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THE ESSENTIAL GUIDE TO ASTRONOMY

SKY & TELESCOPE

APRIL 2013

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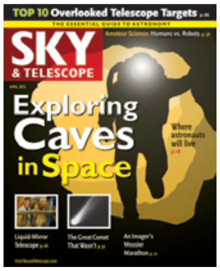

On the cover: Caves will be the safest places for early colonists to live in space's hazardous environments.

S&T: PATRICIA GILLIS-COPPOLA

FEATURES

OBSERVING APRIL

S&T TEST REPORT

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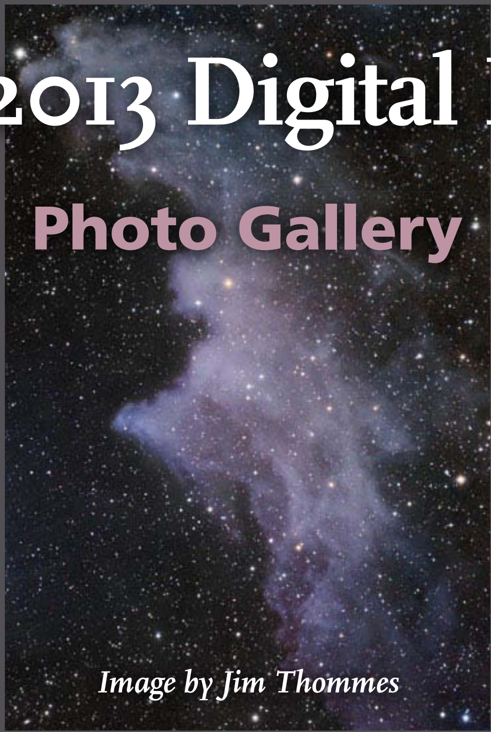

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ONLINE PHOTO GALLERY

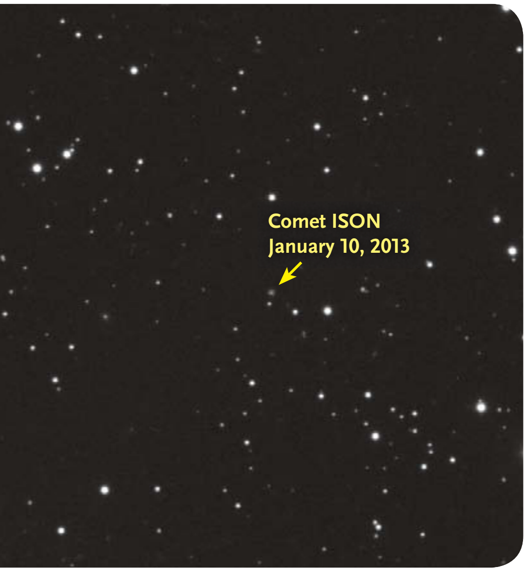
To mark galaxy season, we're featuring Howard Trottier's image of Messier 109, a beautiful barred spiral in Ursa Major. See more images by Trottier and others in our online photo gallery, and submit your own!

Comet of the Century?

EVERY SO OFTEN, my *S&T* editorial colleagues and I hear about the discovery of a potentially great comet. But the operative word here is "potentially." Just because a comet has a large nucleus and a favorable track with respect to the Earth and Sun doesn't mean it will bloom into a showstopper.

Since Comet ISON's (C/2012 S1) discovery in September 2012, many media outlets have been touting it as a "Comet of the Century," or they have used hyperbolic language such as "Super Comet" to give their audiences the impression that ISON will be a sure-fire spectacle in late 2013. With our decades of experience covering such matters, we know better at *S&T*. A number of factors determine how bright a comet will appear in the night sky, and some previously hyped comets turned out to be duds.

The article by Dean Regas on Comet Kohoutek (page 32) describes the quintessential example of an overhyped comet. I still remember from my childhood getting excited about Kohoutek from the intense media coverage it received, and then going out at night to look for it and not seeing anything. I worry the same thing might happen with Comet ISON; if the media cries wolf too often, the public might ignore our exhortations when a future comet is actually putting on a spectacular display.



DEAN SALMAN

As UCLA comet expert David Jewitt explains, "We don't understand all the physics behind the brightness of a comet. Comet ISON could break up. It could run out of supervolatiles before it comes in close. Anything could happen, and Kohoutek is a good example."

I remain cautiously optimistic that Comet ISON will put on a glorious display. We'll continue to monitor it closely at *S&T* and will keep you informed in the magazine and on our website. But we're not going to promise something that nature won't necessarily deliver.

Before closing, I wanted to remind you of our great Kenya eclipse trip coming up this November (**skypub.com/KenyaEclipse**), which will be hosted by senior contributing editor Kelly Beatty. Also, if you're new to astrophotography or want to enhance your processing skills, check out the new webinars from *S&T* imaging editor Sean Walker at **www.skyandtelescope.tv**.

Robert Naeye
Editor in Chief

SKY & TELESCOPE

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

The Essential Guide to Astronomy

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WALTER DALITSCH III

The first man to set foot on the Moon, Neil Armstrong (1930–2012) was a down-to-earth guy. He appears at right, with letter-writer Walter Dalitsch III in May 2012.

Humble Hero

I enjoyed the tribute to Neil Armstrong in the December issue (page 86). I had the fortunate pleasure of meeting him at the 83rd annual scientific meeting of the Aerospace Medical Association last May, where he was the guest speaker at the Society of NASA Flight Surgeons luncheon. He was sharp, engaging, funny, and most impressively, humble. For a guy who took such a giant leap, he still took things one small step at a time. In a culture seemingly obsessed with hero worship, it was so truly refreshing to meet somebody so accomplished who could be so genuine.

Walter Dalitsch III
Chula Vista, California

Observing the Moon's Rilles

A big thank you for Charles Wood's excellent column "Observing History" in the December issue (page 54). Being able to compare the three historical maps and the photo really intrigued me and made me think about how individuals interpret what they observe in our universe. Having spent about an hour examining the maps and re-reading the article, I would greatly enjoy seeing more of this kind of "observing" in the magazine.

Respectfully to Wood, though, I do see the five pits along Rima Hyginus drawn on Mädler's map. They appear as small circles contained within the rille, but are not as prominent as in the other images.

Thank you for a great article!

Kreig McBride
Bellingham, Washington

Wood's question about what size scope can show the Triesnecker rilles is answered in Wilkins and Moore's 1955 classic *The Moon*, where they state that the main members appear in a good 3-inch refractor. Personally, I've seen the "K" pattern in several scopes, including my 3½-inch Questar and 95-mm f/12.6 Lomo Astele Mak-Cass — as long as the grazing illumination is maximized, seeing is very good, and magnification is around 150 to 200×. I've never seen them in my two 2.4-inch refractors.

A more interesting test is Rima Birt, which can narrow to 1 km wide. Some of us in the Lehigh Valley Amateur Astronomical Society dubbed it "the Teardrop Rille" due to its droplike look.

Rodger W. Gordon
Nazareth, Pennsylvania

Write to Letters to the Editor, *Sky & Telescope*, 90 Sherman St., Cambridge, MA 02140-3264, or send e-mail to letters@SkyandTelescope.com. Please limit your comments to 300 words. Published letters may be edited for clarity and brevity. Due to the volume of mail, not all letters can receive personal responses.

Modern Astronomy

Isn't technology absolutely amazing? Bob Fera used a 14-inch scope to image individual stars in M31 (December issue, page 78). A mere 80 years ago, in an attempt to do the same thing, Edwin Hubble spent many long, freezing nights at Mt. Wilson's 100-inch Hooker telescope, succeeding only after months of great persistence and patience. We do live in a wondrous age of astronomy. Let us all be grateful for such amazing times.

Keith B. Hood
San Antonio, Texas

Asterism Not so New?

Regarding the asterism reported by Dan Posey (February issue, page 8), I think this asterism might have been previously noted in the 19th century. I write "might" because my conclusion rests upon an assumption of error in the declination measurement by the original observer, one Reverend T. W. Webb, author of *Celestial Objects for Common Telescopes*.

In the 1881 edition of that work appears the following observation, listed under Aquarius: "Very curious symmetrical group. +XXIII^h 10^m S 5^d 10′." (You can read the book at **http://bit.ly/VBlqPh**; the entry appears on page 226.) The 1962 edition gives 2000.0 coordinates of 23^h 16^m –04° 32′. While that's 3° of declination south of Posey's, there is nothing resembling Webb's group at the 1962 location.

That this object first appeared in the 1881 edition may support the assumption that Webb's and Posey's asterisms are the same. If Webb's observation was made between the previous edition of 1873 (where it does not appear) and the 1881 edition, this quote from *Celestial Objects'* introductory pages has some bearing: "From 1866 to his last observation (1885, March 19) [Webb] used a 9⅓-in silver on glass reflector, by With. This was mounted equatorially on a Berthon stand with rough circles, and in spite of several attempted improvements, the positions obtained with it were never satisfactory."

Interestingly, the double involved, Σ2995, also makes its first appearance in the 1881 edition. However, the listing is from other sources and contains no observational notes by Webb himself, so I assume he never observed it. Too bad: if he had done so, he might have realized the real location of his "symmetrical group" and saved us all a lot of trouble.

Randall M. Poole
Lebanon, Pennsylvania

For the Record

✱ *The gallery photographs of NGC 2070 (January issue, page 76) and the Pipe Nebula (February issue, page 79) credited to Lorenzo Comolli should instead have been attributed to both Comolli and the three imagers who collaborated with him — Giosuè Ghioldi, Luigi Fontana, and Emmanuele Sordini.*

✱ *Sunlight at Uranus is about 1/400th as strong as it is on Earth, not 1/900th (February issue, page 12).*

✱ *Photos credited to the author of February's Telescope Workshop column (page 63) should instead be credited to the author's subject, Albert Highe.*

75, 50 & 25 Years Ago

Roger W. Sinnott

April 1938

Hermes "On October 29th of last year, K. Reinmuth of the Königstuhl Observatory, Heidelberg, Germany, announced by telegraph that on the previous night he had photographed a rapidly moving object of the tenth magnitude in the constellation Pisces. . . . Following the custom for peculiar objects, the discoverer at once gave it the masculine name 'Hermes.' . . .

"Hermes approached the earth more closely than any other known asteroid or comet. The minimum distance, on October 30th at 17^h U.T., was about twice that of the moon. . . . [We] find its diameter to be about three-quarters of a mile."

Hermes was the most dangerous Earth-approaching object then known. What Leland Cunningham failed to note was that it was also lost. Hermes would hurtle unseen among the inner planets for the next 66 years, until Brian Skiff of Lowell Observatory found it again in October 2003 (S&T: January 2004, page 28).

April 1963

Venus Is Hot "Astronomical historians will record that man's first closeup reconnaissance of another planet was made by the Mariner 2 spacecraft on December 14, 1962. . . . The trajectory was planned so that Mariner would pass Venus on the sunlit side. . . .

[We find] a surface temperature of approximately 700° K. . . [which] leads to a concept of Venus' surface as being extremely hot, dry, and hostile to terrestrial forms of life."

Mariner 2's radiometer scans ruled out another hypothesis then current — that Venus's upper atmosphere, and not its surface, had made the planet appear so hellishly hot in earlier observations from Earth.

April 1988

What, No Moons? "Searching for asteroid satellites photoelectrically proves even more difficult than monitoring occultations. However, there is evidence that the light curves of some minor planets have dips, sudden losses of brightness, and short term variations. . . .

"Instead of waiting until the Hubble Space Telescope reaches orbit, astronomers should announce an international campaign for obtaining ground-based observations of certain asteroids that might lead to proof that some minor planets have satellites."

In the face of wide professional skepticism that asteroids could have satellites, amateur astronomers such as Frank J. Melillo (here) and Jim Stamm wrote letters to the editor urging coordinated backyard searches. Their dogged efforts paid off. Today, roughly 100 asteroids are known to possess moons of their own (December issue, page 28).

ASTEROIDS | Easy Miss by Apophis in 2036

On Friday the 13th in April 2029, the 1,000-foot-wide asteroid Apophis will pass close enough to Earth (within 20,000 miles) to appear as a 3rd-magnitude star crossing the night sky.

After precisely tracking the asteroid 99942 Apophis with radar during its January flyby, astronomers are now certain that it won't strike Earth in 2036.

When astronomers discovered the asteroid in 2004, the first orbit computation suggested that it had a 3% chance of hitting our planet in April 2029. A revised orbit including pre-discovery images quickly ruled out an impact in 2029 but left a question mark for 2036.

The chance of that later collision hinged on the 2029 flyby, when Apophis will zip just 20,000 miles (32,000 km) from Earth. Were it to pass through the correct spot in space — a window just 600 meters wide — an impact would become very likely in 2036. The chance that it would thread the unlucky "keyhole" was tiny but couldn't be ruled out.

Adding to the uncertainty was the Yarkovsky effect, a subtle radiation-pressure force caused by the uneven way that a spinning body absorbs sunlight and re-radiates the heat back into space. Ground-based observers determined that Apophis rotates in 30½ hours, but it likely tumbles around multiple spin axes with more than one period. The asteroid's shape and spin configuration are unknown — and could remain so until 2029.

Gentle but persistent nudging from the Yarkovsky effect might have pushed Apophis through the 2029 keyhole. But there's no longer a chance of that. During its flyby on January 9th, Apophis passed within 9 million miles of Earth (37 times the Earth-Moon distance), giving astronomers a chance to study it for several weeks. Radar observations by NASA's 70-meter (230-foot) Goldstone dish in California have ruled out the potential 2036 Earth impact, says dynamicist Jon Giorgini (NASA/Jet Propulsion Laboratory). Based on revised orbit calculations, he says Apophis will come no closer than about 14 million miles that year, and more likely will miss us by about 35 million miles. The next closest call comes in 2068, with an impact probability of 0.0005%.

Were Apophis to hit Earth, it would strike with the energy of roughly 500 megatons of TNT, ten times more than the largest hydrogen bomb ever tested.

■ **J. KELLY BEATTY**

SCOPES | Fire Damages Australian Observatory

On January 13th an intense, fast-moving bushfire swept through portions of Australia's Siding Spring Observatory, home to 13 professional optical telescopes, a 22-meter radio dish, and a just-completed complex of amateur robotic telescopes owned by iTelescope.net.

As flames engulfed portions of the observatory compound, evacuated staff monitored webcams and computer systems on the mountain to see which facilities were in jeopardy. All of the telescopes escaped major harm, but several support facilities and staff houses were destroyed or badly damaged, including the home of comet hunter Robert McNaught. After the flames passed, officials at Australian National University, which runs the facility, closed it for several weeks to determine the extent of damage due to heat and smoke from the fires.

The observatory is located in Warrumbungle National Park, just outside the small town of Coonabarabran in New South Wales. More than a decade of unusually hot weather has turned parts of Australia tinder-dry, and at one point firefighters were battling 170 separate blazes — 50 of them uncontained — in that state alone.

The bushfire at Siding Spring came almost exactly 10 years after a similar blaze destroyed Mount Stromlo Observatory just outside the capital city of Canberra (*S&T:* April 2003, page 18). In the past decade, wildfires have also threatened Steward, Palomar, Mount Wilson, and McDonald observatories in the U.S., with Mount Wilson in California coming closest to destruction in 2009.

Australian National University has set up a relief fund for the observatory's staff: **http://is.gd/59JoUs**.

■ **J. KELLY BEATTY**

IN BRIEF

Using infrared observations by NASA's Spitzer Space Telescope and ESA's Herschel Space Observatory, Kate Su (University of Arizona) and her colleagues have detected hints of an asteroid-like debris belt around Vega. The belt is separated by a gap from the star's outer, colder disk (previously discovered), much like the setup around Fomalhaut and the Sun. Multiple, low-mass planets might be responsible for carving Vega's gap, the team says. Astronomers have imaged a planet candidate sculpting Fomalhaut's outer disk, but observations have not yet revealed a planet around Vega.
■ CAMILLE M. CARLISLE

The Wilkinson Microwave Anisotropy Probe (WMAP) team has released its final results from WMAP's epochal 9-year mapping of the microwave background radiation. There are no cosmic surprises in this latest release, but it refines the precision of many basic parameters. Among them: the universe is 13.77 billion years old, with an uncertainty of only about a half percent. Ordinary matter makes up 4.6% of everything in the cosmos, nonbaryonic dark matter 24%, and dark energy 71.4%. The new data also confirm that density fluctuations in the early universe show a very slight "tilt" in their size distribution. This tilt matches predictions by the simplest versions of inflation.
■ CAMILLE M. CARLISLE

Observations by the NASA/Caltech GALEX mission (*S&T*: April 2012, page 20) reveal that the spiral galaxy NGC 6872 in Pavo is about 522,000 light-years wide, more than five times the diameter of our Milky Way. Astronomers knew the spiral was big, but Rafael Eufrasio (NASA/Goddard and Catholic University of America) and his colleagues found that its arms extend farther than they thought. NGC 6872 does have an unfair advantage: a past collision with IC 4970 stretched it.
■ J. KELLY BEATTY

EXOPLANETS | Kepler Closes in on Alien Earths

NASA's Kepler mission scientists have announced 461 new planet candidates transiting stars. Four of these orbit within habitable zones, the region where liquid water could exist on the surface of a rocky, atmosphere-enshrouded world, team members reported January 7th at the American Astronomical Society meeting in Long Beach, California.

This tally might seem like a letdown given the 2,321 Kepler candidates that were already on the books. However, most of the newest planet candidates are less than twice the diameter of Earth, and small planets are proving to be more abundant than big ones. Of the four in "Goldilocks orbits," one — KOI 172.02 — is 1.5 times Earth's diameter and orbits around its star every 242 days. Given reasonable assumptions, the planet (if confirmed) would have a balmy average temperature of about 46°F (8°C).

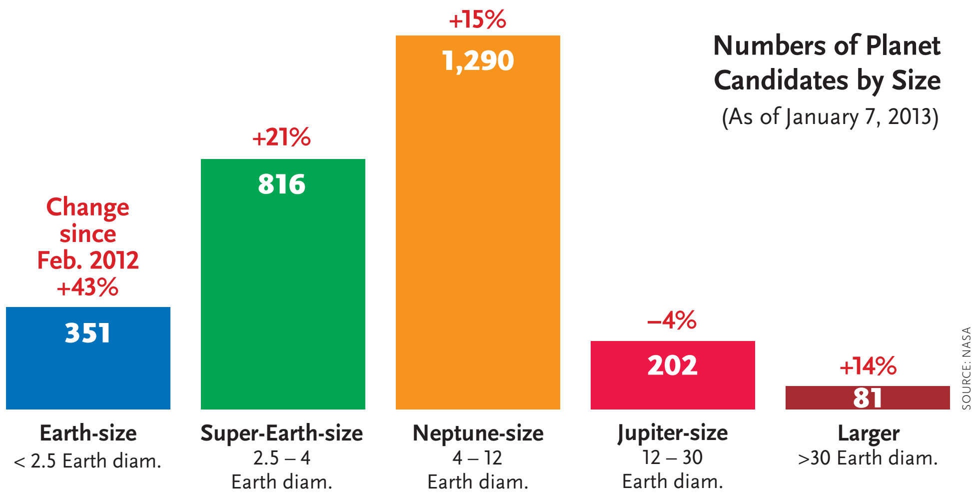
Kepler is now finding fewer giant exoplanets. The graph below shows the updates to its candidate catalog, including the loss of a few in the Jupiter-size class. That drop happened because Kepler's astronomers have become better at weeding out false signals.

