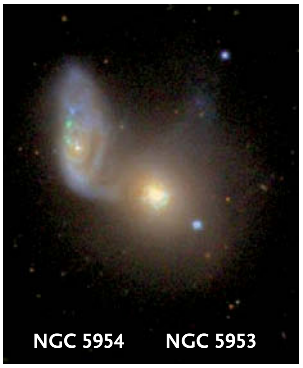
NGC 5953 and NGC 5954 are undergoing bursts of star formation induced by their gravitational interaction. In deep images, the strand of material reaching northwest from NGC 5953 is likely a continuation of the disrupted arm emerging from the southern end of NGC 5954 and passing behind its companion.

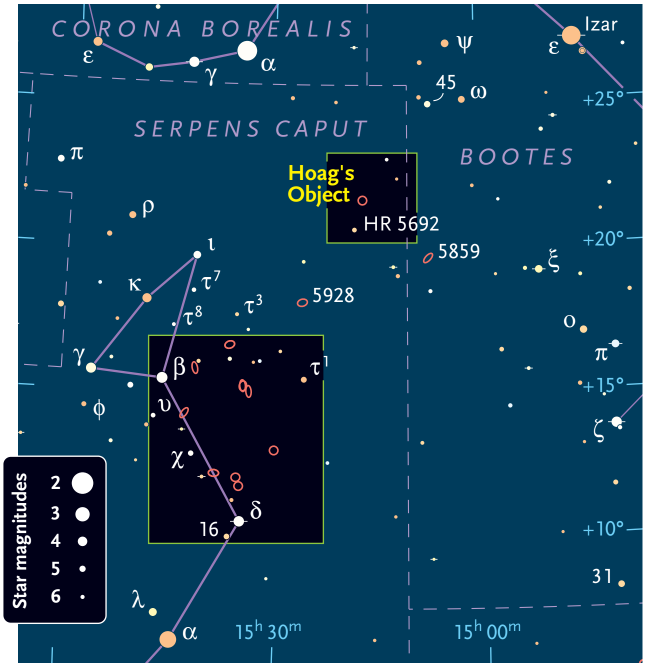
Galaxies in the Serpent's Head

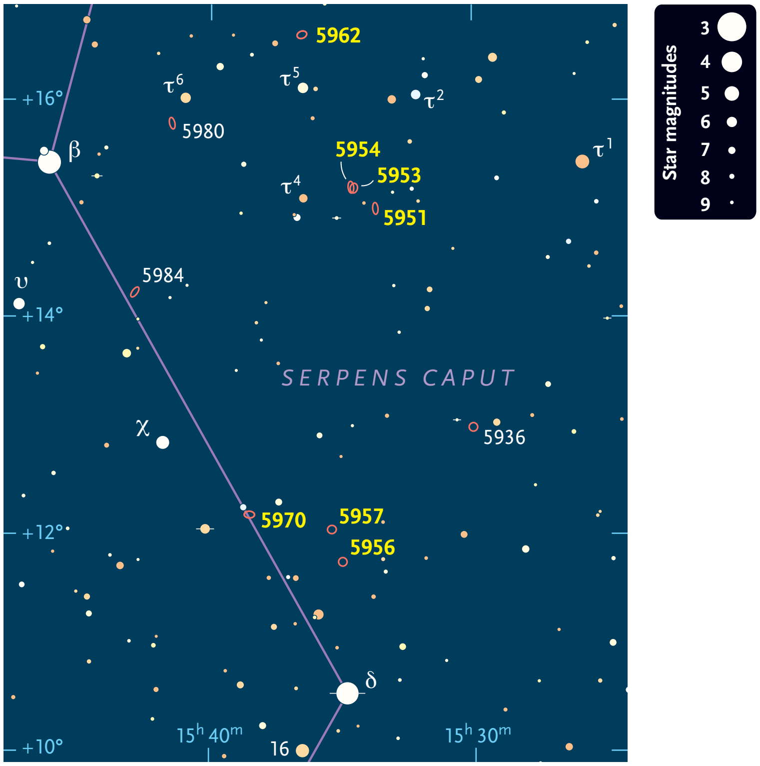
Object	Mag(v)	Size	RA	Dec.
NGC 5962	11.3	2.5′ × 1.5′	15^h 36.5^m	+16° 36′
NGC 5953	12.3	1.4′ × 1.2′	15^h 34.5^m	+15° 12′
NGC 5954	12.2	1.3′ × 0.6′	15^h 34.6^m	+15° 12′
NGC 5951	12.7	3.5′ × 0.8′	15^h 33.7^m	+15° 00′
NGC 5970	11.5	2.9′ × 1.9′	15^h 38.5^m	+12° 11′
NGC 5957	11.7	2.8′ × 2.6′	15^h 35.4^m	+12° 03′
NGC 5956	12.3	1.6′	15^h 35.0^m	+11° 45′
Hoag's Object	15.2	1.0′ × 0.9′	15^h 17.2^m	+21° 35′

Angular sizes 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.


NGC 5962


NGC 5954 NGC 5953





Some labels have been omitted from the wide-field chart above for clarity; see the close-up view at right for details. Page 58 has a detailed finder chart for Hoag's Object.

The interacting pair shares my 10-inch reflector's 115× field of view with **NGC 5951**, but this nearly edge-on spiral galaxy could very easily go unnoticed. Even with averted vision it's merely a slender shaft subtly airbrushed on the canvas of the night sky. More willing to show itself at 213×, the galaxy is 2½′ long, tipped east of north, and it bears a slightly brighter elongated core.

NGC 5951 harbors a small boxy bulge at its center. Most recent sources indicate that a boxy bulge is a galactic bar seen tilted at an angle to our line of sight. If the bar was perpendicular to our line of sight, it would appear peanut-shaped. Many such bars are thought to form due to the natural instabilities of disk galaxies.

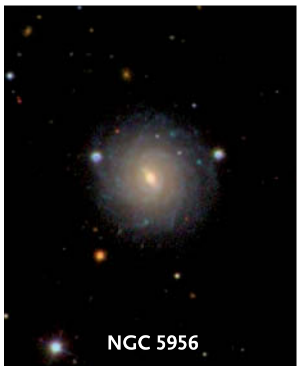
A few degrees farther south we come to a galaxy trio ruled by the barred spiral **NGC 5970**. Look for it 1° southwest of Chi (χ) Serpentis and just 5′ southwest of the middle star in a ¾° gentle arc of three 6th- and 7th-magnitude stars.

In my 130-mm refractor at 37×, I can see NGC 5970 easily with averted vision (looking a bit to one side of the galaxy), but it's difficult with direct vision. At 63× the easternmost star in the arc reveals itself as a double, ΟΣ 300 (STT 300), showing a yellow primary with a much dimmer attendant 15″ west. The galaxy is easy to see with direct vision at 117× as an east-west oval that brightens toward the center. My 10-inch reflector at 213× shows a faint, 2′ × 1′ halo enveloping a highly mottled oval core about 1′ long and half as wide. A very small and bright region surrounds the galaxy's elusive, starlike nucleus. You'll need a large scope, about 15 inches or more in aper-

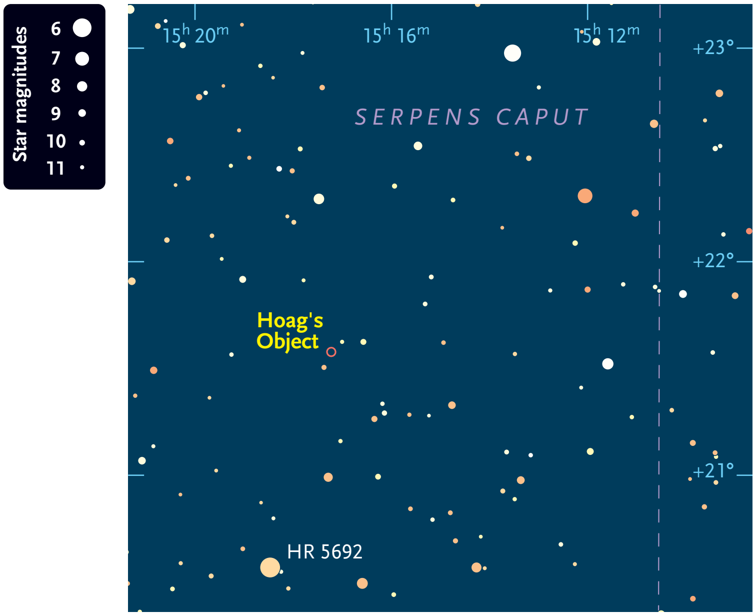

NGC 5951

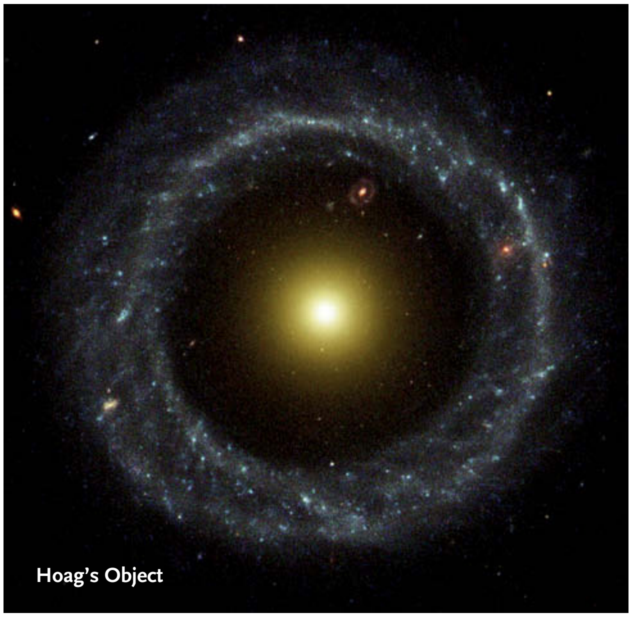

NGC 5970


NGC 5957


NGC 5956

SLOAN DIGITAL SKY SURVEY (6)





NASA / HUBBLE HERITAGE TEAM / STSCI / AURA

ture, to spot NGC 5970's bar, which is ½′ long and slightly tipped with respect to the halo.

The second galaxy in our trio is **NGC 5957**, situated ¾° west and a bit south of NGC 5970. With my 130-mm scope at 37×, NGC 5957 is very small, very faint, and round, and it nudges the outer edge of a 12′ C of six stars that opens toward the northwest. A slightly brighter core is exposed at 102×. The galaxy is easy to spot through my 10-inch scope at 68×, while at 213× the halo and core seem to span about 1.1′ and 0.3′, respectively.

NGC 5956 rests just 19′ south-southwest of NGC 5957. These galaxies appear similar through my 130-mm scope at low power, but NGC 5956 looks smaller than its neighbor at 102×. Our final trio member brightens toward the center and is guarded by a very faint star 2′ south-southeast. In the 10-inch reflector a 115×, NGC 5956 is ¾′ across and strongly concentrated toward its center.

Six times farther from Earth than the other galaxies we've visited, **Hoag's Object** (PGC 54559) doesn't belong to the NGC 5962/5970 Group, but it's a wonderfully exotic object for those who fancy a serious challenge. Arthur Hoag discovered this "pathological galaxy" in 1950, noting that it resembled "a perfectly symmetrical planetary nebula." In the Hubble Space Telescope image at upper right, Hoag's Object is a spectacular cosmic bull's-eye with a bright, yellow core of old stars encircled by a detached blue wheel of hot, young stars.

Hoag's Object sits in far northwestern Serpens, 4° southeast of 45 Boötis. If you want a chart even more detailed than the one at upper left, you can generate one at **http://messier45.com**.

Observers with moderate-size telescopes will have to content themselves with hunting down the core of Hoag's Object and the joy of knowing what an amazing creature they've acquired. My 10-inch scope at 213× shows a 10′ triangle of three 10th- and 11th-magnitude field stars. The galaxy's core is an extremely faint spot halfway between and a little east of the stars that make the triangle's eastern side. In my 14.5-inch reflector, the core sports a painfully faint halo about ¾′ across. Averted vision and knowledge of the galaxy's exact position are prerequisites for success. I couldn't see the dark band that separates the galaxy's ring from its core. With the ring at the hairy edge of perception, my mind just seems to fill in the blank.

Do you wonder what forces shaped this galaxy? So do professionals. Some have suggested a galaxy collision and others the action of a galactic bar that has long since vanished. As if poking fun at our lack of understanding, a distant galaxy remarkably similar to Hoag's Object can be seen through the dark band in the HST image. ✦

DID YOU KNOW?

The Sky & Telescope website includes one of the most comprehensive directories of astronomy clubs available anywhere at skypub.com/clubs. It lists more than 2,000 clubs in countries all around the world, as well as museums, planetariums, and observatories with public outreach programs.

Build a Sun Funnel

This simple and inexpensive device turns your refractor into a solar scope.

WITH THE UPCOMING Transit of Venus and the continuing parade of sunspots, you might be looking for a safe way to view the Sun. There are many options spanning a wide range of sophistication and cost, but here's one that's not only simple and inexpensive, but has the virtue of allowing several people to view the Sun at the same time. It's called the Sun Funnel.

The Sun Funnel is largely based on the Sun Gun, which was briefly described in this magazine's June 1999 issue, page 126. The Sun Funnel was presented by former *S&T* Editor in Chief and current Press Officer for the American Astronomical Society, Rick Fienberg, along with Chuck Bueter and Lou Mayo, at last August's Astronomical Society of the Pacific annual meeting.