The newest release also shows an increase in complex alien systems: the spacecraft added 102 new multi-planet stars to its previous list of 365, including a trio of five-planet systems.

"That makes me smile," says Natalie Batalha (NASA/Ames Research Center). "Just a couple years ago Kepler didn't have any multiple systems, and now we have hundreds."

Kepler's full roster of candidates now stands at 2,740 planets orbiting 2,036 stars. Follow-up confirmations by other instruments haven't kept pace with the rapid-fire transit discoveries: so far only 105 Kepler candidates stand confirmed as bona fide planets. The expectation for false positives among the candidates is between 10% and 20%, says Christopher Burke (SETI Institute). But the rate of impostors also depends on the purported planet's size and orbit, and giant planets close to their stars are less likely to be real than small planets moving in large, slow orbits.

François Fressin (Harvard-Smithsonian Center for Astrophysics) also reported the results of his team's analysis of how many stars have Earth-size planets. Based on Kepler data, the astronomers estimate that one-sixth of all stars have an Earth in an orbit smaller than Mercury's. They also find that, except for gas giants, planets aren't picky about their parent star: they're equally common around all stellar types. The gas giants prefer solar-mass stars, but that might be an observational bias.
■ MONICA YOUNG



This diagram shows the distribution of planet candidates discovered in Kepler data as of January 2013 (using NASA's categories of planet sizes). Percentages indicate changes from the catalog as of February 2012. The Kepler census has increased by 20% and now totals 2,740 potential planets.

METEORITES | Another Sutter's Mill Gold Mine

Samples of the Sutter's Mill meteorite, found quickly after being dropped by a brilliant daylight fireball over Nevada and California on April 22, 2012, contain primitive, carbon-rich matter like none ever studied before.

The fireball peaked at magnitude –18 to –20, halfway in brightness between the full Moon and the Sun, moving east to west at 7:51 a.m. It was widely seen by astonished onlookers — and by two cameras. These records, combined with echoes in weather-radar scans, suggested that pieces of the object fell near the towns of Coloma and Lotus in California.

Reconstructions estimate the object was the size of a small car (2½ to 4 meters across) and weighed perhaps 40 tons before it slammed into the atmosphere and broke up. Meteorite hunter Peter Jenniskens (SETI Institute) quickly arrived on the scene to look for freshly fallen meteorites and eventually he found a 4-gram bit in a parking lot. Other searchers also found fragments from what's now known as the Sutter's Mill (SM) fall, named for the local landmark that triggered the California gold rush that began in 1848.

So far collectors have located nearly 80 pieces, totaling 943 grams (just over 2 pounds). These are dark and crumbly, pegging the meteorite as a primitive, C-class chondrite virtually unaltered since its formation 4½ billion years ago. Geochemists studying the samples found abundant bits of the mineral oldhamite (calcium sulfide), so touchy that it decomposes after the slightest exposure to water vapor.


NASA / PETER JENNISKENS

Happy hunter Peter Jenniskens readies a piece of aluminum foil to pick up a crushed sample of the Sutter's Mill meteorite. This one had been run over by a car in a parking lot.

As Jenniskens and 69 coauthors report in the December 21st *Science*, the SM stones are a *breccia*, a mash-up of formerly loose bits. The bits show varying degrees of exposure to heat and moisture, indicating that they came from a mix of earlier parent bodies. In addition, the object's surface is more complex than other C-class asteroid fragments. Some pieces experienced temperatures of up to 400°F (200°C), unlikely to be the result of the brief flash-heating they experienced in Earth's atmosphere. Others contain clay and carbonate minerals from contact with water in space, and traces of organic compounds.

The team pieced together eyewitness reports, photographs, and radar signatures to deduce the incoming object's prior orbit: it came from the asteroid belt, most likely injected directly onto an Earth-crossing path by tugs from Jupiter. It was exposed to space radiation for less than 100,000 years, implying that it came from inside a larger body that broke up. It slammed into our atmosphere at 17.8 miles (28.6 km) per second, releasing the energy of 4,000 tons of TNT along its path before breaking apart roughly 34 miles up.

■ **J. KELLY BEATTY**

IN BRIEF

Two researchers argue in the December 12th *Earth and Planetary Science Letters* that the solar system's birth was not catalyzed by a supernova, as previous studies suggested. Haolan Tang and Nicolas Dauphas (University of Chicago) analyzed several types of meteorites to estimate how much iron-60 was in the material that formed the solar system. Their results suggest that iron-60 was less than one-tenth as abundant as found by previous work. The new value is consistent with contamination only by winds from aging massive stars, rather than a supernova. Such contamination is the standard explanation for the origin of another short-lived early-solar-system isotope, aluminum-26.

■ **CAMILLE M. CARLISLE**

Contrary to expectations, ethane-methane ice could actually float on the liquefied-natural-gas seas of Saturn's moon Titan. Astronomers had thought that such ice would sink, because it would be denser than its liquid form. But new calculations by Jason Hofgartner and Jonathan Lunine (Cornell University) indicate that if the ice includes small bubbles of atmosphere — like those incorporated into new sea ice on Earth — it could float in conditions like those on Titan's surface, the researchers report in *Icarus*. Like Earth, Titan appears to have long-term climate variations over tens to hundreds of thousands of years. If the ice floats, it would limit methane's evaporation into the atmosphere, reducing the greenhouse effect. That in turn might help push the moon into an ice age.

■ **CAMILLE M. CARLISLE**

The Pan-Andromeda Archaeological Survey (PANDAS) has revealed that roughly half of the many little satellite galaxies of the Andromeda Galaxy (M31) orbit it in the same thin plane and in the same direction, Rodrigo Ibata (Astronomical Observatory of Strasbourg, France) and his colleagues report in the January 3rd *Nature*. The plane is tilted from the Andromeda Galaxy's own plane, but is intriguingly the same as the Milky Way's. Astronomers have seen hints of satellite planes before around both Andromeda and the Milky Way, but PANDAS's distance measurements allowed the team to construct a precise 3-D map. It's unknown why such a plane exists, but suggestions include an en masse accretion of dwarfs or a past interaction between Andromeda and the Milky Way. ✦

■ **CAMILLE M. CARLISLE**

One Galactic Year from Now

Will the Anthropocene be an event, an era, or a transition?

ANY ALIEN WATCHING our planet over the eons could see that Earth is going through a series of new and dramatic changes. This was already evident 75 years ago when Russian geochemist Vladimir Vernadsky wrote, "The rise of the central nervous system has increased the geological role of living matter."

Recently, recognizing that humans have become a major geologic force and that the rocks left from our time will bear many unique stamps, some geologists have proposed the term "Anthropocene" as an official title for our layer in the stratigraphic column. This begs us to imagine these rocks being dug up and studied someday — but when and by whom?

What will be the significance of the Anthropocene rock layer and the ultimate legacy of the human race when, in 230 million years, our star, having completed another galactic year, returns to this quadrant? Will we simply leave a thin layer rich in refined metal and Twinkie wrappers, preceding an era bereft of coral reefs? Or will we leave more lasting changes on this world?

BIGSTOCKPHOTO: JAN HANUS

Will the Anthropocene be an "era" or an "event?" The end of the Cretaceous period was an *event* caused by a disruptive asteroid impact that left a centimeter-thick clay layer around the globe. What immediately followed was an *era*, the Paleocene, which lasted 10 million years and finally ended with an extreme period of global warming.

Is it audacious to think that the changes we bring might be anything more than an event on this world? After all, species come and go, why should we be any different? Notwithstanding the great longevity of certain types of animals such as sharks, this ignores the central observation of the Anthropocene — that human civilization has brought new forces to bear in the dynamics of Earth and of evolution itself.

The past is no longer the key to the present because the game has changed, but not necessarily in our favor. We need to find a way to power our growing civilization without wrecking our environment, but this is merely the first in a string of challenges brought by an expanding human population and the increasing reach of our technology on a finite planet. And yet, we can also see the beginnings of capacities that may facilitate survival in ways never before possible. We are, for example, close to being able to construct effective defenses against future asteroid strikes. And on its own, Earth's climate will someday go through dangerous palpitations, but by then we may know enough to do something about it.

Event or era? There is actually a third possibility: A *transition*. The origin of life, the Great Oxygenation Event 2.4 billion years ago, and the Cambrian explosion are examples of transitions that left Earth dramatically transformed forever after. The Anthropocene could mark a transition of similar importance. If we make it past the next few centuries, it will be because we've honed our survival skills to make them work on a planetary scale. One galactic year from now, the legacy of our civilization will either be a strange layer in the strata, or the early stages of something lasting and wondrous. ✦

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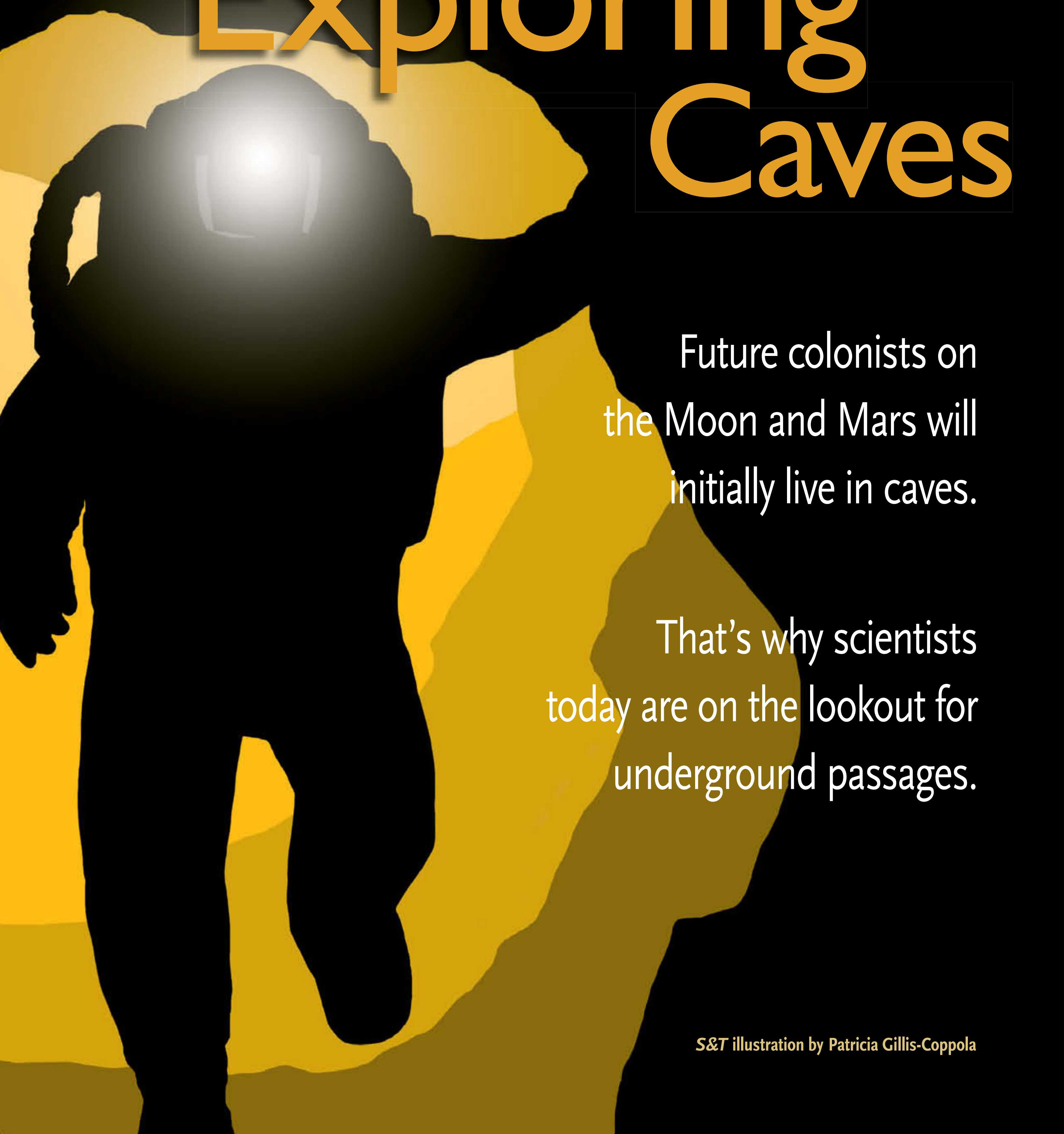
Exploring Caves



Future colonists on the Moon and Mars will initially live in caves.

That's why scientists today are on the lookout for underground passages.

S&T illustration by Patricia Gillis-Coppola

NIKKI FOX

Robert Zimmerman

CAVE EXPLORER Author Robert Zimmerman sketches a newly discovered passage during a spring 2010 mapping trip to a cave in West Virginia. He is standing in a place no human had previously seen.

on Other Worlds

AFTER A DECADE OF SURVEYING and exploring a cave in West Virginia, I had almost finished drawing the map. But surprisingly, my fellow cavers and I found a previously unnoticed crawlway. It was wide and flat, but its height was so low I could barely squeeze my head into it. But the passage ahead seemed to widen, and that possibility drove us onward. We began to dig, scraping out mud so that we could belly-crawl past the tight spot.

After about an hour of digging, fellow caver Rick Royer squeezed his body through, and the passage opened up. We spent six hours joyously mapping and exploring about 300 feet (90 meters) of virgin passage, including a small dome with beautiful stalagmites and stalactites.

What does this brief tale of cave exploration have to do with outer space? Everything. Early colonists on the Moon and Mars will face an extremely harsh environment without much spare equipment. They won't have a breathable atmosphere. The climate will be alternately far too cold or too hot. Deadly radiation will incessantly rain down upon them. To quickly build a permanent colony, the first settlers will have to go underground. They will have to become cave dwellers, like our prehistoric ancestors. "There are a lot of advantages to caves as human habitats," says lunar scientist Paul Spudis (Lunar and Planetary Institute). "They are very protective environments and will be relatively easy to adapt and use."

In our preliminary exploration of the solar system, it's crucial to find out where the caves are and figure out how to get inside them as easily as possible. Scientists studying images from the Moon and Mars have been looking for caves, and have found some intriguing possibilities.

Finding Caves on Mars

When I want to find a virgin cave here on Earth, I take out a geologic map, locate the nearest limestone where caves are likely to form, trace the streams and drainages, and then walk the land looking for places where that water either appears or disappears underground. Because water

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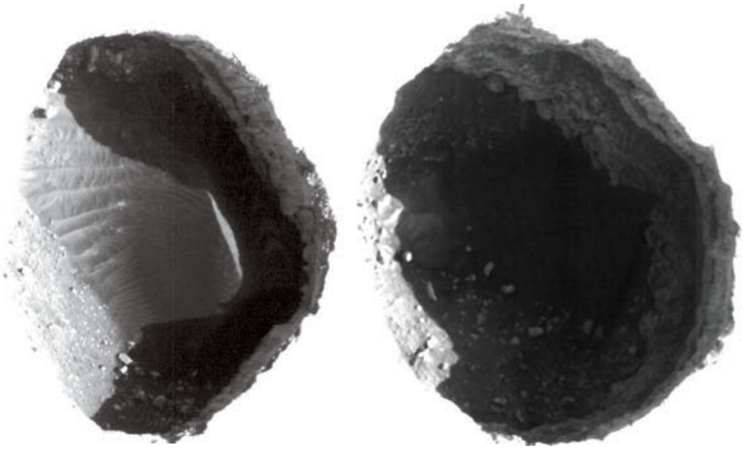
USGS / HAWAIIAN VOLCANO OBSERVATORY

GATEWAY TO HELL ***Top:*** **The Thurston Lava Tube in Hawaii Volcanoes National Park, Hawaii, is a terrestrial version of similar (but often larger) structures found on the Moon and Mars. In this particular tube, the lava has drained away.** ***Above:*** **When the roof of a lava tube collapses, it produces an opening to the outside world known as a skylight. This small skylight provides a view into an active lava tube in Hawaii Volcanoes National Park.**



MARTIAN CAVES ***Right:*** **MRO's HiRISE camera captured these two rimless pits northwest of Ascraeus Mons, a giant volcano on the Tharsis Bulge.** ***Far left and near left:*** **The contrast in these close-up HiRISE images has been enhanced to reveal details of the two pits. They are 590 feet and 1,000 feet wide, respectively, and have steep eastern walls with ledges that overhang their floors.**

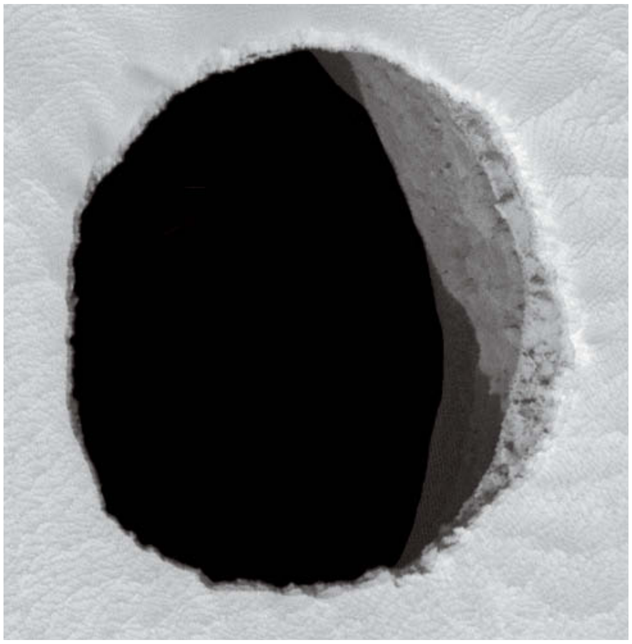
NASA / JPL-CALTECH / UNIVERSITY OF ARIZONA (3)

dissolves limestone to form caves, if you can find where that water flows, you can find caves.

But neither the Moon nor Mars have flowing water. Second, neither world has any known limestone, because this sedimentary bedrock formed on the seafloor from the slow pile-up of the skeletal remains of dead sea creatures. Instead, planetary scientists search for caves on other worlds by focusing on areas with past volcanic activity, because the flow of lava can also form cave passages.