The Sun Funnel is a self-contained projection device with an eyepiece at one end and a viewing screen at the other. To build one you'll have to round up a few components — the only unusual part being a 1-foot-square piece of Da-Lite high-contrast Da-Tex rear-surface projection screen, which is available from Cousin's Video (**http://store.cousinsvideo.com/95774.html**). The other pieces are common hardware-store items: a pair of hose clamps (one large, one small) and a black, $17\frac{3}{4}$-inch-long, 5-inch-wide funnel (the Blitz Super Funnel #05034 available at Lowe's home improvement centers is perfect).

The Sun Funnel is a nifty device that lets you use a small refractor to enjoy a full-disk image of the Sun. Because the beam of sunlight emerging from the eyepiece is contained within the funnel, there is no chance someone will accidentally see an unfiltered image of the Sun.

RICK FIENBERG (2)

Assembly is straightforward and should take only 10 or 15 minutes. Begin by using a hacksaw to cut about 7 inches off of the narrow end of the funnel, leaving a 10-inch-long cone. You'll also need to trim off a pair of tabs from the top and side of the cone and make a 1- to 2-inch-deep slit into its narrow end perpendicular to its long axis. You can use a piece of sandpaper to tidy up the edges where you've made your cuts.

The next step is to drape the square of screen material (it doesn't matter which side faces out) over the wide end of the funnel and secure it with the large clamp. This takes a little finesse — tighten the clamp a bit, then pull the material taut, tighten, pull, and so on until the screen is taut and wrinkle free. Lastly, use the small clamp to mate an eyepiece to the narrow end of the funnel.

What eyepiece is appropriate? To project the entire solar disk onto the screen, divide the focal length of your telescope in millimeters by 43 to derive the correct eyepiece focal length. For example, if you're using a telescope with a 400-mm focal length, a 9-mm eyepiece would be just about perfect. You'll want an eyepiece with a barrel that fits into the tapered end of the funnel. Fortunately, a plain-Jane $1\frac{1}{4}$-inch Plössl or orthoscopic is ideal, but even an economical Ramsden or Kellner will do.

To use the Sun Funnel, simply insert the assembly into your telescope's star diagonal. Of course, all the usual solar-observing caveats apply about not leaving the scope unattended and capping the finderscope. For the best views, keep sunlight from falling directly on the screen. Additional details and more photographs on the construction of a Sun Funnel are available at **http://cdn.transitofvenus.org/docs/Build_a_Sun_Funnel.pdf**. ✦

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*Contributing editor **Gary Seronik** is a longtime ATM and observer. He can be contacted through his website, **www.garyseronik.com**.*

A Springtime Globular Cluster Tour

These amazing starballs, more varied than you might imagine, are now swarming into view.

TED FORTE As spring turns toward summer, our evening sky begins turning toward the heart of the Milky Way, and we find ever more globular star clusters coming into sight.

Globular clusters swarm throughout the Milky Way's huge, spherical halo, which is centered on the galactic core in Sagittarius. Our own offset position 27,000 light-years to one side of this point makes globulars seem over-weighted toward the southern part of the summer sky. In late spring we can get a head start by observing the vanguard of these magnificent jewels, which Sir William Herschel described as "undoubtedly the most interesting objects in the heavens."

Interesting indeed. Globular clusters are mostly ancient, dating from when the universe was young and star formation was thick and furious. They typically contain hundreds of thousands of stars, and almost no gas, in a volume less than 100 light-years wide. The study of globulars over the last century led astronomers to greater understandings of stellar evolution, the age of the universe, and the formation of galaxies. Within them, stars swarm thousands of times more densely than in our part of the Milky Way — making them a dynamicist's dream and resulting in such odd close-encounter products as blue stragglers and millisecond pulsars. Globular clusters may predate the Milky Way itself, or at least formed at the same time.

As the name implies, globulars are spherical or nearly so. They're strongly bound together by gravity; being so old, whatever stars could be lost from them were mostly lost long ago, and we see what's left. The star density usually increases greatly toward the center, but the degree of central condensation varies widely. Since the 1920s astronomers have classified globulars by their degree of central condensation, dividing them into 12 classes ranging from a very high concentration toward the center (Class I) to almost no central concentration (Class XII).

The degree of central condensation is perhaps the most relevant assessment to make at the eyepiece when comparing and describing globulars. In addition, observers say that a cluster is "well resolved" when individual stars can be seen across its core, and "unresolved" when it appears as a fuzzy glow with few individual stars visible. At the eyepiece this judgment will vary with aperture, magnification, and sky conditions.

Most of the Milky Way's 158 known globulars are bright and obvious enough to have NGC numbers. In fact, about half were discovered before 1800. The Messier catalog contains 29. The brightest are good binocular objects, and in a dark sky, a few can be spied with the unaided eye. Through the telescope they range from challenging to spectacular.

The 11 described here all appear on a few charts of the *Pocket Sky Atlas* (amid stars to magnitude 7.6) and *Sky Atlas 2000.0* (stars to magnitude 8.5) You can find them on your atlas by their coordinates in the table on page 64.

Let's begin with late spring's finest.

M3 (NGC 5272) in Canes Venatici lies nearly halfway from Arcturus to Cor Caroli (Alpha Canum Venaticorum). In a decent finderscope it appears distinctly fuzzier than the pinpoint stars, especially the 6.2-magnitude orange star ½° southwest of it. M3 is a fine object in binoculars, and many have bagged this bright cluster (total magnitude 6.2) with the naked eye. In a telescope M3 always elicits wows at star parties. It's

COMPARE AND CONTRAST M3 and M5 barely differ in size, brightness, and degree of central condensation, as shown in these equally exposed and scaled images taken by Jim Misti with a 32-inch scope and processed by Robert Gendler. Both frames are 0.33° wide, and are shown at 2.6 times the scale of the other images in this article.

bright enough to be enjoyed even in severe light pollution. M3 was Charles Messier's first original discovery, and by some accounts it was the object that encouraged him to begin the systematic search for nebulous comet impostors that led to the catalog for which he is known today.

M5 (NGC 5904) in Serpens is just a bit larger and brighter than M3 (compare their photos on the previous page), but I'm hard pressed to choose between them when picking a favorite for this time of year. M5 is easier to pick out with the naked eye and through binoculars (see page 44), and it is certainly impressive in the telescope. I find it remarkable that M5 was discovered more than 60 years before M3, especially given its rather obscure sky location. It's in Serpens Caput about 2/5 of the way from Arcturus to Antares, 8° southeast of Alpha Serpentis. The 5.1-magnitude white star 5 Serpentis, 1/3° to the cluster's south-southeast, dramatically highlights its low-power telescopic field.

M3 and M5 are similar in their degrees of concentration. It is so easy to be overwhelmed by the spectacle of bright globulars that their distinctions can be lost, so make the effort to compare them at the same power and try to consider their differences instead of their similarity. You'll be rewarded for your diligence.