On Mars, images from NASA's Mars Reconnaissance Orbiter (MRO) and other craft have revealed the first possible cave entrances, located north of Arsia Mons, a giant volcano on the Tharsis Bulge. Almost all of Mars's nearly 100 potential caves have since been found in this region.

CANDIDATE CAVE ***Below:*** **This HiRISE image reveals a 540-foot-wide atypical pit crater, a possible cave entrance on the dusty lava plain northeast of the giant Tharsis volcano Arsia Mons. Most Martian candidate caves have been found in this region. This pit is so deep (at least 800 feet) and has such a large overhang that cameras have yet to see the floor illuminated by direct sunlight.** ***Right:*** **MRO's Context Camera captured this 29-mile-long lava tube that emerges from the northwestern flank of Arsia Mons. The tube's roof collapsed in many locations, producing multiple skylights. The actual lava tube is underground, and could be considerably longer that what we can actually see.**



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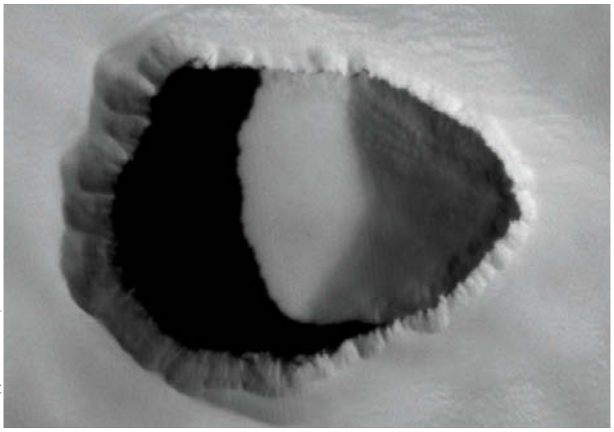

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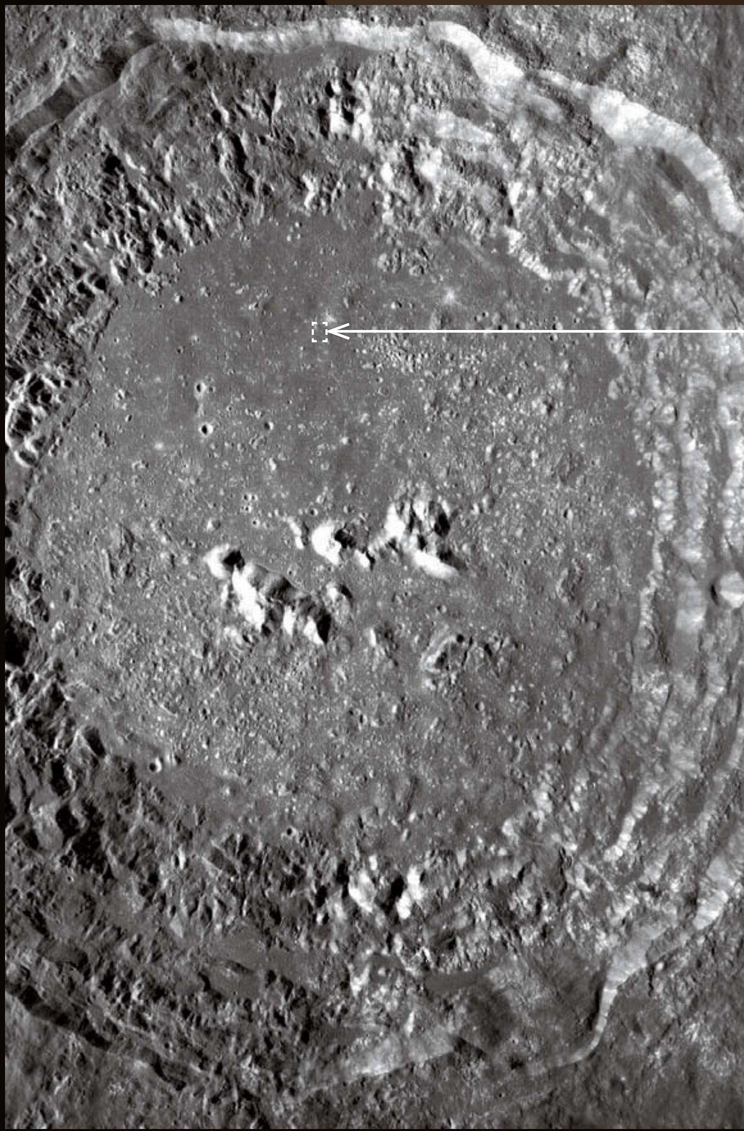
MARTIAN SKYLIGHT ***Above:*** **This 165-foot Martian skylight probably formed when the Tharsis Bulge began to rise, producing cracks in the crust that were later filled with lava. The lava eventually drained away, possibly leaving a cave behind.**

Geologists have sorted these Martian caves into three types. The first kind is similar to lava tubes on Earth, near-surface tunnels running down the flanks of volcanoes with occasional skylights or pits that provide access. A lava tube forms when the top and sides of a lava flow solidify. The lava continues to flow inside a tube, eventually draining out and leaving behind a long, sinuous cavern. Because the crust is often structurally weak, sections of the tube eventually collapse, producing entrances. Being near the surface, this type of lava tube can often be identified as a depression. When presented as a string of pits along its length, a lava tube can be relatively easy to spot.

Scientists have so far identified eight different features resembling lava tubes in the Arsia Mons area alone, ranging in length from 6 to 60 miles (10 to 100 km), each having from one to dozens of skylight openings. These entrances are generally less than 20 feet (6 meters) across with depths ranging from 30 to 100 feet.

The second type of cave in this area is also volcanic, but is more complex than a lava tube. Here, the tubes are associated with fractures or cracks. These caves probably formed when the Tharsis Bulge began to rise, causing the crust to crack. As lava flowed up into these cracks, the tops crusted over. When the molten lava drained away in various places, it left behind caves, just like lava tubes. Unlike lava tubes, however, these caves are not sinuous; they follow the fracture lines. These caves may extend downward as much as three miles.

Members of the third type, dubbed "atypical pit craters," are generally larger and deeper than the common lava tube pit entrance, sometimes with diameters as wide as 1,000 feet. They also have very steep vertical walls, sometimes with significant overhangs that suggest lateral passages of unknown extent. These atypical pits are circular and resemble impact craters at first glance, but they were not formed by impact. Though geologists



COPERNICUS CAVE
Above: **NASA's Lunar Reconnaissance Orbiter (LRO) captured this wide-angle view of Copernicus Crater.** ***Left:*** **A zoom-in view reveals what appears to be a 200-foot-long natural ramp leading directly into a small pit that might be a cave entrance. It might be relatively easy for future robotic or human explorers to enter this cave. The arrow in the top photo marks the pit's location in Copernicus.**

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ESA / VITTORIO CROBU

BRIAN MASNEY

CAVENAUTS ***Top:*** **To prepare for future space exploration, an international team of six astronauts spent six days in September 2012 living in the Sa Grutta caves on Sardinia. This image shows four of the "cavenauts" entering the cave.** ***Above:*** **A shaft of sunlight enters a cave in West Virginia.**

have not yet determined the actual formation process, they theorize that these structures originated by a process somewhat similar to the caves formed in fractures, but in a more localized manner that produced large, isolated pits.

Unknowns remain with all three Martian cave types. Many appear to have overhangs with cave passages disappearing just out of sight. Without better imagery, much of it possible only on the surface, there's no way to measure the lengths of these potential cave passages. We might be looking at a mere alcove that goes nowhere, or the start of a cave that extends for miles. Many possible smaller openings are too poorly resolved for positive identification.

Lunar Caves

Similar caves have been found on the Moon. In the 1960s, planetary scientists proposed that lunar rilles (long, very narrow valleys) were formed not by water but by lava flows, making them comparable to lava tubes on Earth though possibly much larger due to the Moon's weaker gravity. This realization meant that the Moon might harbor underground chambers that were miles long with rooms as wide as 1,500 feet. Calculations suggested that the roofs of some of the large chambers could be 100 to 200 feet thick, making them stable and capable of providing ample protection from harsh space radiation.

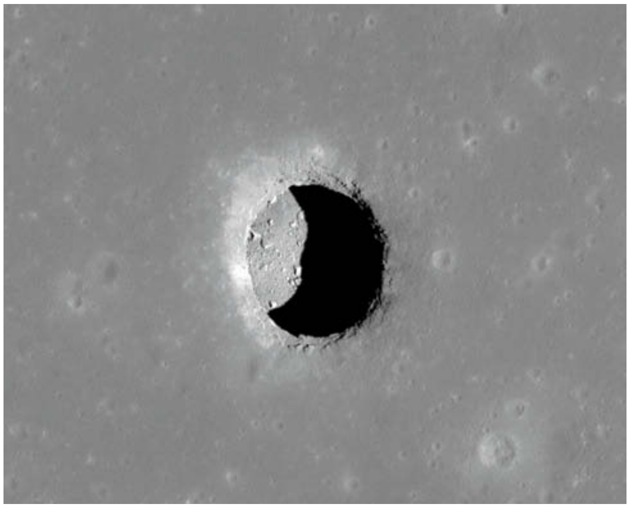
When the first unmanned orbiters imaged the Moon decades ago, scientists found a plethora of potential lava tubes. Though the majority were scattered in Oceanus Procellarum, located on the westernmost edge of the Moon's nearside, searches turned up many possibilities in other spots. Unfortunately, the cameras on these early probes produced insufficient image resolution for scientists to determine if these tubes had significant underground passages.

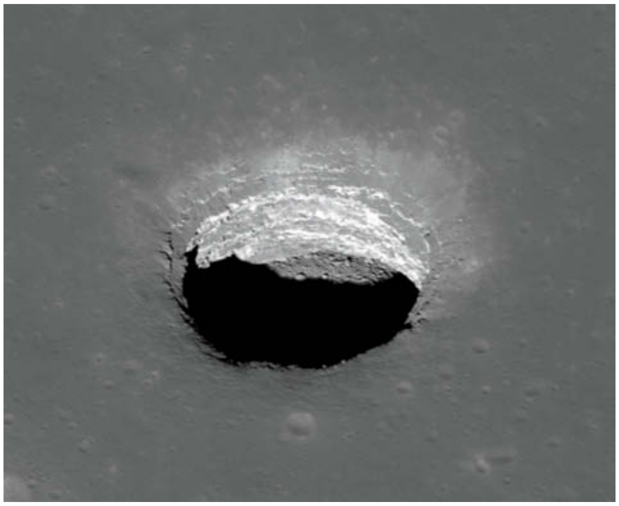
In the past decade, lunar orbiters from Japan, China, India, and NASA, with far superior cameras, have resolved numerous features that may indicate caves. Similar to Mars, some have been associated with lava tubes, others with fractures, and some with no additional related surface features.

Two nearside pits, one in the Marius Hills area of Oceanus Procellarum and the other in Mare Tranquillitatis, have attracted the most interest because they have floor space beneath overhanging ceilings, says James Ashley (Arizona State University). Their walls also show dramatic layering, possibly indicating multiple lava flows.

The Japanese Kaguya orbiter revealed the Marius Hills pit. It's estimated to be about 200 feet wide and about 270 feet deep, with a substantial roof of several layers from 130 to 200 feet thick. The Tranquillitatis pit is larger. Also circular with a roof showing many layers of lava flow, the pit is estimated to be approximately 300 feet across and more than 300 feet deep.

These two pits are just a small sampling of the most interesting lunar cave entrances found so far. For example,





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LAYERED PIT **These images from LROC capture a 300-foot-wide, 330-foot-deep pit in Mare Tranquillitatis as seen from different angles. The highly oblique view *(right)* reveals multiple layers, indicating many different lava flows.**

India's Chandrayaan-1 probe resolved a 1-mile-long lava tube with an interior cross-section thought to be from 500 to 1,200 feet across. NASA's Lunar Reconnaissance Orbiter Camera (LROC) has imaged approximately a dozen pits that might have caves at their bottom. In fact, LROC data alone have been so copious that scientists haven't been able to review it all. The mission's science team set up a website (**http://target.lroc.asu.edu/da/qmap.html**) so that anyone can study the high-resolution pictures.

NASA engineer James Fincannon and I have done this, focusing our search for caves on the northern half of Copernicus Crater. On one weekend alone, I located six pits and fissures that have not yet been documented in the scientific literature (**http://behindtheblack.com/behind-the-black/essays-and-commentaries/exploring-the-floor-of-copernicus**). These features, though formed by volcanic processes, are not strictly lava tubes. Ashley and his colleagues have suggested one possible formation process: immediately after the impact that formed Copernicus, its floor was molten, like a lava lake. As this impact melt cooled and contracted, its crusted-over surface developed cracks and voids. Such systems might have extensive underground environments, maybe even networked systems of tubes suitable for habitation.

Getting Underground

I found one Copernicus skylight that was particularly interesting because it appears that a rover might be able to drive down a slope into the cave. In fact, accessibility is a key factor in determining whether a cave will be useful as a future lunar base. It's ironic that after traveling almost a quarter of a million miles from Earth, the task of traversing a measly 200 to 300 vertical feet into a lunar cave pit is actually a significant engineering challenge.

Flying a manned spacecraft down through a cave opening using rockets is far more difficult than Hollywood makes it appear. Nor can we use parachutes or helicopters because the Moon and Mars lack a thick atmosphere. Although the gravity on these worlds is far lower than Earth's, an astronaut couldn't jump in because a 300-foot fall would be fatal.

On Earth, the art of descending 300 feet into a pit has become quite sophisticated and almost routine. When I want to explore the bottom of a deep pit, I rig a rope, don my harness and vertical gear, and rappel in. When it's time to leave, my ascending equipment makes climbing a 300-foot rope simple, fun, and actually quite safe.

But these techniques won't work so easily on the Moon or Mars. For example, using cave rope-climbing equipment requires delicate fingertip control. A space-suited astronaut wearing thick, unwieldy gloves will find such tasks difficult. Moreover, simply donning the harness will be a challenge.

Perhaps a climbing system could be incorporated directly into the spacesuit, thereby eliminating the need for a harness and separate gear. But a better solution is to find entrances that don't require a vertical descent and instead have some form of natural access ramp. As mentioned above, at least one such entryway appears to exist on the Moon. Scientists have found a handful on Mars, apparently created by wind-blown sand grains that have partially filled the entrances and created slopes that a vehicle could drive down. As Glen Cushing (U.S. Geological Survey, Flagstaff) notes, "It looks like you could just cruise right into it."

The problem, which cannot be underestimated, is the roughness of the terrain. The ramp visible in the lunar example is not smooth, and would give the best four-wheel-drive vehicle some difficulties. Making access easy might require bulldozing equipment to grade a road.

The Martian examples seem more drivable, but the stability of the thick dust that provides these slopes remains unknown. The grains might have congealed into dunes as hard as rock or they might still be as shaky as Jell-O.

Because of these difficulties, the first interplanetary cavers will likely be robotic rovers. Engineers at Carnegie Mellon University in Pittsburgh have proposed a combined lander/rover mission to image the Marius Hills pit in detail. As the mothership descends it would fly over the pit, take radar data and images with a resolution as sharp as 4 inches per pixel, then land within several hundred feet of the pit edge, where the rover would then circle the pit and study its features. If the engineers revised this proposal and the rover instead touched down near a cave with a ramp, they would then have the option of directing the vehicle to work its way down into the cave.

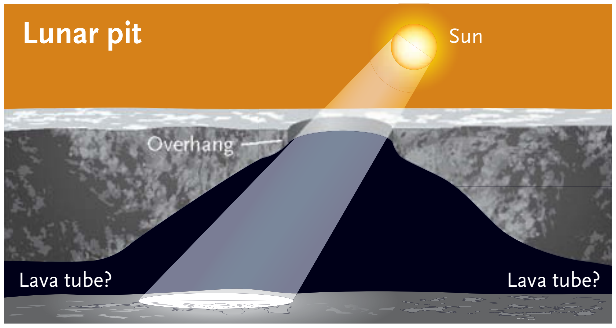
Building the First Space Colonies

If humans colonize the Moon and Mars, caves will likely be the first place they live. The thick, ready-made roofs will shield them from harsh radiation. The caves will also provide a more benign thermal environment, so humans can avoid, for example, the lunar surface's 450°F (250°C) temperature swings. Like terrestrial caves, lunar and Martian caves will stay nearly the same temperature year round. Caves will also provide a structure within which settlers will find it easy to build and expand colonies. "It would be far more difficult to build and transport shelters than to work with the available terrain," says Cushing.

On the Moon, the biggest drawback for using caves as habitats is location. "They're often in places you don't necessarily want to be," explains Spudis. Most have been found in the low latitudes and on the maria. The poles, today's favored lunar real estate because of the possibility of water, don't appear to have any caves. And if none are found, the establishment of permanent lunar bases will be much harder. Either the bases will not be in caves and thus difficult to build, or they'll be underground but far from potential sources of water.

The situation on Mars is far more exciting. The Tharsis Bulge, where most of the caves have so far been found, probably contains a lot of buried ice. The geology suggests that ice glaciers once flowed down the northwestern slopes of Arsia Mons, not far from where many lava-tube openings have been found. Computer models suggest that this region's climate would allow water ice deposited in these caves to remain stable for hundreds of thousands of years. If water once flowed into these caves, there's a good chance it's still there.

If Martian colonies are ever built, they'll probably be on the flanks of the giant volcanoes. Early Martian colonists will likely end up being cavers like myself, exploring the small cracks underground to find places unseen by humans. But their purpose will be far different than mine. Besides going where no one has gone before, they'll also be looking for water and a place to live. To them, caving will not be a recreational activity, but an essential task making possible the construction of their homes. ✦

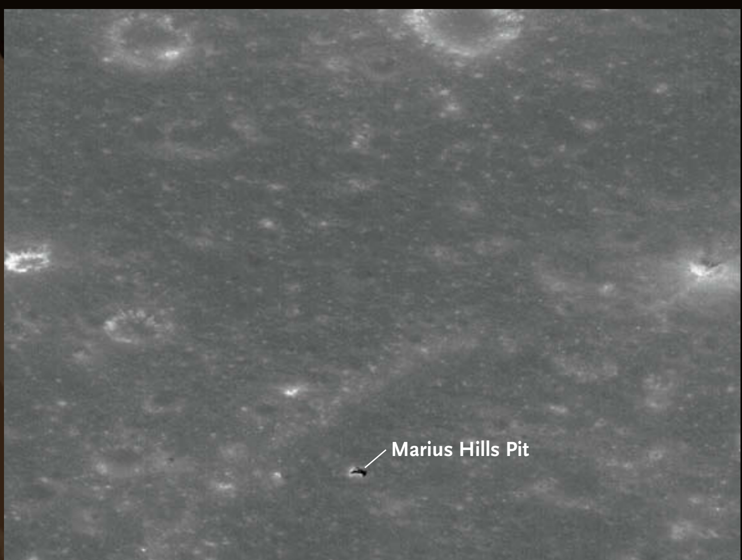


S&T: LEAH TISCIONE

MORE THAN MEETS THE EYE? Deep lunar pits could be just the visible surface manifestation of extended underground passages. Geologists currently lack the information they need to determine the extent of lunar caves.