VARIETIES OF GLOBULAR EXPERIENCE The following frames are all 0.6° wide, made from red and blue images in the Digitized Sky Survey with an averaged image added in green.

COLOR COMPOSITING BY *S&T*: SEAN WALKER

Some Springtime Globular Clusters

Names		Constellation	R.A.	Dec.	Class	Magnitude	Diameter	Distance (l-y)
NGC 4147		Com	12^h 10.1^m	+18° 33′	VI	10.3	4.4′	63,000
NGC 4590	M68	Hya	12^h 39.5^m	–26° 45′	X	7.8	11′	34,000
NGC 5024	M53	Com	13^h 12.9^m	+18° 10′	V	7.6	13′	58,000
NGC 5053		Com	13^h 16.5^m	+17° 42′	XII	9.5	10′	57,000
NGC 5139	Omega Cen	Cen	13^h 26.8^m	–47° 29′	VIII	3.7	55′	17,000
NGC 5272	M3	CVn	13^h 42.2^m	+28° 23′	VI	6.2	18′	33,000
NGC 5466		Boo	14^h 05.5^m	+28° 32′	XII	9.0	9′	52,000
NGC 5634		Vir	14^h 29.6^m	–05° 59′	IV	9.5	5.5′	82,000
NGC 5694		Hya	14^h 39.6^m	–26° 32′	VII	10.2	4.3′	114,000
NGC 5897		Lib	15^h 17.4^m	–21° 01′	XI	8.5	11′	41,000
NGC 5904	M5	Ser	15^h 18.6^m	+02° 05′	V	5.7	23′	24,000

Magnitudes are total visual including the faintest outlying portions; the clusters may appear fainter than these values compared to stars, especially in light pollution. Most data are from William H. Harris's online table of globular clusters, McMaster University (2010). Sizes are from Archinal & Hynes, *Star Clusters*. The Shapley-Sawyer classes are from spider.seds.org.

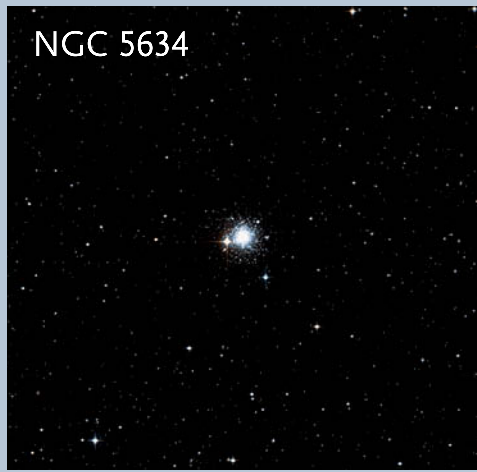
Personally, I have difficulty detecting any color in globular clusters, but many observers claim to see a slightly blue tinge to M5 and a pinkish hue to M3. What do you see?

Comparisons are easier when the differences are more pronounced, as in the case of **M53** (NGC 5024) and its neighbor **NGC 5053**, two vastly different globulars less than 1° apart. M53 is the brighter one. It lies 1° northeast of 4th-magnitude Alpha Comae Berenices (a close, equal double star in a 26-year orbit with a separation of 0.5″ this year and closing). William Herschel called M53 "one of the most beautiful sights I remember to have seen in the heavens." It's mostly round and similar to M3 in its intermediate degree of central condensation.

Its neighbor, NGC 5053, lies 1° to the southwest. The two are at about the same distance from us, affording a clear comparison of their very different physical natures. With one-sixth as much light, NGC 5053 presents a ghostly echo of M53. Visually, 5053 could pass as a very rich open cluster, but its classification as a globular is supported by its color-magnitude diagram and by the presence of RR Lyrae variables, indicators of great age. It's often a difficult target for small telescopes, especially in light-polluted skies. But in larger apertures you may find it "a little gem of woven fairy fire," in the words of the late *S&T* columnist Walter Scott Houston.

Although globulars hold their stars tightly, some are distorted slightly out of round by tidal interactions with other massive objects, especially the galactic center. A close enough plunge by the galactic center can strip stars clean off a globular. Faint **NGC 5466** in Boötes, just 5° east of M3, shows strong evidence of such a past interaction. In 2007 astronomers analyzing Sloan Digital Sky Survey data discovered a long, narrow, extremely sparse "tidal tail" of stars stripped loose from it. Stretching 45° all the way to Ursa Major, the tidal stream is so long that researchers suspect that NGC 5466 is not actually a globular cluster but the remnant core of a dwarf spheroidal galaxy that fell into the Milky Way. The grand, far-southern globular Omega Centauri is a better-known likely example of this type of non-globular origin.

NGC 5466 is dim: a large, loose cluster of low surface brightness with no central condensation, well resolved. More than once I've noted that it looks more like a rich open cluster than a typical globular. It lies ⅓° west-northwest of a brighter 7th-magnitude star.

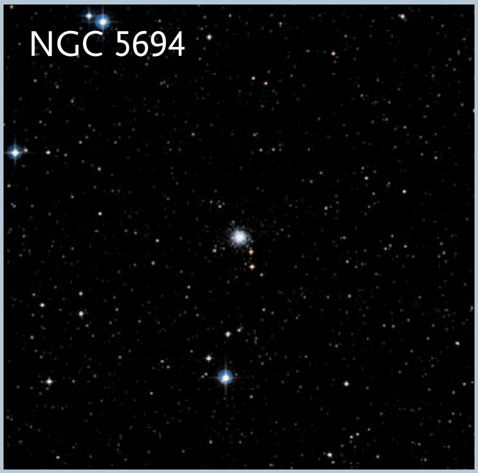


NGC 4147 is a small globular in Coma Berenices on the northern fringe of the Virgo-Coma galaxy cluster. So you might mistake it for a galaxy on first look. In a 4- to 8-inch scope, only a few of its outer stars are faintly resolved.

Much farther southeast, near Virgo's feet, **NGC 5634** is nestled in a little, 5′-long triangle of stars that just frames it and adds interest to an otherwise unremarkable object. The brightest of the three stars is magnitude 8.0 and aids in finding the cluster halfway between 4th-magnitude Iota and Mu Virginis (the Virgo stick-figure's southern leg). The cluster is unresolved and presents a round, comet-like glow in an 8-inch scope. It does, however, earn some notoriety for being the only globular cluster among Virgo's countless deep-sky targets.

Farther east, Libra is home to **NGC 5897**. This fairly large, sparse cluster appears a bit lopsided to me, its eastern side being a little brighter. It's very open and moderately well resolved. Its low surface brightness makes it appear dimmer than its listed magnitude of 8.5 would suggest. The stars in NGC 5897 have very low metallicity even for a globular (astronomers term any element heavier than helium a "metal"), indicating extreme age. NGC 5897 lies 2/5 of the way from Sigma to Gamma Librae.