To view more images of caves on the Moon and Mars, visit skypub.com/Caves.

MARIUS HILLS PIT These LROC images show another potential cave, in the Marius Hills region of Oceanus Procellarum. At 200 feet wide and 270 feet deep, the Marius Hills pit is smaller than the one in Mare Tranquillitatis, but it also has multiple layers.



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*Contributing editor **Robert Zimmerman** is a cave explorer and cartographer. When he's not writing about space on his website, Behind The Black (**http://behindtheblack.com**), he is often underground, exploring virgin territory never before seen by human eyes.*

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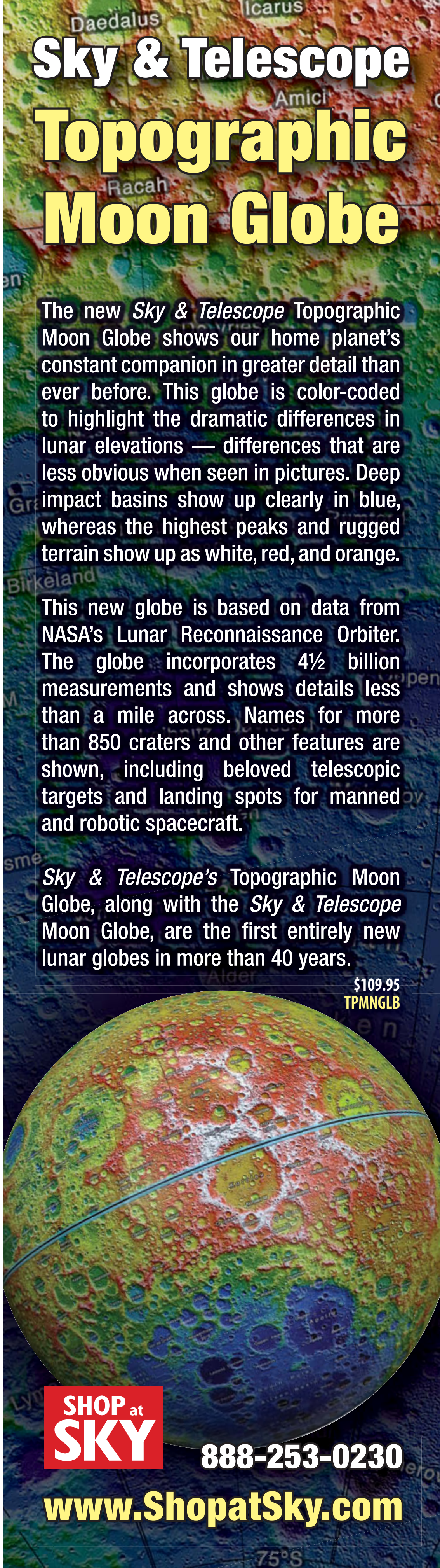

Sky & Telescope
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The new Sky & Telescope Topographic Moon Globe shows our home planet's constant companion in greater detail than ever before. This globe is color-coded to highlight the dramatic differences in lunar elevations — differences that are less obvious when seen in pictures. Deep impact basins show up clearly in blue, whereas the highest peaks and rugged terrain show up as white, red, and orange.
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The Large Zenith Telescope's mercury mirror provides critical insights for next-gen instruments.

Deep within the forests of British Columbia, on a granite outcrop atop a hill, sits a hidden gem — a shining pool of mercury. At 6 meters in diameter, the Large Zenith Telescope (LZT) ranks among the world's largest scopes. It's also the largest of a unique type of instrument: the liquid-mirror telescope.

After a long trek through tranquil forests — surrounded by scents of western red cedar and sights of sprawling woodland growth — it feels surreal to stand next to the cool, clear primary "mirror," like stumbling on a spaceship in a fairy tale. A thin layer of mercury mere millimeters deep rests on a dish designed to minimize the volume of liquid. This dish spins the mercury at a constant speed of 8.5 revolutions per minute, creating a smooth, highly reflective parabolic surface. (Stir a cup of coffee with circular motions, and you'll see a similar valley form in the center.) When united with corrector lenses and other telescope hardware, the immense mirror works like a conventional scope.

PAUL HICKSON / UNIVERSITY OF BRITISH COLUMBIA

The Large Zenith Telescope sits in the University of British Columbia's Malcolm Knapp Research Forest, about 50 kilometers (30 miles) east of Vancouver.

This unique instrument is clearing the way for other incredible technology. Researchers are using studies of Earth's atmosphere undertaken with the LZT to design the next generation of superscopes, particularly the proposed Thirty Meter Telescope and the 39-meter European Extremely Large Telescope. Liquid-mirror telescopes might also be the inexpensive solution astronomers need in order to pursue survey work that eats up valuable time at conventional observatories.

Simple Has its Perks

Paul Hickson (University of British Columbia, Canada) built and directs the Liquid-Mirror Observatory, the home of the LZT. He leads the world in designing these exotic telescopes. A clever, acute man with a sense of adventure, Hickson also flies and builds experimental aircraft, and his telescope's design has influences from aerospace.

When it came time to build the Liquid-Mirror Observatory, his team surveyed several candidate sites within reach of the university — looking at weather statistics and maps, flying overhead, and driving around by Jeep. They selected this forest sanctuary, far away from city lights, over several other locations.

The LZT has a relatively tiny price tag. Large conventional telescopes cost many millions of dollars to build, and tens of thousands of dollars per night to operate. That's orders of magnitude more than the Liquid-Mirror Observatory, which was built for half a million dollars. Canadian physicist Ermanno Borra (Laval University), pioneer of liquid-mirror telescopy, thinks that cost is the essential advantage of these instruments.

"It's something like a factor of 100, the difference in the cost of the mirrors," he says. "It's really very, very inexpensive."

The same simplicity that makes liquid-mirror telescopes so affordable also results in excellent optical quality. The LZT produces astronomical observations with resolutions comparable to a conventional telescope of similar size, and it observes stars and distant spiral galaxies at around the atmospheric resolution limit. Because a fluid naturally flows to a smooth shape, liquid mirrors achieve impeccable optical quality far more easily than polished glass, with the potential to produce a perfect mirror.

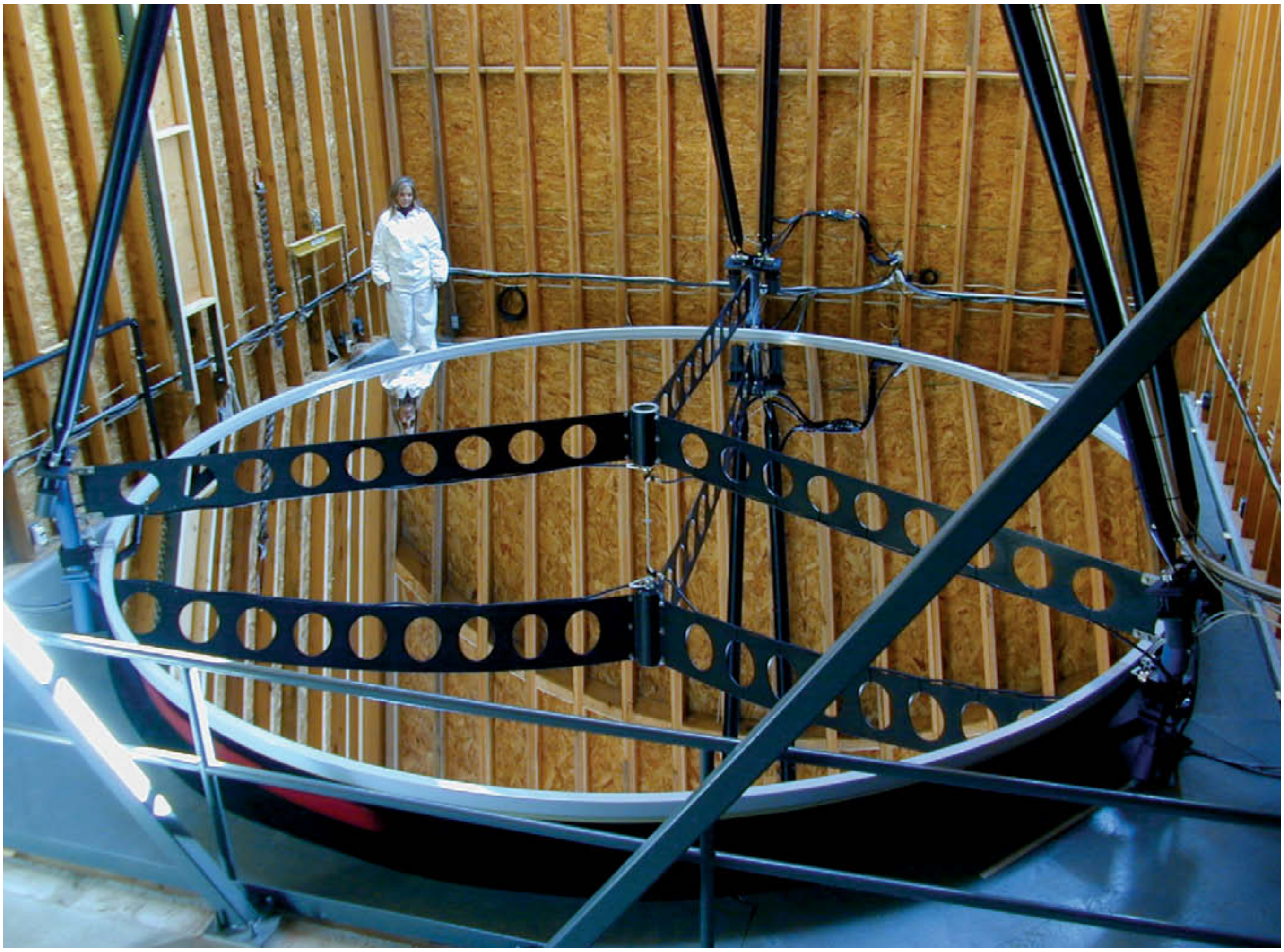
That perfection depends on finely tuned hardware. A display in the control room shows variations in the rotational speed of the spinning mirror: nine parts of error per million. When Hickson first built the mirror, he measured the rotational error at 1,000 parts per million. The ensuing jitters set mercury sloshing, destroying the reflected images.

How Liquid-Mirror Telescopes Work

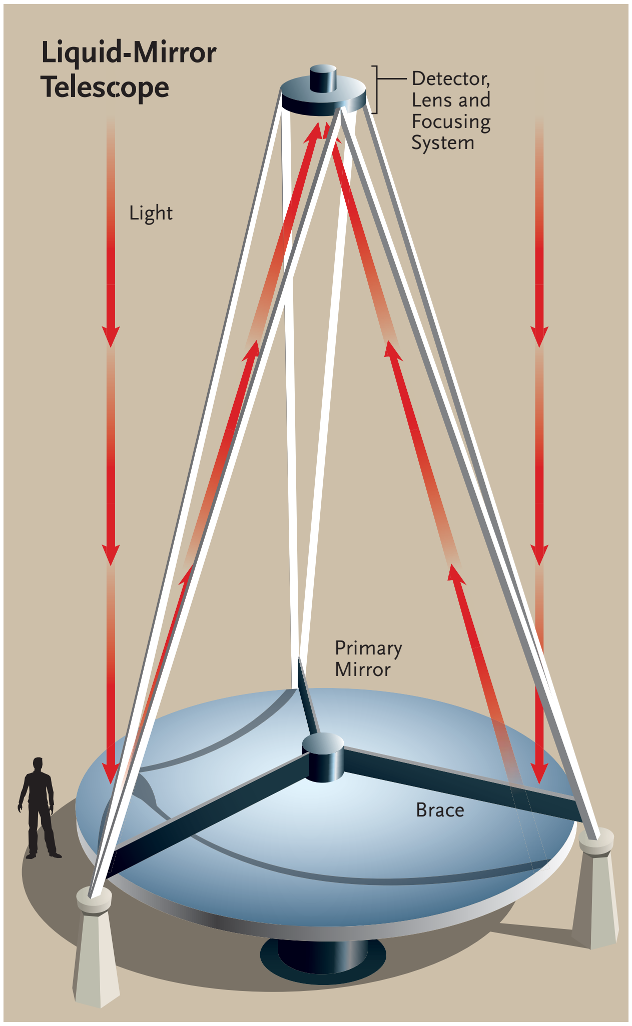
Isaac Newton first described the rotating-fluid concept that makes the liquid-mirror telescope possible. When a liquid spins at a constant speed, the combination of gravity and rotational acceleration finds a dynamic equilibrium that makes the top surface of the fluid form a smooth parabolic shape. The paraboloid arises because a liquid surface always forms its local surface perpendicular to the net acceleration it experiences. In the case of a spinning mirror, the net acceleration becomes stronger and more inclined with distance from the spin axis at the mirror's center.

Put a camera at the focal point of the paraboloid, where the reflecting surface focuses light into a single point, and you have yourself a liquid-mirror telescope.

Mercury vapors from the Large Zenith Telescope can be dangerous during the first hours after its setup. But oxidation soon prevents vapor emission, and after a day or so gas masks are unnecessary.



PAUL HICKSON / UNIVERSITY OF BRITISH COLUMBIA



S&T: LEAH TISCIONE

A liquid-mirror telescope's defining trait is its rotating primary mirror. Paired with correcting lenses and a detector, the parabolic liquid surface becomes an inexpensive large-aperture scope.

Hickson added a control system to actively stabilize the mirror speed, based on its angular movement. He also installed an optically clear Mylar cover, only a few microns thick, that sits a few centimeters above the mercury and rotates with the mirror. This cover protects the liquid from wind blowing in through the open roof and also prevents the formation of small vortices in the air above the moving liquid, which create tiny waves that degrade images.

As the name implies, the Large Zenith Telescope only sees the portion of the sky directly above the observatory: tipping the mirror would spill the mercury, so the liquid mirror must face straight up. Researchers get around the limitation somewhat by "drift scanning," delaying the CCD's readout to match the sky's drift speed and allow for artificial tracking. But liquid-mirror telescopes still only serve for astronomical studies that do not require steering. The observatory sits at a latitude of 49°, which means that as Earth rotates, the telescope observes a strip of sky at 49° declination. Such zenith strip surveys are useful for a variety of scientific pursuits, ranging from cosmology to the detection of supernovae.

The LZT currently pursues none of these science projects, though. It has a far greater demand on its time: guiding astronomers in designing the upcoming gargantuan telescopes by studying sodium in the atmosphere.

Solving the Sodium Problem

A new generation of so-called "extremely large telescopes," such as the Thirty Meter Telescope and the European Extremely Large Telescope, has major design challenges to tackle. The telescopes will house primary mirrors three to four times the diameter of today's largest optical telescopes. Huge mirrors make it possible to get large, sharp, intense images — yet that very same sensitivity subjects the telescopes to atmospheric distortions

PAUL HICKSON / UNIVERSITY OF BRITISH COLUMBIA (2)

The liquid mirror's construction began with its large supporting steel trusses (*left, with Hickson*). Over these went segments made of a composite of fiberglass, foam, and epoxy (*above*).

that smaller instruments don't notice. Optical sensitivity grows proportionally with the diameter to the fourth power, which means that increases in size have dramatic impacts on scopes' abilities.

One particular challenge facing the upcoming giants is their adaptive optics. Adaptive-optics systems compensate for the atmosphere's blurring effects by distorting the shape of a telescope's secondary mirror. At some observatories, astronomers map these atmospheric changes by beaming a laser into the mesophere's sodium layer, effectively creating a bright fluorescent lamp in the sky that acts as a "guide star." The secondary mirror then adjusts its shape rapidly and repeatedly — sometimes more than 1,000 times per second — in order to match the distortions in the atmosphere detected from the laser guide star. Large ground-based telescopes require adaptive optics to perform better than the seeing limitation imposed by Earth's atmosphere.

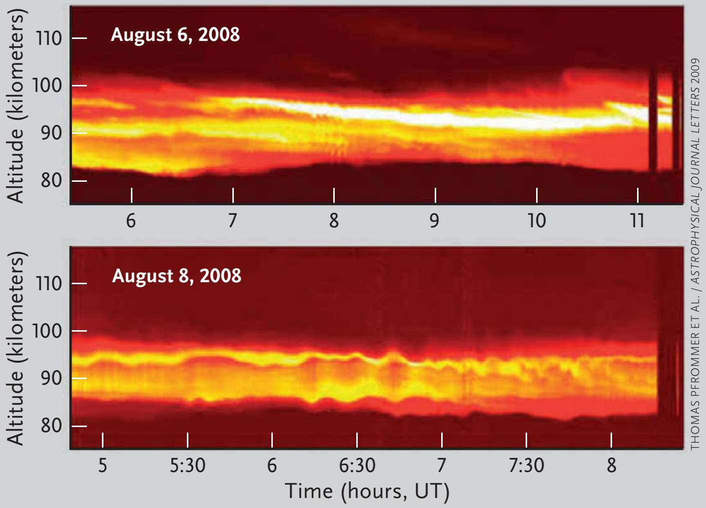
The sodium layer consists of several distinct levels, varying in density and altitude. Ocean-like waves roll along the entire layer, and turbulence induces variability. These irregularities, coupled with changes in the entire layer's average altitude, change the structure and distance of guide stars, confusing the adaptive optics system. Even five meters of variation in the sodium layer's altitude can affect the system.

"If a meteor trail occurs in the middle of an observation, it can change the average range to the sodium layer by a hundred times that much, or more," says Brent Ellerbroek, department head of instrumentation for the TMT. The consequent error would be bigger for larger telescopes, increasing with the square of the diameter. Such errors would wreak havoc on the behemoths' observations. "So it's very important to understand how the sodium layer is evolving in time."

Scientists had come to this conclusion by extrapolating from data taken on timescales six orders of magnitude longer than those on which adaptive optics operate. To verify that the sodium layer would behave on small scales as they thought it would — before building the billion-dollar observatories — the scientists needed a way to measure the actual variations of atmospheric sodium density at a fine enough resolution to correct for any errors. The best existing data in the world would not do.

It turns out that the LZT can collect precise enough data to resolve the problem. During a lull created by a broken camera sensor, Hickson and one of his graduate students installed a laser at the facility. The laser effectively turned the observatory into the world's largest facility of its kind, a research center for "lidar," or light radar. The same laser technique is also used to create guide stars.

Using lidar, the LZT picked up never-before-seen eddies and vortices in the sodium layer, as well as details of both its structure and dynamics. Observations have also revealed the first detection of turbulence waves in the mesosphere — curling licks of sodium that interact chaotically with neighboring layers of the atmosphere.



The atmosphere's sodium layer varies over time. Two nights of observation by the Large Zenith Telescope show multiple, transitory layers, with densities, altitudes, and structures that evolve over time. The brightest layers are about two to three times denser in sodium than the background. The dark vertical bars are from aircraft interruptions.

Ellerbroek lauds the unique situation that such a large telescope can be devoted to lidar studies. The LZT has 100 to 500 times the collecting area of other lidar systems, he says, and its incredible sensitivity enables measurements with resolutions in meters and on timescales of much less than one second.

"For an 8-meter telescope that's not important," he says. "But for future 30- to 40-meter telescopes, under-

Brief History of Liquid-Mirror Telescopes

Despite coming up with the rotating-fluid idea, Newton apparently did not consider a telescope based on a liquid paraboloid. The concept went through several periods of development and dormancy. In 1982 Ermanno Borra revived the idea and soon realized, in his words, "Whoa, wait a second, you can do science with that!"

In 1994 he and Hickson built a successful 2.64-meter telescope. After that, Hickson created a series of mirrors, enhancing the size and performance with each iteration. At first he essentially worked out of his garage, building liquid mirrors for North American universities. Then NASA found out about his work and contacted him. The agency wanted a large, affordable telescope — both of which describe liquid-mirror scopes. Hickson built a 3-meter mirror for a device housed at NASA's Johnson Space Center in Houston. NASA later moved the scope to the Orbital Debris Observatory, in the Lincoln National Forest of New Mexico. The telescope collected data on space debris for many years, earning a NASA Group Achievement Award. Some surplus NASA components made their way into the Large Zenith Telescope.

standing how the range to the sodium layer changes on that timescale becomes important."

Ellerbroek says that he and his colleagues use the LZT's lidar data to design the wavefront-sensing equipment they'll use on the TMT, even to determine what kind of lasers they need to buy. "We're actually able to input this data into simulations of the adaptive optics systems, then predict how well the components we're designing and buying will work with the sodium layer as we understand it," he explains. A carefully planned adaptive-optics system will give the TMT three or four times better resolution than one of the Keck telescopes on Mauna Kea, which are among the world's premier ground-based visible and near-infrared telescopes and the standard by which others are measured. "It's going to have a dramatic impact on the types of observations that can be done."

PAUL HICKSON / UNIVERSITY OF BRITISH COLUMBIA (2)

The 6-meter f/1.50 Large Zenith Telescope can observe objects fainter than magnitude 25. These images are from its perpetual view of declination 49° 16′.

Futuristic Scopes

The LZT may herald a new wave of liquid-mirror telescopes, even though this particular scope will not immediately contribute to astronomical research. Hickson says that they chose the observatory's site because it's a good location for testing and developing liquid-mirror technology, but the site sees few clear nights. Good weather comes mostly in the short summer nights.

"Our aim all along was to put one of these telescopes at a competitive astronomical site once the technology had been perfected," he says.

One of these future instruments, the 4-meter International Liquid Mirror Telescope, was developed independently from the LZT but has benefited from knowledge gleaned from its forest counterpart. The ILMT is being installed at Devasthal in the Himalayas, a high-altitude site already home to two observatories.

Bigger dreams include a network of mirrors reminiscent of the Atacama Large Millimeter/submillimeter Array in Chile. Moreover, a few years ago Hickson and Borra contributed to a proposal to place a telescope of ionic liquid (basically, molten salt) as large as 100 meters in diameter on the Moon. The innovative technology, including superconducting bearings and a cryogenic vacuum, would allow astronomers to observe the early universe at higher resolutions and fainter magnitudes than the upcoming James Webb Space Telescope (*S&T*: January 2010, page 24). Even a much smaller Moon-based liquid mirror would be a useful survey instrument to follow up on JWST's observations.

Borra also proposed that technological developments in future decades might allow scientists to launch an orbiting liquid-mirror telescope as large as one kilometer across. "It was propelled by a solar sail," he says. "It was really a monster."

The space proposals received serious consideration: at the time (before the cancellation of the Constellation program) NASA thought that the 100-meter mirror would be a major reason for going back to the Moon, Borra says. Despite changes in NASA's focus, Borra thinks that the gigantic lunar liquid-mirror telescope will one day see first light.

In the meantime, astronomers' next-gen scopes will stand on the shoulders of a shining pool of mercury in the forests of British Columbia. ✦

Freelance writer ***Eagle Gamma*** *covers adventurous science, particularly discoveries in astronomy and optics.*

Remembering Comet Kohoutek

"The Comet of the Century" proved to be anything but.

Dean Regas

On March 18, 1973, 38-year-old Czech astronomer Luboš Kohoutek was pouring over photographic plates at Hamburg Observatory in Bergedorf, Germany, scouring the skies for the fabled "missing comet" Biela. This periodic comet had dramatically broken apart in 1845, and although two pieces were observed during its 1852 return, it was never seen again. Kohoutek was hoping to find it on photographs taken earlier in the year. While examining the plates under a microscope, he noticed a faint smudge. It wasn't Biela, but instead an unknown 16th-magnitude comet beyond the orbit of Jupiter. Reflecting on that first glimpse, Kohoutek now recalls, "I was rather excited, but I supposed this comet would not become very bright — like the majority of known comets."

Kohoutek's new comet may not have been bright at the time, but it had potential. Thanks to its early discovery, an upcoming Christmas rendezvous with the Sun, and an unlikely public relations campaign, Comet Kohoutek

Riding on nearly a year of advanced publicity, Comet Kohoutek put on its best showing in the opening days of 1974. Patrick Michaud was near Banning Pass in southern California when he snapped this view of the comet forming a right triangle with brilliant Venus and Jupiter on the evening of January 8th.

ALL PHOTOS ARE FROM THE S&T ARCHIVES

became one of the most famous comets in history. The media proclaimed it the "Comet of the Century," and tall tales of the potentially historic apparition created a remarkable public interest in astronomy. But when Comet Kohoutek failed to live up to the extraordinary hype, it turned into one of the most infamous astronomical letdowns. Although it might have been a bust of a comet for backyard astronomers, it turned out to be a gold mine for planetary scientists. Observing it from land, air, and space — in visible and ultraviolet light and also at radio wavelengths — astronomers unlocked important secrets of this icy visitor.

Operation Kohoutek

The buildup to the Kohoutek apparition actually began in 1965 with the sudden appearance of Comet Ikeya-Seki. Discovered just a month before its swing by the Sun, this sungrazing comet grew from an 8th-magnitude telescopic blur to a brilliant naked-eye spectacle in just a few weeks. At perihelion, some observers saw Ikeya-Seki at midday, and its tail extended 20° across the October morning skies as the comet headed away from the Sun. Then, in late 1969, another bright comet appeared. Discovered less than three months before perihelion, Comet Bennett was a beautiful naked-eye sight for two months in early 1970.

The late Brian Marsden of the Smithsonian Astrophysical Observatory, a world authority on orbital calculations, computed an early ephemeris for Kohoutek's new comet. It suggested that the comet could outshine all of its 20th-century predecessors. Kohoutek was thought to be a new comet, one untainted by repeated trips near the Sun. And unlike Ikeya-Seki or Bennett, scientists had nine months to prepare for it.

NASA's Goddard Space Flight Center initiated Operation Kohoutek, a coordinated effort to view the comet with an unprecedented arsenal of equipment. It included ground-based observatories, aircraft, high-altitude balloons, rockets, unmanned satellites, and even the newly launched manned *Skylab* mission. Kohoutek was going to be the best-observed and most-studied comet in history.

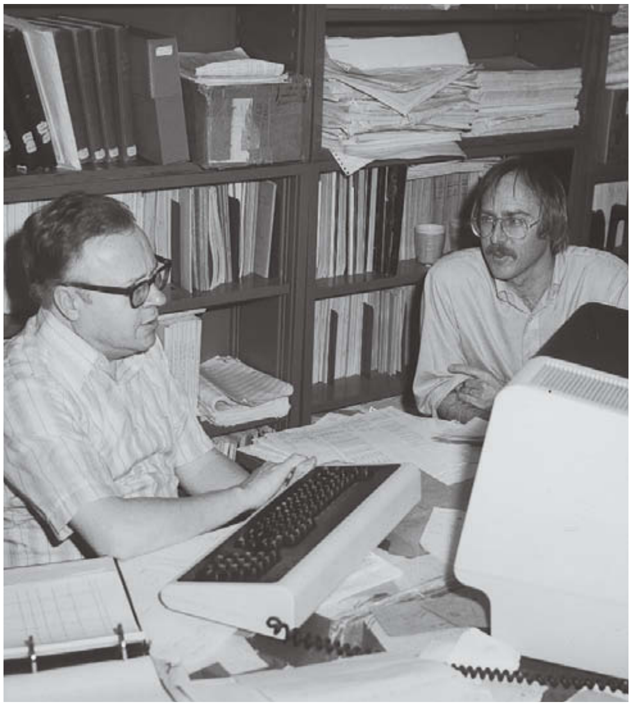
NASA also managed Operation Kohoutek like a public relations campaign. When Dale Myers, Associate Administrator for Manned Spaceflight, stated that "comets this size come this close once in a century," Kohoutek suddenly became "The Comet of the Century."

Media Hype

The media bought NASA's pitch, and Kohoutek soon evolved into a news sensation. The long-time science writer Charlie Petit remembers covering the comet for the *San Francisco Chronicle*. "When you call it the comet of the century, editors are going to follow it," Petit said. This was also a time when spacecraft were beginning to visit other worlds. "Interplanetary discoveries were coming every day, and Kohoutek fed the public appetite for

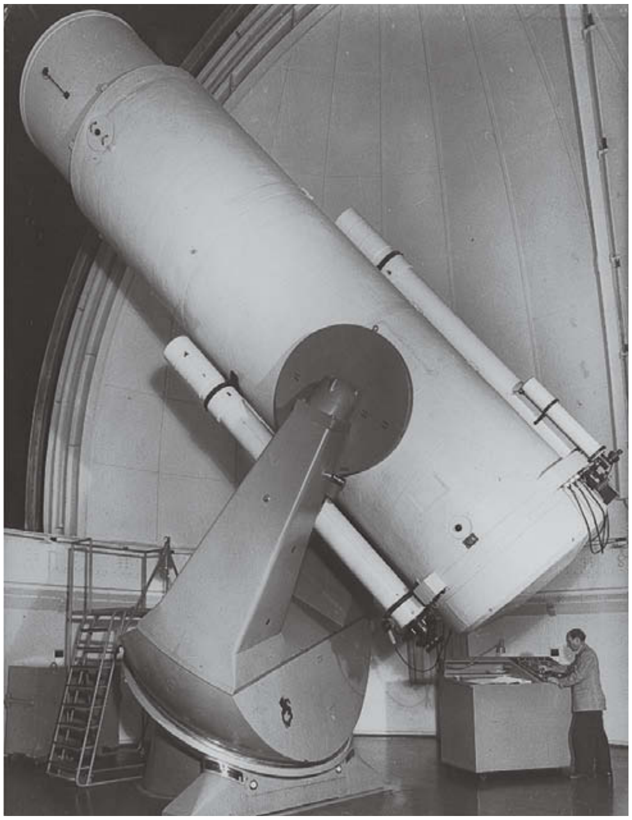
Czech astronomer Luboš Kohoutek (right) was searching for the lost Comet Biela when he stumbled across the one that would bring him international fame. Harvard astronomer William Liller interviewed Kohoutek when he visited the university in December 1973 as his comet was making its closest approach to the Sun.

Comet of the Century



A leading expert on comet orbits, Brian Marsden (left) was the first to suggest that Kohoutek could become a spectacular sight. He is pictured here in 1980 with *S&T* assistant editor Dennis Overbye, who is now a science reporter for the *New York Times*.

as bright as the full Moon



astronomy stories," Petit added.

The timing of the comet greatly added to its mystique. Kohoutek would shine most brilliantly around Christmas in 1973. It was easy for people to imagine a similar object of wonder guiding three travelers to a manger in Bethlehem 2,000 years earlier.

Speculation got the better of even seasoned reporters. Based on optimistic predictions, they wrote that Kohoutek would be brighter than the 1910 apparition of Halley's Comet. Some said it would be visible at midday, while others reported that it would be as bright as the full Moon with a tail stretching across one-sixth of the sky.

Such definitive descriptions created grand visions in the minds of the public even though amateur and professional astronomers were preaching caution. "It was not simple to explain that this comet might not be a bright object," Luboš Kohoutek recalls. "We warned reporters in all our interviews of too-high expectations, but without great success."

Telescope sales soared, as did the number of brochures on how to observe and photograph the comet. Planetariums arranged special shows that likened famous comets of the past to the one that was rapidly approaching. Astronomy organizations created comet hotlines where callers heard prerecorded updates on the comet, guidance on public viewing locations, and tips on observing.

In 1973, Andrew Fraknoi, now chairman of the astronomy department at California's Foothill College, had just started working as a part-time educator at the Astronomical Society of the Pacific (ASP). "There was a tremendous public interest in the comet," Fraknoi says. "With all the media publicity, we decided that the public needed an observing guide." The resulting ASP pamphlet contained background information on comets in general along with an observing guide to Comet Kohoutek. Deluged with requests, the staff had to recruit volunteers from amateur astronomy clubs to label and mail comet packets to the public. In the ASP's 123-year history, no similar publication has had a wider circulation.

Kohoutek seemed like such a slam dunk that the White House proposed a half-hour television special linking the comet and the achievements of the country's new *Skylab* space station with the first family's holiday message to the nation. The timing of the comet seemed perfect for President Richard Nixon, who needed a diversion from the increasing scrutiny of his involvement in the developing Watergate scandal. The TV show never aired, but that didn't stop some pundits from linking the timing of Kohoutek's evening apparition with the impeachment of

Kohoutek discovered his comet in early 1973 at Hamburg Observatory (*above*) in Bergedorf, Germany, using the 80-cm (31.5-inch) f/3 Schmidt camera (*left*) completed in 1955 and second in size only to Palomar Observatory's 48-inch Schmidt at the time. The camera was moved to Spain's Calar Alto Observatory in 1974.

Nixon, in the same way that the ancients viewed a rogue comet signaling the fall of a king.

The first mention of Comet Kohoutek in *Sky & Telescope* came in the May 1973 issue. A news item titled "A Bright Comet Next Winter!" said Kohoutek should reach 1st magnitude or brighter around the end of the year. Expectations were still growing when another article appeared in the August issue. "Just how bright the comet will become cannot yet be forecast reliably. Estimates range from a spectacular magnitude –10 to –3. If the former is correct, it may be possible to see the comet in full daylight with the naked eye, by simply screening the sun with an outstretched hand, as with the great comets seen in 1843 and 1882."

Flop of the Century

Despite the excitement, Kohoutek failed to brighten as many had expected. With only a month until perihelion,

Main photo: **California amateur Robert Birch said his January 8th photograph made from Berkeley's Grizzly Peak looking westward across San Francisco Bay closely matched his naked-eye impression of the comet's appearance.** ***Top left:*** **At about the same time, Patrick Michaud used a 200-mm telephoto lens for his close-up shot under darker skies near Riverside, California.**

Top: S&T senior editor Dennis di Cicco was living in Costa Rica when he photographed the comet in evening twilight on January 9th, noting that it wasn't the sight many expected for a comet some believed heralded the end of the world. *Above:* Three nights later, Palomar's 48-inch Schmidt camera recorded a view unlike anything visual observers experienced regardless of their location.

observers still needed telescopes to find the 10th-magnitude comet. When Kohoutek failed to liven up before Christmas, dreams of a spectacular apparition faded.

Kohoutek reached magnitude –3 at perihelion, but it appeared so close to the Sun that it did not stand out. It made its best showing during the first week of 1974. Then a respectable zero-magnitude object, Kohoutek was nevertheless washed out by strong evening twilight, and it took persistence for most observers to locate it.

The media backlash was almost as strong as their previous coronation of this king of comets. Kohoutek was called, among other things, the "Flop of the Century," "The Comet that went Phzzt," "No Ball of Fire," and "Kohou-flop." Astronomers sold them a sure thing, the media thought, and when the comet fizzled, writers played the victims, echoing the sentiments of the greater public who never saw Kohoutek in the night skies.

This disappointment, however, contrasted sharply with the excitement that Comet Kohoutek brought to research astronomers. Professional observatories around the world turned their telescopes toward the comet. NASA launched an Aerobee rocket from New Mexico to observe Kohoutek in ultraviolet light, and the Mariner 10 spacecraft on its way to Venus and Mercury added more data. Soviet cosmonauts studied Kohoutek from their orbiting *Soyuz 13* capsule.

At Lick Observatory in California, astronomer George Herbig made spectrographic observations of Comet Kohoutek in January 1974 that revealed ionized water — the first conclusive evidence that water existed in comets. Herbig owed his discovery to the media hype that preceded the comet. "Without it," he says, "hardly anybody would have taken the trouble to observe it in real detail."

After the comet passed perihelion, Luboš Kohoutek traveled to the European Southern Observatory in Chile to record the brightness and spectra of his comet. Later he compiled a list of firsts that surrounded the apparition. In addition to the discovery of ionized water, it included the first radio signals (at millimeter wavelengths) detected from a comet, and the first comet observed from space.

View from Orbit

Jerry Carr, Bill Pogue, and Ed Gibson had an enviable opportunity to view Comet Kohoutek from aboard the orbiting *Skylab* space station. NASA had rescheduled their mission to put the astronauts in a better position for viewing the comet before and after perihelion. From orbit, they would be above Earth's atmosphere and better able to make visual and ultraviolet observations. Ed Gibson recalls that during their pre-flight training, "We were excited about being part of the 'attack' on Comet Kohoutek. We received good briefings about the nature of comets, the high hopes that existed for Kohoutek, and the importance of taking precise, clean data."

Houston radioed the crew on November 30, 1973, asking for an update. When told that the comet should be magnitude 5, and visible to the naked eye, William Pogue responded, "My naked eye must have a few clothes on it." For the next two weeks the astronauts could only see the comet with binoculars. On December 13th Pogue finally reported success, "Kohoutek has a really significant tail now." On Christmas Day, Carr and Gibson observed the comet during a spacewalk. The comet was so bright that Gibson could even see Kohoutek through one of the darkened protective visors on his helmet. "It was essentially dividing into three different sections," Gibson commented. "The coma, which we'd seen before; the tail, which now was quite a bit wider and quite a bit more intense than we've seen before . . . and then there was a spike, which was going straight forward and it was heading for the Sun." This sunward spike, or antitail, had not been seen on Kohoutek before, and the astronauts debated if it was real or an illusion.

After watching the comet every day for two months, Gibson told Houston, "I think it's lived up to my expectations in terms of what we're learning from it scientifically. . . . It's lived up to my expectations also in terms of just shear appreciation of it. It's a beautiful sight."

Despite its underwhelming visual performance, Comet Kohoutek, seen in this January 14th Palomar close-up, provided a wealth of new information for astronomical researchers.