NGC 5694, another of the Milky Way's oldest globular clusters, lies in easternmost Hydra in the same general area. It sits just north of a tiny triangle of 11th- and 12th-magnitude stars, as seen in the image below. Given its low declination and inconspicuous appearance it would, perhaps, be little-known to northern observers if not for its inclusion in two popular observing lists: the Herschel 400 and the Caldwell Catalog, as well as Walter Scott Houston's "Hydra Hysteria" tour (*S&T:* June and July 1991). The Herschel 400 are the "best" of the 2,500 objects in Sir William Herschel's deep-sky catalog (the predecessor of the NGC), as selected by members of the Ancient City Astronomy Club in St. Augustine, Florida.



Inspiration for that list came from James Mullaney's letter to *Sky & Telescope* (April 1976, page 235) suggesting that observing objects from Herschel's catalog would make a worthy project.

The Caldwell Catalog was compiled by Sir Patrick Caldwell-Moore for an article in the December 1995 *Sky & Telescope*. It represented his 109 favorite non-Messier objects, though he selected some for their astrophysical significance rather than observability. Working through these two lists has become a rite of passage for many amateur astronomers as the next step after the 110 Messier objects, and these lists have no doubt introduced many deep-sky hunters to this small globular. It is mostly unresolved, well concentrated toward the center, with a grainy-looking halo around it.

Hydra's better-known globular resident is **M68** (NGC 4590). I locate M68 by extending a line from Delta through Beta Corvi (the long side of the Corvus quadrilateral) onward south another 3.4°. A 5th-magnitude star ½° southwest of the globular helps guide the way. "A beauty!" is how John H. Mallas described M68 in his book *The Messier Album* (Sky Publishing Corp., 1978). And why not? To the amateur astronomer, globulars are favorites for their looks. They sparkle like sintered jewels against a dark sky. I don't know who coined the phrases "diamond dust on black velvet" and "sugarpiles in moonlight," but at observing sessions one often hears these descriptions for large, bright globulars such as M68. It's not very concentrated toward the center, and it has a lot of outlying stars.

Yet those of us in mid-northern latitudes have to content ourselves with the lesser examples of the genre. Most of the best and brightest reside in the southern sky. But in late spring, some of us are privileged to enjoy one hint of this far-southern splendor. From my location in southeastern Virginia, I can briefly catch a glimpse of the most magnificent one of all. **Omega Centauri** (NGC 5139) hugs our horizon in May and can be seen as a very pale, very large, unresolved circular glow. If you live where Omega Centauri breaks the horizon — technically, anywhere south of latitude 42° north — you owe it to yourself to give it a try. Extend a line from Spica down through 2.8-magnitude Iota Centauri and southward for another 11°. Omega Cen is just a touch east of there. Even as a faint apparition dimmed by the thickest of Earth's atmosphere, it's a memorable sight. ✦

Contributing editor ***Ted Forte*** *loves all types of deep-sky objects. Take his tour of springtime galaxies in the Virgo Cluster in the May 2011 issue, page 66, and winter planetary nebulae in the February 2012 issue, page 60.*

Answers to Crossword Puzzle

K	E	L	P	■	L	A	M	P	■	S	C	E	N	T
O	N	E	A	■	A	W	A	R	■	T	H	R	O	E
A	D	A	R	■	N	A	N	O	■	O	I	L	E	D
L	U	N	A	R	D	I	S	T	A	N	C	E	S	■
A	R	E	■	E	S	T	■	O	W	E	■	■	■	■
S	E	D	A	T	E	■	A	T	E	■	N	O	R	A
■	■	■	C	A	N	A	R	Y	■	A	A	R	O	N
B	L	A	C	K	D	R	O	P	E	F	F	E	C	T
L	O	I	R	E	■	T	H	E	A	R	T	■	■	■
T	A	R	A	■	S	E	A	■	R	I	A	T	A	S
■	■	■	■	R	U	R	■	A	T	C	■	O	D	A
■	J	E	R	E	M	I	A	H	H	O	R	R	O	X
A	E	R	I	E	■	A	M	O	I	■	E	U	R	O
P	A	I	N	S	■	L	I	R	E	■	B	I	E	N
E	N	C	K	E	■	S	E	A	R	■	A	N	D	S

Crossword can be found on page 82.

Deep Sky with your DSLR

Michael A. Covington

Getting started in astrophotography has never been easier.

Astrophotography with digital single-lens reflex (DSLR) cameras spans all facets of amateur astrophotography. Today's camera models have much lower noise than in the past and more features useful to amateurs. In the accompanying text, Michael A. Covington explains how you can capture spectacular images like the one above of the Pipe Nebula in Sagittarius. All images are courtesy of the author unless otherwise credited.

THERE'S NO QUESTION that digital single-lens reflex cameras (DSLRs) are the most versatile cameras available today. No other device can go from shooting your children's birthday party in the backyard to recording distant galaxies through a telescope without needing any modifications. DSLRs have truly thrust open the door of astro-imaging to anyone with an interest in shooting the night sky.

Several factors make DSLRs good for astronomy. Most of the cameras are designed to use the same lenses as their 35-mm film precursors, and they have relatively large sensors compared to their point-and-shoot counterparts. The common APS-C size CMOS sensors in many consumer DSLRs are about 65% as big as 35-mm film, and about as large as many mid-range astronomical CCD cameras.

Unlike film, the CMOS sensor in a DSLR has no reciprocity failure; it never forgets a photon. (Well, hardly ever.) A 2-minute exposure is long enough to capture a respectable image of the Orion Nebula. In 10 minutes with a modest telephoto lens, you can record 16th-magnitude stars. And DSLRs don't require you to bring along a computer when you're shooting the night sky.

There are many DSLR cameras available for purchase, but Canon manufactures the most popular ones for astrophotography. It is the only DSLR maker that has actively cultivated the astronomy market, at one time even marketing a DSLR specifically for astrophotographers (the 20Da). This model has long since been discontinued, but Canon has incorporated many of its best features useful for astrophotography into current models.

Other DSLRs from Nikon and Pentax are similar, differing mainly in the way functions are accessed and image files are formatted. Virtually all current DSLRs block the astronomically important far-red end of the visible spectrum where hydrogen gas fluoresces. To increase their camera's red sensitivity, many astrophotographers have had their cameras modified. They remove the camera's infrared-blocking filter and replace it with a filter that transmits more of the red light from hydrogen emission. Those daring individuals willing to tinker with their cameras can purchase a modified infrared-blocking filter and do the work themselves, or you can send your camera to Hap Griffin (**www.hapg.org**) or Hutech (**www.hutech.com**) to have the filter replaced for you. Once the camera is modified, you'll have to set a custom color balance to shoot pleasing daytime images.