Lessons Learned

Comets are notoriously fickle. Sometimes they brighten unexpectedly and sometimes they underwhelm. In retrospect, veteran astronomers declared that the Kohoutek flop was nothing compared to Comet Cunningham in 1941. Discovered far from the Sun with a similar media build-up to a Christmas perihelion, Cunningham underachieved mightily — only reaching 4th magnitude. Kohoutek was actually a solid, bright comet in comparison, and not much dimmer than Bennett. *Sky & Telescope* declared Kohoutek "A Scientist's Comet" in a March 1974 article, further adding that "any disappointment was mainly due to overenthusiastic advanced publicity."

Astronomers soothed their disappointment with the phrase, "Just wait until Halley comes back." But they didn't have to wait for Halley's return in 1986. The next great comet came just two years after Kohoutek. In early 1976 Comet West had everything: –3 magnitude, a perfect tail that fanned into multiple streams, and visibility at the right time for Northern Hemisphere observers. To the average stargazer, Comet West was a real comet. For all the attention Kohoutek garnered, West received almost no notice from the media. Astronomers and NASA were afraid to hype it up too much, lest they serve up yet another washout.

Fast-forward to the present, and we have Comet ISON. Discovered last September with eerily similar characteristics to Kohoutek, ISON was also found while beyond the orbit of Jupiter, and it will swing within about 1 million miles of the Sun's surface this coming November. The media has already latched onto it, calling it the "Super Comet." Will ISON blaze like West or fizzle like Kohoutek? As the late Harvard astronomer Fred Whipple famously noted in this magazine's April 1974 issue, "If you must bet, bet on a horse, not on a comet." ✦

Dean Regas *is Outreach Astronomer at Ohio's Cincinnati Observatory and cohost of* Star Gazers, *a nationally syndicated astronomy television program on PBS. He authored the article about eclipse chasing in the July 2012 issue of* S&T.

The Future of A

In a roboscope-dominated future, backyard observers will



Pamela Gay

Amateur astronomers actively involved in scientific research are worrying about the future of their community: visual astronomers fear being replaced by CCD observers, who in turn fear being replaced by survey telescopes. And as online denizens swarm like easily distracted locusts over every new data-mining project on the web before scurrying off to read LOLCats, web forum participants debate whether online "citizen science" might displace telescope-wielding amateurs altogether.

In reality, everyone has a place in the future, but that future will look different from what many might expect. Astronomy has changed drastically with the advent of modern technology. Whereas astronomers of the past spent long, cold nights at the telescope, now astronomers stay warm, accessing the sky via their keyboards. Large surveys, remote observing, and robotic telescopes are altering professional astronomy in countless, generally positive ways, and they're also having a profound effect on how amateurs participate in science. Although technology might squeeze amateur scientists out of some areas, it's also opening up new and exciting paths to discovery.

The Birth of Amateur Science

Astronomers before the modern era often straddled the line between amateur and professional. Composer and concert director William Herschel eventually gave up his music career to study astronomy full-time, but only after he discovered Uranus in 1781 through a self-built telescope. About a century later, sanitation engineer Andrew Ainslie Common pioneered the field of astrophotography. And the early 20th century saw radio operator Grote Reber retune his commercial skills to build a 31-foot backyard dish to map the radio sky.

Amateur associations flourished even as a professional astronomy community began to develop. Most notably, Benjamin A. Gould, editor of the *Astronomical Journal*, called for observations of variable stars in 1856, and many amateurs responded. In the grassroots movement that evolved, individuals documented changes in the brightnesses of thousands of stars. In 1911 William Tyler Olcott founded the American Association of Variable Star Observers (AAVSO) to systematically archive these variable-star observations, data that scientists could — and still do — use for research. The AAVSO is the oldest organization shepherding pro-am collaboration, but many more, such as the Minor Planet Center and the Center for Backyard Astrophysics, developed over the next century.

Amateur Research Today

Amateur astronomers today still hold an important advantage over professional astronomers: since they typically own their own equipment, they can dedicate as much time as they want to any particular target. Backyard observers can follow an asteroid or a variable star in a way that professional astronomers can't — night after night, sometimes for years on end.

mateur Science

still play an important role in astronomical research.

FROM LEFT TO RIGHT: ANDREW NIESEN, TERENCE DICKINSON, BERTO MONARD, ANTHONY WESLEY, IRENE SIMONSEN

Dedicated observers who focus their time — and their telescopes — on specific topics continue to make significant contributions to science, primarily via data collection. David Levy discovered and codiscovered 23 comets, Tim Puckett and his team of observers discovered 271 supernovae, and Anthony Wesley observed two unpredicted impacts on Jupiter and the loss of one of Jupiter's bands.

"Citizen science is a great pathway into real science," says Peter Lake, an amateur astronomer and science advisor to iTelescope, an online network of remote telescopes. "Many people study for years and then end up working in a totally different industry. With citizen science, you can 'try before you buy' and work out what you are really passionate about."

In addition to extraordinary individuals, teams have grown around specific science goals, with members providing time as they can. For example, observers in the Gamma-ray Coordinates Network delve into the mysterious nature of the gamma-ray flashes that accompany extremely energetic stellar explosions. When a gamma-ray burst triggers an alarm in a space-based detector, the network notifies individual observers, who attempt to catch the explosion's visible-light afterglow.

Although amateur discoveries continue to make the news, a shift is taking place as dedicated robotic survey scopes come online. Projects such as Lincoln Near Earth Asteroid Research (LINEAR) and the Catalina Sky Survey are churning out hundreds of asteroid and comet discoveries a year, a tough act for

From left to right:

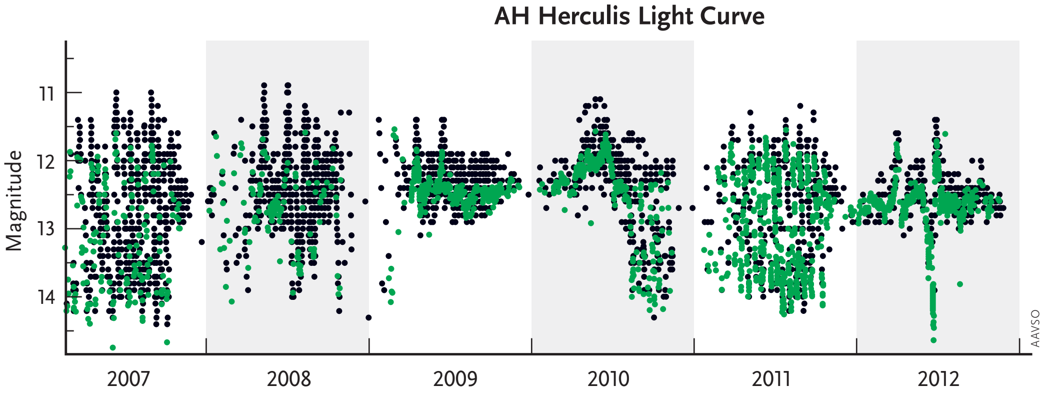
Tim Puckett leads the Puckett Observatory's Worldwide Supernova Search, a team of dedicated amateur astronomers who have discovered 271 supernovae.

David H. Levy poses with Miranda, his 16-inch Dobsonian reflector, one of the instruments he used to discover and codiscover 23 comets.

Berto Monard became the first amateur astronomer to discover the visible-light afterglow of a gamma-ray burst, using his 12-inch telescope to follow up on the coordinates of GRB 020725. Monard is also involved in exoplanet research.

Anthony Wesley discovered impacts on Jupiter in 2009 and 2010, and also observed the loss of one of Jupiter's bands.

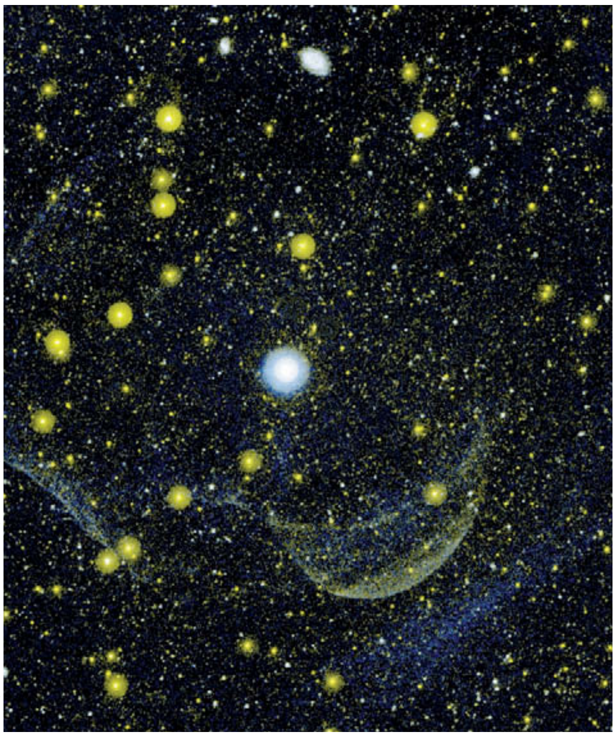
AAVSO membership director and development officer Mike Simonsen leads the Z CamPaign, which seeks to conclusively classify a special class of variable stars.



Before the Z CamPaign began in 2009, few data existed for variable stars classified as "Z Cams." Now, amateur visual (black) and telescopic (green) observations distinguish the bona fides from the imposters. Detailed light curves such as that of Z Cam AH Herculis will help astronomers understand how these complex systems work.

amateurs to follow. And robotic all-sky surveys such as the partially-built Panoramic Survey Telescope and Rapid Response System (Pan-STARRS) and the planned Large Synoptic Survey Telescope (LSST) will leave very little sky for the amateur to search for transient events, such as supernovae or new variable stars. The robots — or at least the robotic survey telescopes — are taking over.

But even in the era of robotic astronomy, there is still a need for amateur data, especially of single objects requiring many observations per night. Variable stars such as cataclysmic variables (CVs) continue to lend themselves to this kind of research. In these star systems, a white dwarf — the compact remnant of a Sun-like star — feeds on a closely orbiting companion star, brightening as it



NASA / JPL-CALTECH / MARK SEIBERT / TIM PYLE / ROBERT HURT

Z Camelopardalis is the poster child for white dwarfs that get "stuck" between quiescent and outburst phases. The Galaxy Evolution Explorer (GALEX) spacecraft shows a near-ultraviolet (yellow) and far-UV (blue) view of Z Cam and its gaseous shells.

quickens its meal and fading as it slows down. On rare occasions, stellar material builds up on the white dwarf's surface, igniting a runaway thermonuclear explosion and unleashing a tremendous burst of light. Observer networks, including those led by the AAVSO and the Center for Backyard Astrophysics, document these outbursts to shed light on the stars' volatile interactions.

Exploding stars have long been popular observing targets, but there's still a lot of ground to cover. Professionals and amateurs alike neglected a particular type of variable star for years — these variables get "stuck" in a middle-bright phase between luminous outbursts and fainter quiescence. Many of these Z Cams (named after the first such system, Z Camelopardalis) were studied only briefly following their initial discovery. Their provisional designations stood unconfirmed in the literature for years while awaiting further data.

The AAVSO's Mike Simonsen is addressing this need with the Z CamPaign. He leads a group of observers who collect extensive light curves of potential Z Cams with the aim of conclusively classifying each system.

The Z CamPaign has obtained extensive observations of bona fide Z Cams while ruling out "imposters" mimicking Z Cam behavior. "Improved coverage has revealed a richness of behavior never seen before," Simonsen says. "And we still have years to go."

A new project focuses amateurs' skills on a different kind of object: dozens of near-Earth, carbon-rich asteroids, many of which are categorized as "potentially hazardous." Target Asteroids! calls on amateurs to collect observations including astrometry, photometry, and even spectroscopy to refine asteroids' orbits and characterize their brightness and composition. Such observations require, at minimum, an 8-inch telescope, a CCD camera, and an internet-connected computer. Observers without equipment can still take part by teaming up with a local astronomy club or using various remote observatories.

For Target Asteroids! and similar projects, surveys such as the Catalina Sky Survey might provide the initial discovery data, but it's the backyard astronomers together with the professionals who refine the science, one object at a time.

Preparing for the Data Flood

In modern astronomy, focusing on a single source for extended periods is a luxury. Myriad new telescopes and surveys are collecting mountains of data, and the online databases are growing too large for the professional community to explore alone. Fortunately, the same remote-observing technology that's changing amateur science grants public access to professional databases, giving citizens a chance to organize the chaos.

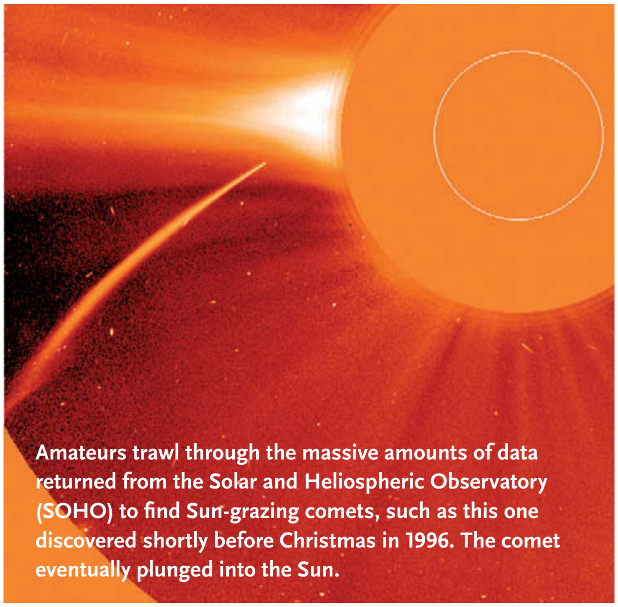
Citizen scientists became involved in data mining with the launch of the Solar and Heliospheric Observatory (SOHO), which studies the Sun's atmosphere and solar wind. Astronomy buffs were soon searching SOHO's data archives for serendipitous observations of Sun-grazing comets. The tally since 1996 is 2,378 and counting.

Organized citizen science really took off with the launch of GalaxyZoo (*S&T*: Nov. 2011, p. 24), where anyone with a few minutes for a tutorial could learn to classify galaxies imaged by the Hubble Space Telescope. The enormously successful enterprise led to the Zooniverse initiative, a collection of online projects where citizen scientists help discover new planets and find newborn stars.

One of the newest online citizen-science sites is the NASA-funded CosmoQuest, where the public can map out the rocky surfaces of the Moon, Mercury, and the asteroid Vesta. CosmoQuest aims to take citizen science a step beyond individual projects, building a community via online forums, virtual star parties, seminars from leading scientists, a weekly news roundup, and even online classes.

In the future, an active community of online citizen scientists will be crucial for sifting through the ever-growing databases. And amateurs will be just as crucial in providing extensive follow-up on interesting targets.

The LSST-funded mobile app "Transient Events" is already making that future a reality. The app posts coordinates of transient sources, currently provided by the Catalina Real-Time Transient Survey, to amateur astronomers and interested laypeople.



Amateurs trawl through the massive amounts of data returned from the Solar and Heliospheric Observatory (SOHO) to find Sun-grazing comets, such as this one discovered shortly before Christmas in 1996. The comet eventually plunged into the Sun.

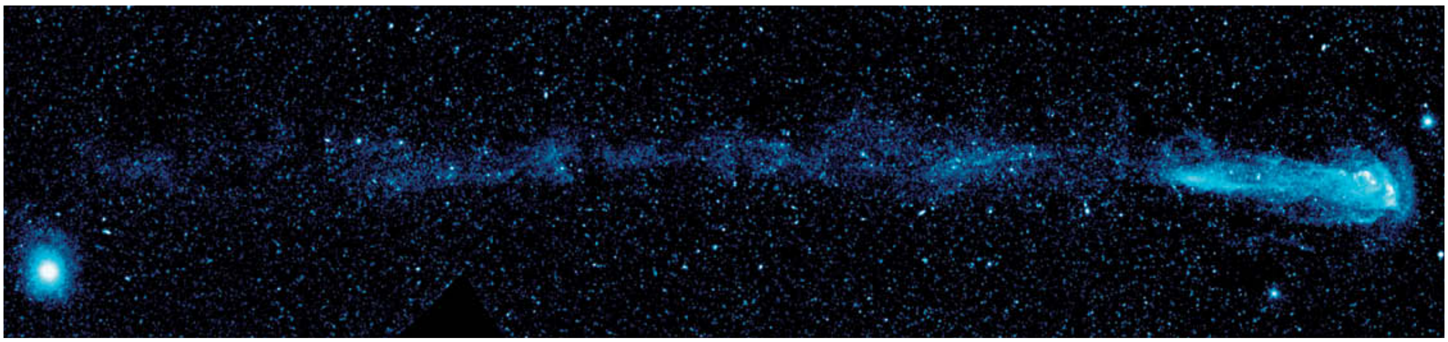
SOHO

Within the decade, the LSST will add to the app's alert system by discovering potentially tens of thousands of transients every night. Even if most transients will be too faint for amateur telescopes, the plethora of events should supply a steady stream of bright asteroids, comets, novae, and supernovae observable from modest telescopes.

The combined efforts of amateur observers and online citizen scientists will advance astronomy in ways as impossible to predict as Herschel's discovery of Uranus. Amateur research may change, but it isn't going away. The vast sky provides plenty to explore for citizens, amateurs, and professionals alike. ✦

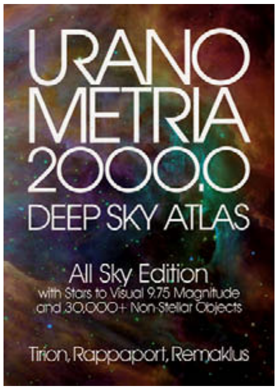
Get involved! Learn more about amateur research and online citizen science programs at skypub.com/amateur_research.

__Pamela L. Gay__ is an astronomer, writer, and podcaster focused on using new media to engage people in science and technology. Hear her take a fact-based journey through the cosmos on Astronomy Cast (__www.astronomycast.com__).



NASA / JPL-CALTECH / CHRIS MARTIN / M. SEIBERT

The AAVSO has monitored Mira's variable brightness since 1902, watching as the star gleamed and faded over an 11-month period. More recently, this GALEX ultraviolet image from 2007 offered a wider perspective on Mira, revealing a 13-light-year-long tail. The star's high speed through ambient gas in the galaxy has stripped off its outer layers to create the tail.



▸ **BIG ATLAS UPDATE** One of the most popular printed star atlases has undergone a makeover. *Uranometria 2000.0 Deep Sky Atlas All Sky Edition* ($59.95) is now available as a single volume covering the entire sky from pole to pole. This famous atlas by Wil Tirion, Barry Rappaport, and Will Remaklus features stars plotted down to magnitude 9.75, as well as more than 30,000 nonstellar objects. The book features 220 double-page charts at a scale of 1.85 centimeters per degree of declination, and an additional 29 close-up charts of selected regions of heavy congestion. Objects are indexed by common names, star names, Bayer Stars, Messier, and NGC/IC designations. Hardcover, ISBN 978-0-943396-97-2.