If you're shopping for a new DSLR with astrophotography in mind, one particular feature worth seeking out is known as "Live View." This feature allows you to turn on the sensor and view a live video on the camera's rear LCD screen. This makes focusing your lens or telescope a breeze compared to other methods. If you don't have Live View, you'll need some form of focusing aid, or you can confirm focus by taking short 5-second exposures and immediately viewing them on the rear screen.

SHOOTING STARS

Once you've picked your camera, there are a few additional accessories you'll need to start shooting the night sky. The first is a device that will let you shoot long exposures without touching the camera. You can make single exposures up to 30 seconds by pressing the shutter release on the camera, and setting a delay so the vibration from pressing the button will have died away before the shutter opens. For longer exposures, you can use a special cable release with a built-in intervalometer. It allows you

ALAN DYER (2)

Most DSLR cameras have filters that block the far-red end of the spectrum to produce natural-color daylight images. *Left:* Unfortunately, these stock filters block much of the reddish nebulosity in the Milky Way, as seen in this image of Orion's Belt. *Right:* When the stock filter is replaced with a custom filter, the resulting image of Orion's Belt reveals much more nebulosity.

to program a series of long exposures and eliminates the need for a delay between images. Versatile, inexpensive cable release intervalometers are made by Phottix (**www.phottix.com**) and other accessory makers, and are easy to find on Amazon.com or ebay.com. Make sure you select the proper model for your particular camera.

You'll also want a tripod for your first foray into DSLR astrophotography. Even if your primary goal is to shoot close ups of deep-sky objects through your telescope,

S&T: SEAN WALKER

Because DSLRs look and feel a lot like 35-mm film cameras, the way you attach one to your telescope is similar. To start shooting the sky with a DSLR, you'll need a few accessories, such as an intervalometer (far left) that can automatically shoot multiple long exposures, and a T-ring adapter (bottom right center) for your particular model.

shooting simple camera-on-tripod shots will help familiarize you with the functions of your camera that you'll use for all types of deep-sky astrophotography. The tripod also comes in handy for shooting conjunctions, wide-field photos of the Milky Way, and meteor showers — popular targets for all astrophotographers.

Under a starry, moonless sky, put your camera on your tripod. Use a wide-angle lens at its widest f/stop (lowest f/number) and focus manually on a bright star using live focus, if the feature is available with your camera. Zoom in on the live-focus view to help achieve the sharpest focus. Set the ISO speed to 1600 and expose for 30 seconds. You'll get a picture that shows plenty of stars and possibly some of the brighter deep-sky objects.

A few nights of practice will familiarize you with your camera's features that are beneficial for astrophotography, such as mirror lock-up, noise reduction, and programming sequences of exposures on your intervalometer.

If you long for deeper exposures with round stars, you can "piggyback" your camera on top of your telescope, photographing the sky through your camera lens while using the telescope to track. With this method, you'll find that the standard 18-55-mm zoom lens that comes bundled with many DSLRs isn't very good for astronomy; it's slow (usually no faster than f/4.5) and less sharp than many fixed-focal-length lenses. Also, being a zoom, it may shift focal length or focus as the telescope tilts to track the sky.

Fixed-focal-length lenses are better suited for astrophotography. You can of course buy superb telephoto lenses from Canon, Sigma, and other makers. Here's a useful tip: adapters are available to convert old manual-focus Olympus, Nikon, Pentax, Contax/Yashica, and screw-mount lenses to work on your Canon EOS or Nikon DSLRs. Because autofocus doesn't work for deep-sky astrophotography, you can use old manual-focus lenses that are much less expensive than the newest lenses on the market. These adapters are available from Fotodiox (**www.fotodiox.com**).

If you want to try your hand at shooting objects *through* your telescope, you'll need an adapter. This usually consists of a T-ring and an adapter that couples your camera to your telescope in place of an eyepiece. With this setup, you can immediately take photographs of the Moon using your telescope as a camera lens. To take pictures of deep-sky objects, you can experiment and make exposures of 5 seconds or more to test how long your telescope mount will track before stars appear as streaks. Even most high-end telescope mounts require an autoguider or other special measures to compensate for errors in the mount's gears, wind buffeting, or other variations in tracking.

IMAGE PROCESSING

No matter what kind of astrophotography you're doing, the image that comes out of the camera isn't usually the finished product. A short, fixed-tripod exposure often appears too dark, while a 2- or 3-minute guided exposure is likely to look too bright because of light pollution. That's normal. Any automatic white balance in your camera is not usually applicable to deep-sky astrophotos because the subject is too faint for the camera's computer to make an accurate judgment. You can adjust all of these settings with image-processing software. Although some programs that come with digital cameras offer rudimentary adjustment abilities, I highly recommend acquiring a software program specifically geared toward DSLR astrophotography. These programs are necessary to get the most out of your images.

***Left*: At high ISO settings, DSLRs are far more sensitive than the best films of the past. This 5-second exposure with a Canon 40D at ISO 1600 and a 50-mm f/2.8 lens captures 6th-magnitude stars and the bright globular cluster Omega Centuri at lower right. *Above*: Every deep photograph recorded with a DSLR requires some adjustment. The author shot this picture of Comet Holmes from his urban backyard on November 15, 2007. Note the reddish background sky *(left)*, which was easily corrected using image-processing software *(right)*. This piggybacked 3-minute exposure was taken with a Canon 40D at ISO 400 using a 300-mm f/5 lens.**

Some popular programs available for DSLR astrophotography include *MaxIm DL* (**www.cyanogen.com**), *ImagesPlus* (**www.mlunsold.com**), *Nebulosity* (**www.starklabs.com**), and *DeepSkyStacker* (**http://deepskystacker.free.fr**). Most are available as a trial before purchase, and *DeepSkyStacker* is freeware.

Once you've chosen your processing software, two steps will immediately make your images better. The first is dark-frame calibration. When you take an exposure longer than a few seconds with most DSLRs, you'll see a random scatter of colored pixels — red, green, and blue specks — indicating places where the sensor has what are known as "hot pixels."

The best way to get rid of hot pixels is to subtract a dark frame, a picture taken with no light reaching the sensor, but in all other respects just like the original, with the same exposure time, ISO setting, and sensor temperature. The dark frame will have the same hot pixels, so subtracting it from your picture will remove them. Most DSLRs can do this for you automatically if you turn on your camera's long-exposure noise-reduction function. Then, after you take a long exposure, the camera will immediately take another one just like it with the shutter closed, perform the subtraction automatically, and record the resulting image. Although this feature is handy and guarantees that the dark frame matches all the settings of the original exposure, it takes up precious time that you could be using to record images.

The alternative is to take one or more dark frames manually with the lens cap on and subtract them later with software. Preferably, take several — at least a half dozen — so that software can average them to eliminate random noise. One set of dark frames can serve for pictures of several celestial objects taken on the same evening with the same exposure time and ISO setting.

Besides dark-frame calibration, the second technique that will make your images smoother is to shoot multiple exposures of your target and combine them. This technique, known as stacking, has many advantages. You can get an hour's exposure without needing an hour of perfect guiding. If you have guiding problems, you can take many exposures and simply toss out the poorly tracked ones. You can also avoid reaching the sky fog limit because no single exposure is excessively long. Stacking algorithms in image-processing programs can automatically discard airplane trails, random hot pixels, and other large discrepancies between the images you are combining. And when you stack multiple exposures, the noise level in the stacked image is reduced proportional to the square root of the number of exposures you combine.

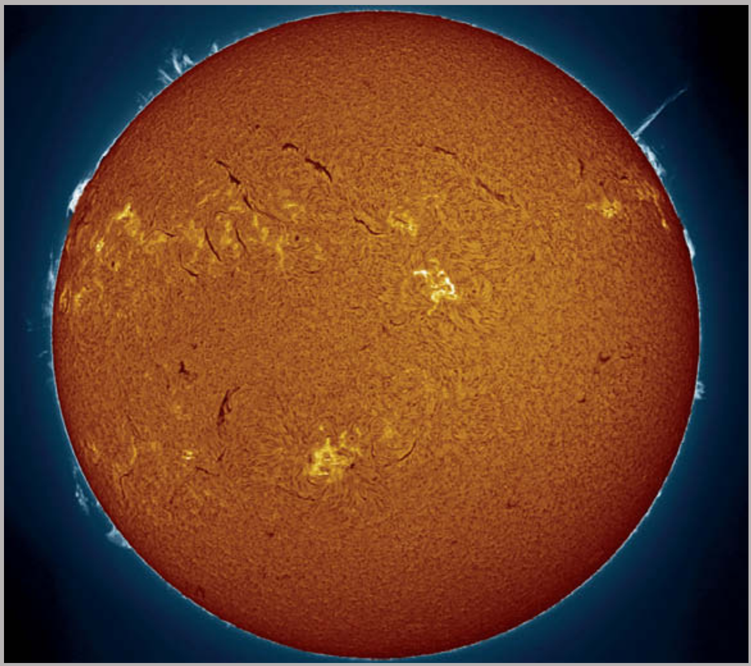
There are limits, of course. You can't stack 3.6 million 1/1000-second exposures and get the equivalent of an hour-long exposure. The individual exposures have to be long enough for a useful image. That is typically 5 to 10 minutes, unless tracking limitations compel you to go shorter.

Stacking multiple exposures helps to reveal faint nebulosity. Combining eight 4-minute exposures shows the Messier objects (from top to bottom) M21, M20, and M8 in Sagittarius.

Stacking and dark-frame subtraction are also best done with raw files, not JPEGs, because JPEGs have been stretched nonlinearly for display, and data is thrown away in the compression process that makes JPEG files small compared to raw format. After dark-frame calibration and stacking, you can then adjust the brightness, contrast, and color balance of your image and perhaps sharpen it if necessary before saving the final version.

As you improve at recording data, you can learn many additional tricks and techniques to squeeze even more out of your images. But the tips in this article will put you well on your way to taking great astrophotos while avoiding many pitfalls. ✦

Michael Covington** is an avid astrophotographer and author of* Digital SLR Astrophotography*, which is available at* ***www.covingtoninnovations.com/dslr*.*



▲ **STELLAR FIREWORKS**
Jim Lafferty
Last December the solar atmosphere was teeming with activity visible in hydrogen-alpha light. Dark filaments and bright active regions riddled the disk, while tall prominences danced along the limb.
Details: *Lunt Solar Systems LS-100THa solar telescope and DMK 41AU02.AS video camera. Stack of multiple frames recorded December 4, 2011.*

▶ **THE POLAR VICINITY**
Jérôme Astreoud
The area surrounding Polaris (left) and open cluster NGC 188 (right) is awash with faint reflection nebulosity visible in this deep photographic exposure.
Details: *Canon EOS 7D DSLR camera with 200-mm lens at f/1.8. Total exposure was 2 hours.*

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▸ **THE FIRST MESSIER**

Larry Van Vleet

The famous supernova remnant M1, the Crab Nebula, appears as a complex network of reddish filaments projecting outward from the whitish central cloud.

Details: *16-inch f/9 RCOS Ritchey-Chrétien with Apogee Alta U16M CCD camera. Total exposure was more than 60 hours through Astrodon filters.*

▸▾ **ANCIENT NEIGHBORHOOD**

Anthony Ayiomamitis

The bright open cluster M67 in Cancer is dominated by older yellowish stars, many of which have evolved off of the main sequence.

Details: *Astro-Physics AP 160 Starfire EDF refractor with SBIG ST-10XME CCD camera. Total exposure was 2 hours through Astrodon color filters.*

▾ **MARTIAN CLOUDS**

Sebastian Voltmer

Captured only slightly after opposition, Mars displays brilliant white orographic clouds along the flanks of Olympus Mons (center), as well as dark gaps in the North Polar Cap at bottom.

Details: *PlaneWave Instruments CDK20 corrected Dall-Kirkham reflector with Imaging Source DMK 21BF04.AS video camera. Stacked videos captured on the evening of March 16th at 0^h Universal Time.* ✦

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PARADISE ASTRONOMY: 40 acres located in Southern Arizona. 40 x 80-ft insulated steel building, living area, garage, workshop, 200 amp service, excellent well, two septic systems, RV parking, $360K. 520-398-2722, W7UO@Hotmail.com.

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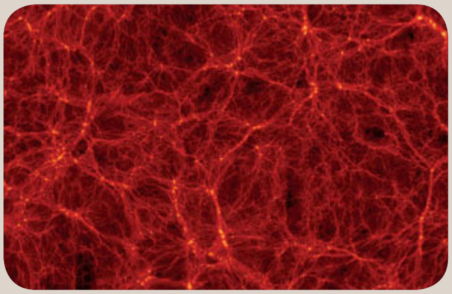