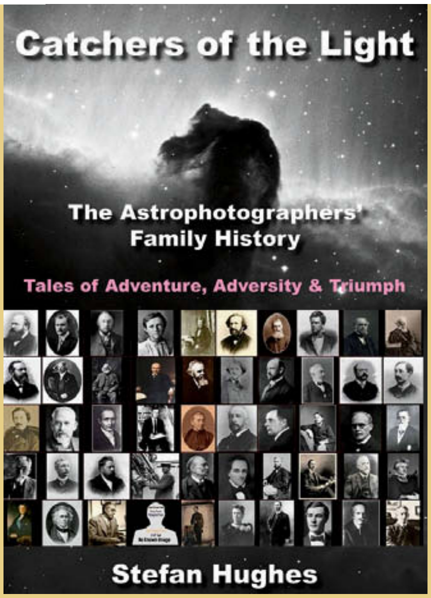
Willmann-Bell
P.O. Box 35025, Richmond, VA 23235
804-320-7016; www.willbell.com

◂ **VERSATILE GO TO** Orion Telescopes & Binoculars introduces its new Atlas Pro AZ/EQ-G Computerized GoTo Telescope Mount ($2,999.99). This three-in-one equatorial mount is capable of operating in equatorial mode holding one telescope, or in alt-azimuth mode bearing one or two different telescopes weighing up to 44 pounds (20 kg) combined. Its belt-driven stepper motor drive can slew to more than 42,000 objects in its database at 3.4° per second, and its closed-loop electronics with two encoders per axis maintain alignment even after an inadvertent bump or nudge. The Atlas Pro AZ/EQ-G features smooth altitude adjustments with a complete range from 10° to 90°, and a 1-inch counterweight shaft with a thread-on extension. Both include saddle plates that accept Vixen-style and Losmandy dovetail mounting bars. The mount includes a steel-legged tripod, two 11-pound counterweights, a Go To hand controller, and a 12-volt DC power cable.

Orion Telescopes & Binoculars
89 Hangar Way, Watsonville, CA 95076
800-676-1343; www.oriontelescopes.com

▸ **ASTROPHOTOGRAPHY HISTORY** Author Stefan Hughes has self-published *Catchers of the Light: A History of Astrophotography* ($79.99). This compendium chronicles the lives and contributions of the pioneers of astronomical photography, with an emphasis on the early pioneers of the 19th century. Each chapter is devoted to a particular astrophotographer, such as Henry Draper and John Adams Whipple, and includes little-known background information on the subjects relating to their lives. The book discusses the first astronomical photographs of the Moon and the development of spectroscopy all the way up to the growing role of the amateur astrophotographer in the modern digital age. See the author's website for additional details.

www.catchersofthelight.com



In This Section

IMAGE: NASA / HUBBLE HERITAGE TEAM / STSCI / AURA

Saturn's rings are now tilted a little more toward Earth than they were in October 1998, when this picture was taken.

Sky at a Glance

APRIL 2013

13 EARLY EVENING: The thin crescent Moon floats between Aldebaran and the Pleiades in the western sky, with Jupiter above it. See page 48.

14 EVENING: Jupiter pairs beautifully with the crescent Moon.

22 EARLY MORNING: The usually modest Lyrid meteor shower peaks in the hours before dawn; see page 50.

24 EVENING AND NIGHT: Spica is very close to the nearly full Moon for North America and is occulted (hidden) by the Moon for parts of Central America, South America, and southern Africa.

25 A VERY SLIGHT LUNAR ECLIPSE is visible from most of the Old World, centered on 20:07 UT.

EVENING AND NIGHT: Saturn is upper left of the full Moon.

27–28 ALL NIGHT: Saturn is at opposition, opposite the Sun in the sky and closest to Earth for 2013.

28 DAWN: The red supergiant Antares glows below the waning gibbous Moon in the south-southwest, as shown on page 49.

Planet Visibility

SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH

◀SUNSET — MIDNIGHT — SUNRISE▶

Planet	Visibility
Mercury	Visible with binoculars in early April — E
Venus	W — Visible starting April 21
Mars	Hidden in the Sun's glow all month
Jupiter	W — NW
Saturn	E — S — SW

Moon Phases

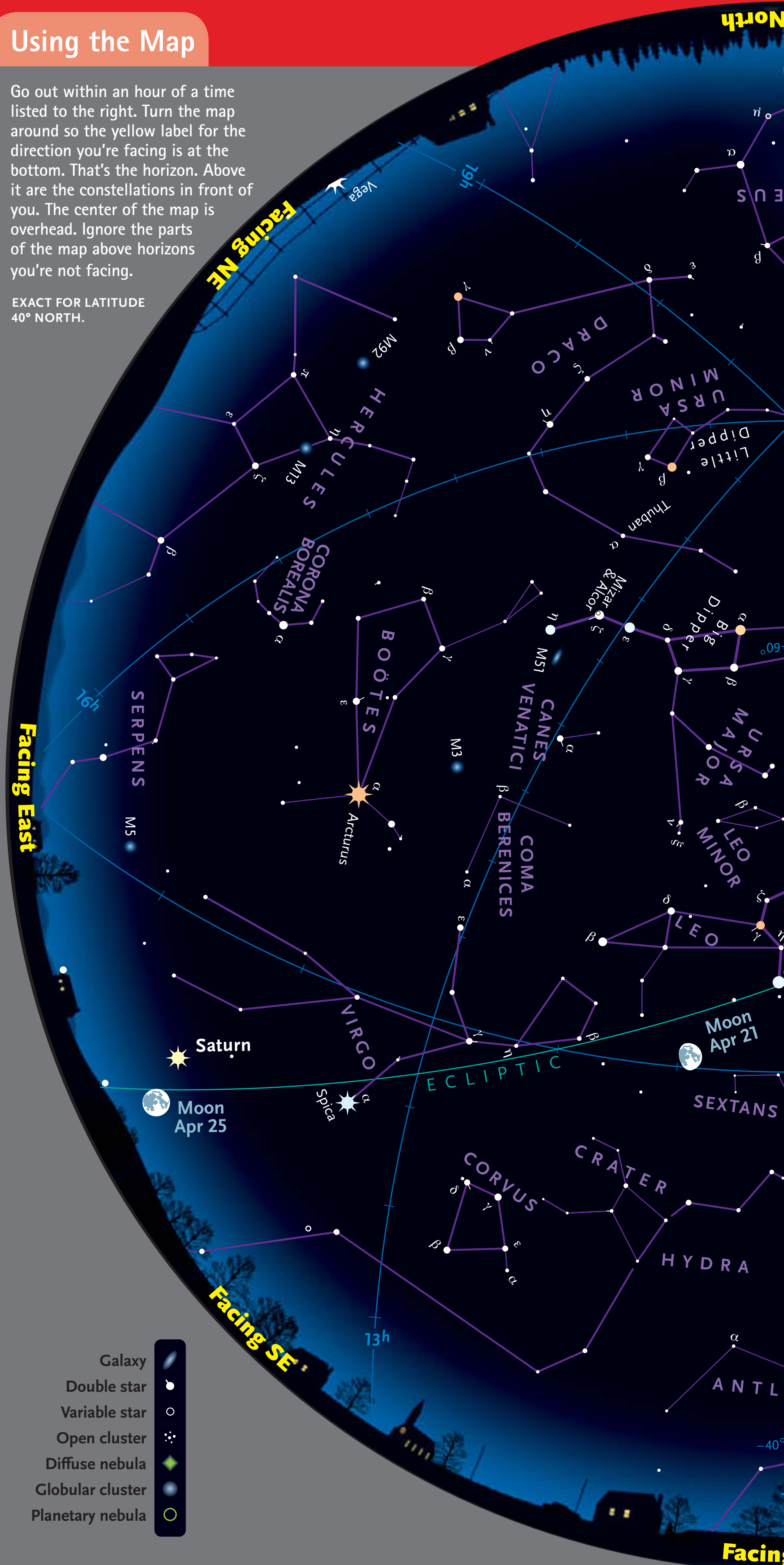
Last Qtr	April 3	12:37 a.m. EDT	
New	April 10	5:35 a.m. EDT	
First Qtr	April 18	8:31 a.m. EDT	
Full	April 25	3:57 p.m. EDT	

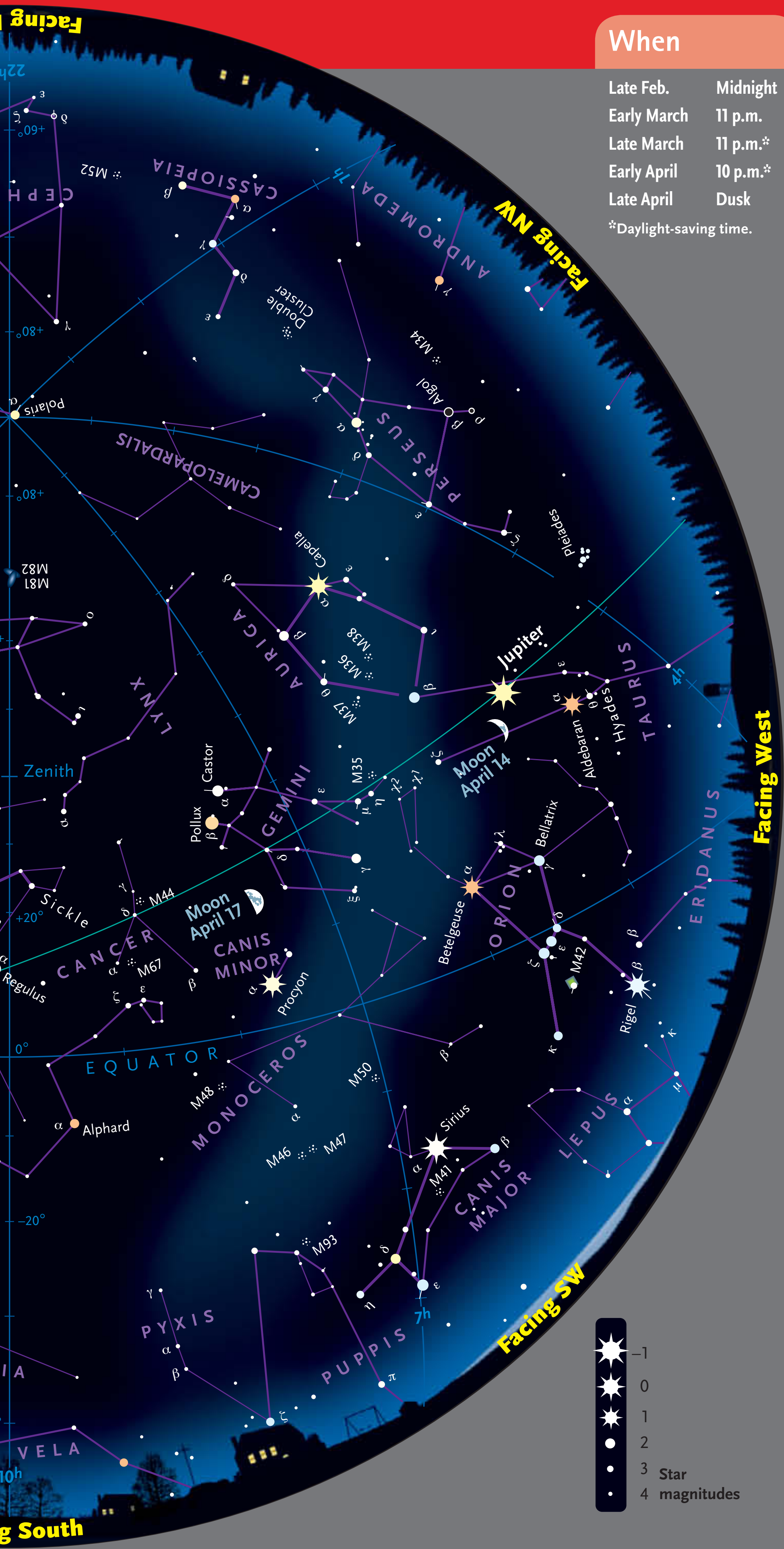
SUN	MON	TUE	WED	THU	FRI	SAT
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30				

Using the Map

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

EXACT FOR LATITUDE 40° NORTH.





When

Late Feb.	Midnight
Early March	11 p.m.
Late March	11 p.m.*
Early April	10 p.m.*
Late April	Dusk

*Daylight-saving time.

Gary Seronik

Binocular Highlight

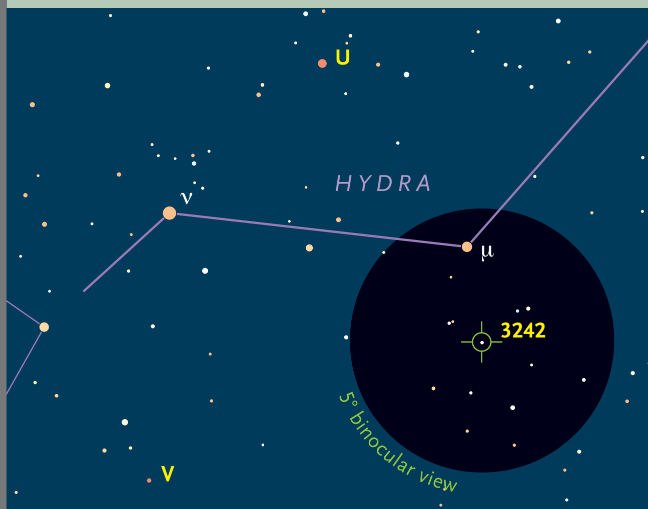
Hydra Hits

Bridging the setting stars of winter with summer's early risers, Hydra sprawls across more celestial real estate than any other constellation. But the celestial Sea Serpent is more famed for its size than its sights. Still, it's impossible to cover that much of the celestial sphere without offering up at least a few binocular hits. The section of Hydra draped over the meridian this month includes a couple of nice carbon stars and a bright, though small, planetary nebula.

Carbon stars are among my favorite deep-sky targets because of their rosy tints — though their colors often appear subdued in binoculars. The hue comes from an abundance of carbon and carbon compounds in their atmospheres, which filter out the shorter wavelengths. As it turns out, central Hydra has two of the best carbon stars for binos: **U** and **V Hydrae**. The pair straddles 3.1-magnitude Nu (ν) Hydrae, one of the constellation's leading lights.

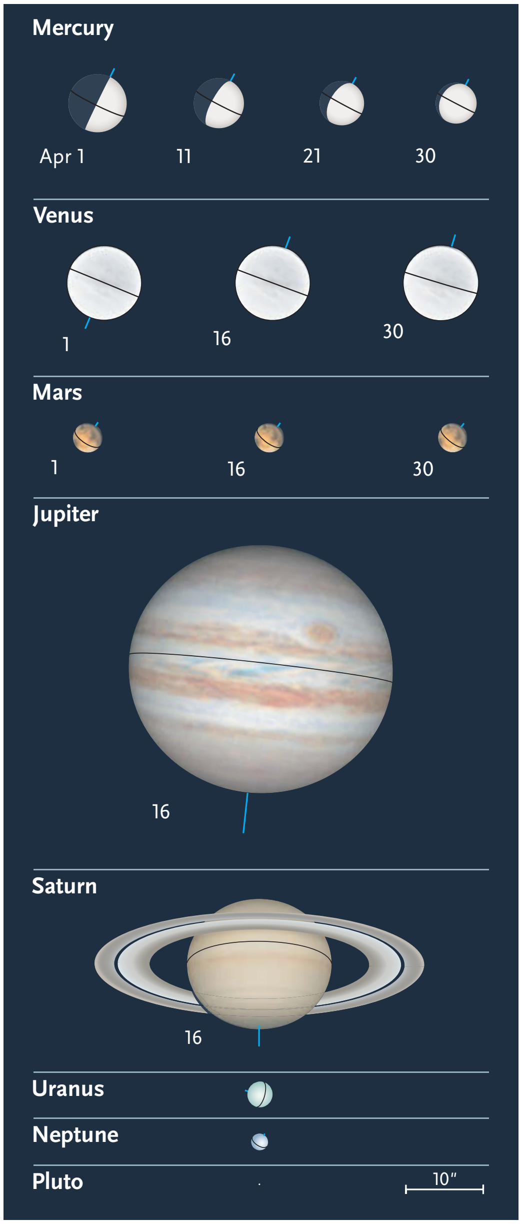
Both carbon stars are variable, with U hovering around 5th magnitude and V ranging from 6th to 9th magnitude. How red they appear will also vary, depending on how bright they happen to be on a given night. To enhance the color, try defocusing your binoculars slightly — a trick that works surprisingly well to make star hues more obvious.