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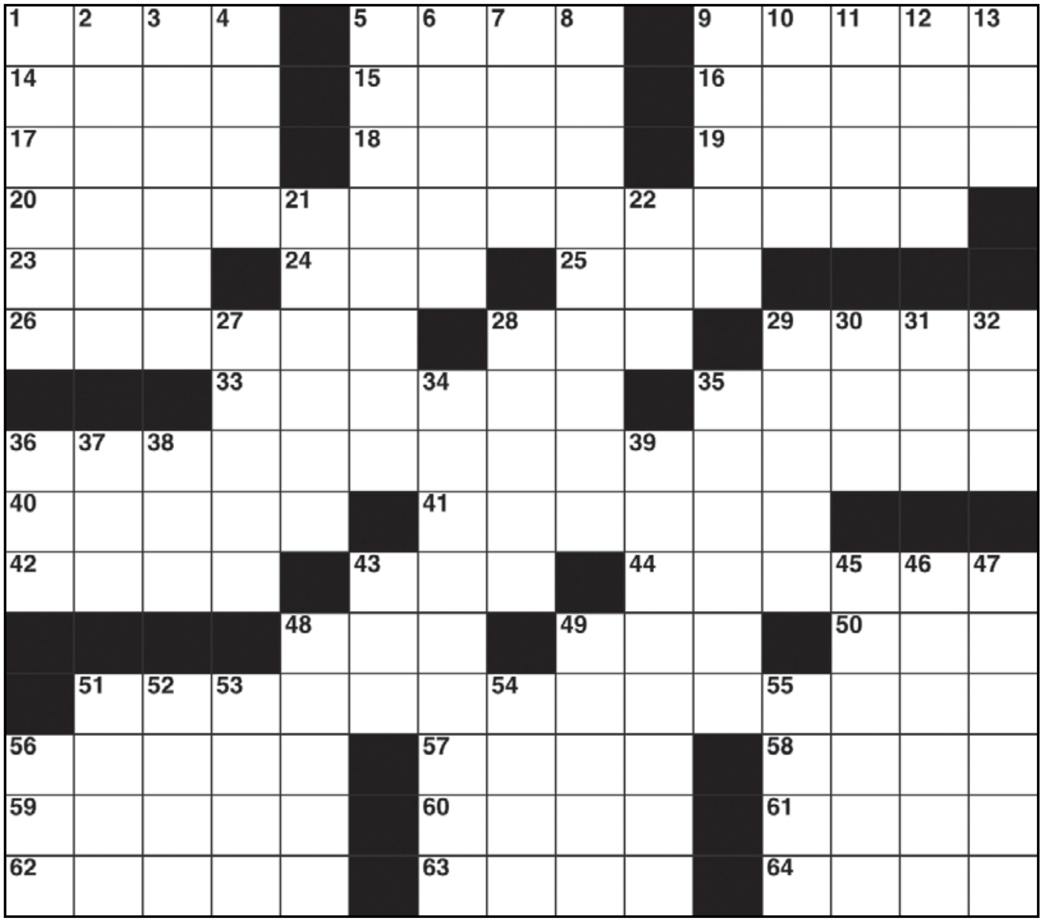
Crossword

Transit of Venus by Naomi Pasachoff

Focal Point will return next month.



ACROSS

1. Seaweed encountered by more than one transit of Venus (ToV) expedition

5. British 1874 ToV scientists attributed "discordant" observations to "the disturbing effect of heat radiated from the illuminating ________"

9. American 1874 ToV scientists noted this feature of a bird called "stinker"

14. ______ __ Day Multivitamin

15. In his 11- year quest to time a transit, Le Gentil was impeded by ___ ______

16. SN 1987A was a blue giant's death ____

17. Month in which astronomers at the Wise Observatory celebrate Purim

18. First Japanese space astrometry satellite mission ______-JASMINE

19. ________ refractor objectives have both advantages and disadvantages

20. Captain Cook determined his longitude at sea using this method

23. Transits of Venus ____ very rare

24. Standard time for New York City December 1882 ToV observations

25. One could say Australians ___ their existence to a ToV

26. Placid

28. Cook's men on the *Endeavour* ____ sauerkraut and citrus fruit to prevent scurvy

29. 2009 tropical storm imaged by NASA's TRMM satellite

33. Telescopes on the ________ Islands photographed the 2004 ToV

35. Northwestern University astronomer Geller

36. ToV optical phenomenon complicating astronomical unit calculation ___ _______ ____

40. Pays de la ______ hosted a meeting of planetary scientists in October 2011

41. Erich Fromm's ____ ____ *of Loving*

42. O'Hara plantation

43. The VLA stands at an elevation of 6,970 ft (2,124 m) above ____ level

44. Tools used by paniolos near W. M. Keck Observatory Headquarters

48. Famous science-fiction play

49. Telescope design center at ROE

50. Harem room

51. First observer of a ToV (var. sp.)

56. High-altitude observatory?

57. How astronomers at Pic du Midi might call for help

58. Currency used at Vatican Observatory

59. Tycho Brahe took great ______ to have his observations be as accurate as his instruments allowed

60. Currency for Piazzi when he discovered Ceres

61. Well, to astronomers at l'Observatoire de Meudon

62. He calculated the Sun's distance from Earth using 1769 ToV data

63. Verb astronomers at Hale Pohaku might associate with ahi

64. *Ifs-buts* bridge

DOWN

1. Marsupials native to area explored by James Cook following 1769 ToV

2. Many astronomers no longer ______ the hardship of cold, dark observatories

3. In the early 20th century, Berlin astronomy ________ toward the use of astronomical data to study Earth

4. Prefix in comet's orbit?

5. Cornwall cape in path of 1999 eclipse

6. After his disappointing ToV experience in 1761, Le Gentil remained abroad to ______ the 1769 ToV

7. Galileo's telescope forever changed ______ understanding of the universe

8. Preliminary model

9. Director of NASA's Jet Propulsion Laboratory, 1991 to 2001

10. Stylish

11. Perry Mason creator ______ Stanley Gardner was also an amateur astronomer

12. Negative votes

13. American Museum of Natural History astronomer Williams

21. Capture again

22. Total solar eclipse feeling

27. Seaport in Ghana in path of 2004 ToV

28. New Zealand spa town Te ______

29. 1994 trilateral trade bloc

30. What asteroid mining might yield

31. Legendary bird of prey

32. Mz3, the ______ Nebula

34. Transportation networks

35. Commune near Reggio Calabria's Planetarium Pythagoras

36. Diagram for comparing young stellar objects, analogous to H-R diagram

37. HAO's Mauna _____ Solar Observatory

38. On Earth, its main constituents are nitrogen and oxygen

39. More like our own planet

43. Jupiter's mass exceeds the ___ of the other planets' masses

45. Go from rack ___ _____

46. The Mayans ________ Venus

47. 606R refractors and 767 AZ reflectors

48. New Mexico State University astronomer who first published proof of the Great Red Spot's internal circulation

49. Now, to scientists at the Roque de los Muchachos Observatory

51. 18th-century ToV observer ______ -Baptiste Chappe d'Auteroche

52. Infrared astronomer Becklin

53. Saturn's icy rings wouldn't make a good ______

54. Girlfriend, to astronomers at the Astronomy Observatory of Marseilles Provence

55. University of Florida X-ray-binary astronomer Bandyopadhyay

56. Mimic

For answers to the puzzle, see page 67.

Scientist biographer ***Naomi Pasachoff*** *takes breaks to construct crosswords. Asteroid 68109 Naomipasachoff orbits in the main belt.*