For a change of pace, jump from Nu to Mu (μ) Hydrae, then look a half binocular field south for the 7.7-magnitude planetary nebula NGC 3242, also known as the Ghost of Jupiter (see page 56). Like its namesake planet, the nebula is about 40″ in diameter, which means it will appear nearly stellar in your binos. NGC 3242 can be tough to distinguish from field stars, but armed with the chart above, you should be able to pin down Hydra's planetary prize. ✦



Watch a SPECIAL VIDEO

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

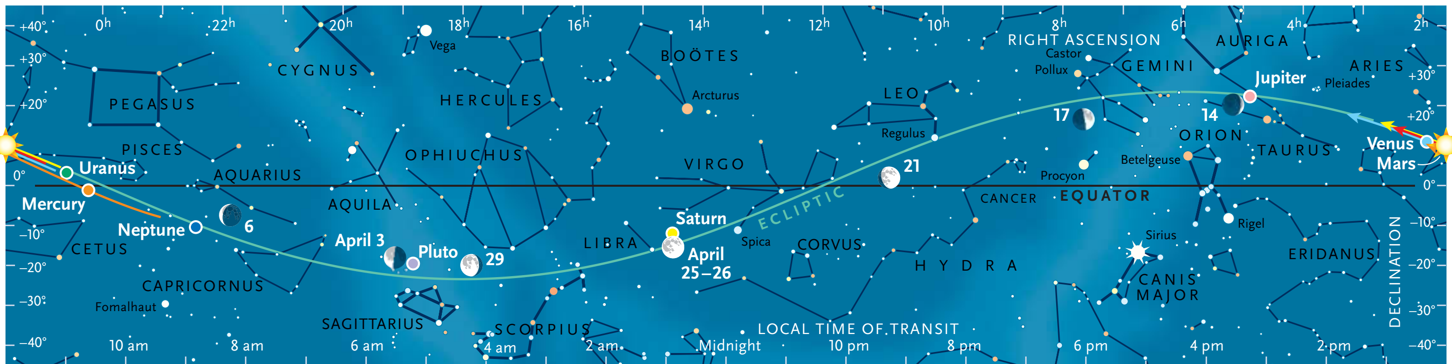


Sun and Planets, April 2013

	April	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	$0^h\ 41.3^m$	+4° 27′	—	–26.8	32′ 01″	—	0.999
	30	$2^h\ 28.9^m$	+14° 42′	—	–26.8	31′ 45″	—	1.007
Mercury	1	$23^h\ 01.5^m$	–8° 00′	28° Mo	+0.2	7.5″	51%	0.891
	11	$23^h\ 47.1^m$	–4° 07′	26° Mo	0.0	6.5″	65%	1.035
	21	$0^h\ 42.8^m$	+1° 53′	20° Mo	–0.3	5.7″	77%	1.170
	30	$1^h\ 41.4^m$	+8° 38′	13° Mo	–0.9	5.3″	89%	1.271
Venus	1	$0^h\ 46.4^m$	+3° 36′	2° Ev	—	9.7″	100%	1.724
	11	$1^h\ 32.3^m$	+8° 30′	4° Ev	–3.9	9.7″	100%	1.722
	21	$2^h\ 19.1^m$	+13° 06′	6° Ev	–3.9	9.7″	99%	1.715
	30	$3^h\ 02.5^m$	+16° 47′	8° Ev	–3.9	9.8″	99%	1.703
Mars	1	$0^h\ 56.3^m$	+5° 24′	4° Ev	+1.2	3.9″	100%	2.407
	16	$1^h\ 38.7^m$	+9° 49′	1° Ev	+1.2	3.9″	100%	2.430
	30	$2^h\ 18.7^m$	+13° 34′	3° Mo	+1.2	3.8″	100%	2.446
Jupiter	1	$4^h\ 40.8^m$	+21° 48′	60° Ev	–2.1	35.8″	99%	5.512
	30	$5^h\ 04.1^m$	+22° 30′	37° Ev	–2.0	33.6″	100%	5.866
Saturn	1	$14^h\ 33.7^m$	–12° 17′	151° Mo	+0.3	18.6″	100%	8.928
	30	$14^h\ 25.7^m$	–11° 36′	177° Ev	+0.1	18.9″	100%	8.817
Uranus	16	$0^h\ 35.3^m$	+3° 05′	17° Mo	+5.9	3.4″	100%	21.011
Neptune	16	$22^h\ 26.3^m$	–10° 27′	52° Mo	+7.9	2.2″	100%	30.601
Pluto	16	$18^h\ 48.4^m$	–19° 41′	105° Mo	+14.1	0.1″	100%	32.153

The table above gives each object's right ascension and declination (equinox 2000.0) at 0h 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-April; 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

Hercules and His Enemies

Two great constellations are linked in legend with the celestial strongman.

Last month we began a tour of the early spring skies, exploring groups of constellations that are bound together by a single overarching myth. This month the myth-group is the one connected to Hercules, featuring Leo and Hydra.

The Hercules group, starring Leo. At the time of our sky map, the constellation Hercules is just rising. But the most important constellations related to Hercules in legend are now superbly placed in the evening sky. They represent the beasts that the mythological strongman had to vanquish to complete the first two of his 12 famous labors. The more conspicuous and important one is Leo the Lion.

Not far from the middle of our all-sky chart is the constellation of the "king of the beasts" — a title from legend for sure! I don't mean dim, modern Leo Minor, of course. Nor am I talking about Asad, the vast constellation of the early Arabs, which stretched from our Gemini to Libra. No — the prime lion of the heavens now is Leo.

The heart of the lion (it makes you think of Robin Hood's king, Richard Lionheart) is marked by the star Regulus, Latin for "little king." At magnitude 1.36 Regulus is the least bright of the 1st-magnitude stars. But Leo also possesses two 2nd-magnitude stars: the fine double star Algieba, or Gamma (γ) Leonis, and Denebola, also called Beta (β) Leonis, which marks the Lion's tail. There are two lovely Leo Trios for telescopic observers: the galaxy groups M95/M96/M105 and M65/M66/NGC 3628.

Leo can be associated with the lions of many legends, for instance Aslan, C. S. Lewis's godly lion of Narnia. (Aslan, by the way, is Turkish for "lion.") But the ancient Greeks usually connected Leo with the Nemean Lion. No weapon could tear through the hide of this rampaging lion, so Hercules had to strangle him. Some ancient writers said that Selene, the Moon goddess, gave birth to the lion and that he fell from the Moon — as a meteorite, suggests folklorist Gertrude Jobes.

The Hercules group, co-starring Hydra. The second foe that Hercules defeated was the Lernean Hydra — a female water snake. Curiously, ancient writers explained the constellation Hydra with a farfetched story about a snake, a cup (Crater), and a crow (Corvus), and never connected the celestial Hydra with Hercules' foe. But Medieval and Renaissance made up for lost time and decided that the celestial Hydra is indeed the Lernean Hydra, making for a much juicier star myth.

The serpentine-shaped Hydra is by far the longest constellation in the sky. At our map time her compact and attractive head is fairly high in the south-southwest, while her tail is still emerging from the southeast horizon.

Unlike the celestial Hydra, the mythological beast had multiple heads. Whenever someone tried to cut off one head, two more grew back in its place. And one of the heads could not be killed. Hercules' solution was to burn each stump as soon as he cut off a head, and then bury the immortal head under an immense rock.

Hydra features one 2nd-magnitude star, Alphard, which marks her heart. Some of her most interesting deep-sky objects are the open cluster M48, the planetary nebula NGC 3242 (the Ghost of Jupiter, see pages 45 and 56), and the magnificent spiral galaxy M83.

Other connections with Hercules. According to some storytellers, Hera, queen of the gods, sent a crab to nip the toe of Hercules when he was attacking the Lernean Hydra — and he kicked it up into the sky where it became Cancer the Crab. The constellation Hercules also can be imagined to have his foot on the head of Draco the Dragon and to have shot the summer constellation Sagitta the Arrow from his bow. ✦

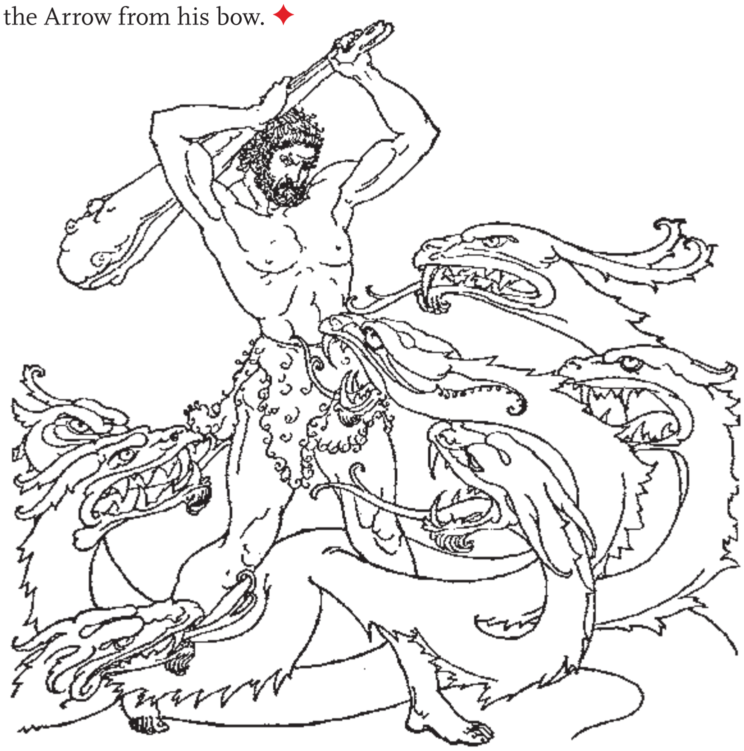


ILLUSTRATION BY WILLY POGANY FOR *THE GOLDEN FLEECE*, BY PADRAIC COLUM

Saturn Rules the Night

The ringed planet comes to opposition in late April.

Jupiter starts April roughly halfway up the western sky at dusk, but ends the month only about a quarter way up at dusk. Saturn doesn't rise in the east-southeast until well after dark on April 1st but rises before sunset by month's end.

Venus is very low in the west after sunset this April, barely creeping into view by month's end. And binoculars show Mercury very low in the east during bright dawn early in the month.

DUSK AND EVENING

Jupiter is still well placed for telescopic observation during early evening in early April. But by month's end Jupiter is so low that its image won't appear very crisp. Jupiter moves rapidly away from 1st-magnitude Aldebaran, from 5½° at the opening of the month to 9° at the close — when it will be directly above Aldebaran as seen from mid-northern latitudes.

During April, Jupiter fades marginally from magnitude –2.1 to –2.0 and its disk shrinks to less than 34″ wide. The planet sets after midnight (daylight-saving time) in early April but around 11 p.m. by month's end.

Comet PanSTARRS (C/2011 L4) moves rapidly north and higher at nightfall in April — but is it still bright? See **skypub.com/panstarrs** for the most up-to-date information.

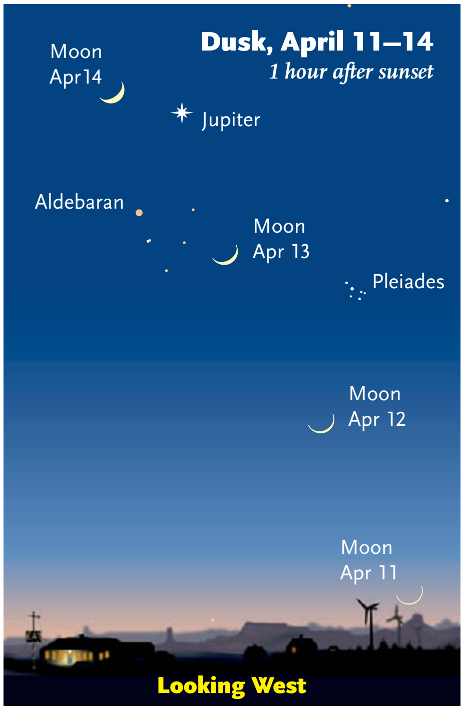
Venus is in superior conjunction on the far side of the Sun on March 28th, so it's hidden in the Sun's glare in early April. By April 30th, however, Venus should be visible very low in the west-northwest about 15 or 20 minutes after sunset. It appears faint in such bright twilight despite shining at magnitude –3.9; bring binoculars. On April 6th Venus is only ⅔° from Mars, but both planets are invisible, being only 2½° from the Sun.

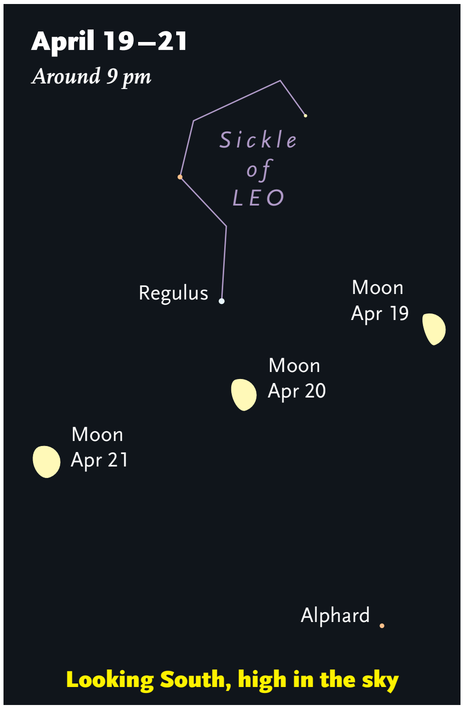
Mars passes through conjunction with the Sun on April 18th and will be lost in the solar glare for several months to come.

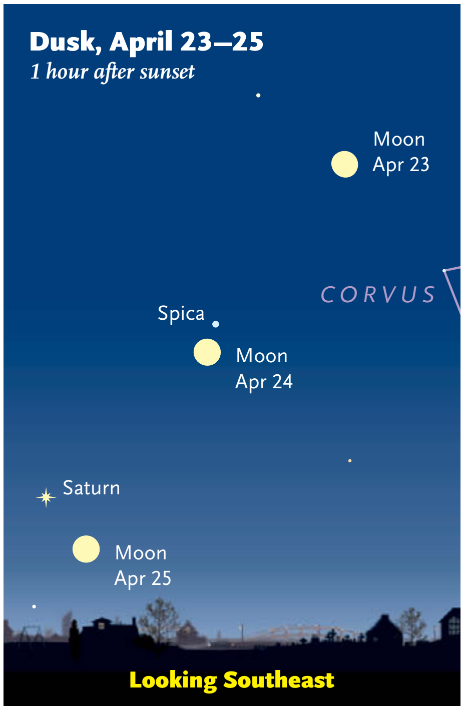
ALL NIGHT

Saturn shines bright in western Libra. The ringed wonder arrives at opposition on April 28th, when it rises around sunset, is highest in the middle of the night, and is visible all night long. It begins the month, however, rising about a half hour after nightfall and reaching its highest point in the south as late as 3 a.m. daylight-saving time.

Whatever its hours of visibility, Saturn is impressive this month, both to the naked eye and in the telescope. It brightens from magnitude +0.3 to +0.1, rivaling much higher Arcturus in luster. Saturn retrogrades about 2°, pulling within 15° of 1.0-magnitude Spica by late April. Saturn's golden globe enlarges to 19″ in equatorial



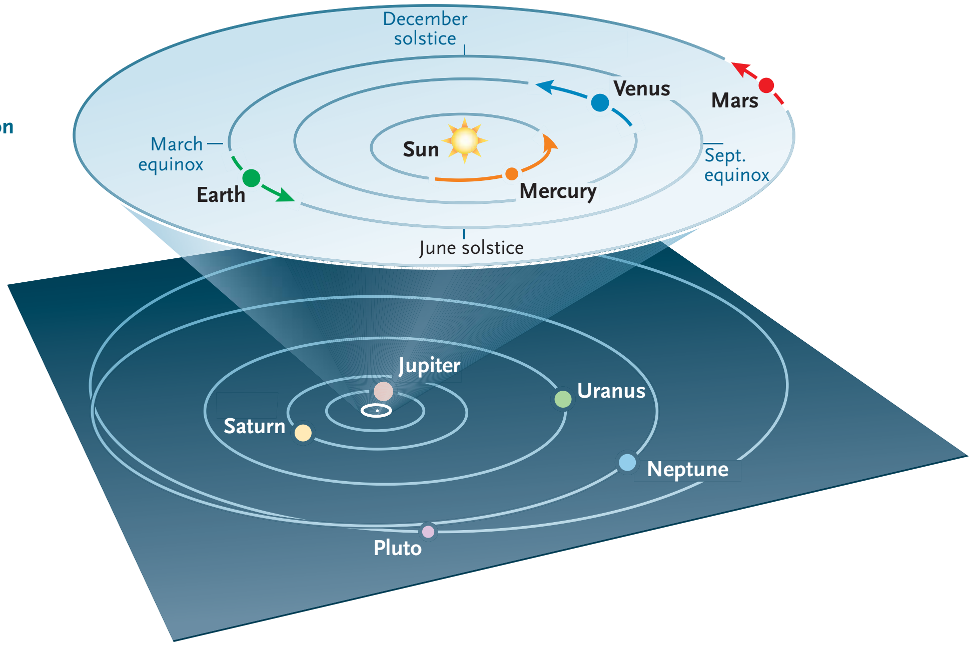




diameter — though the rapidly spinning planet is only 18″ from pole to pole. The rings close a little — to an 18° tilt by month's end. The visible ring system measures 43″ × 13″ at opposition.

The only problem for telescope users at mid-northern latitudes is that Saturn is now well south of the celestial equator, so it never appears very high.

How many of Saturn's moons can you spot? Some observers detect six in medium-size telescopes. Check **skypub.com/satmoons** for their positions at any date and time.



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

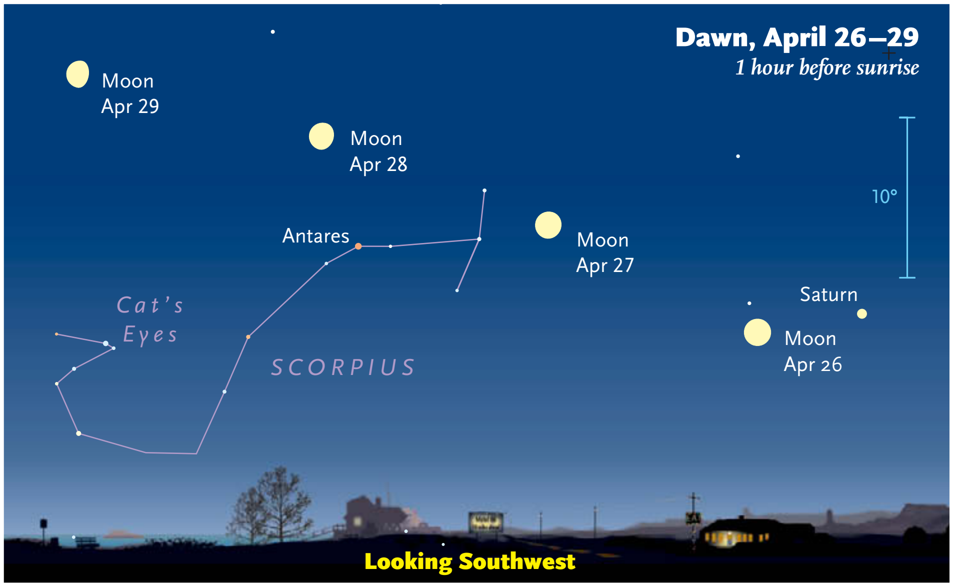
DAWN

Mercury was at greatest elongation from the Sun on March 30th. But the ecliptic makes a very shallow angle with the dawn horizon in the Northern Hemisphere's spring. So, while Mercury is 28° from the Sun as April begins, it's only a few degrees above the east horizon by the middle of morning twilight — visible with binoculars but probably not the naked eye. Mercury continues to appear lower each morning as April progresses, though it won't reach superior conjunction with the Sun until May 11th.

Uranus is lost in the solar glare this month, so it won't be visible on April 19th when Mercury passes 2° to its south.

Neptune is probably visible through telescopes in morning twilight, but it's very low in Aquarius.

Pluto is well placed just before the onset of morning twilight, but most Pluto observers will wait a few months until Pluto is viewable in the evening sky. The June issue will contain a finder chart.



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.

MOON PASSAGES

The **Moon** is a lovely waxing crescent floating between the Hyades and Pleiades after dusk on April 13th (use binoculars to see the clusters better). The next evening, the Moon hangs left or upper left of Jupiter. The nearly full Moon glows very close below Spica on the American evening of April 24th, with an occultation visible from parts of Central and South America and southern Africa.

The Moon is full on the 25th, shining lower right of Saturn. An extremely slight partial lunar eclipse will be visible in much of the Eastern Hemisphere, centered on 20:07 Universal Time. And the waning gibbous Moon is well above Antares at dawn on April 28th. ✦

April's Lyrid Meteors

Dodge the Moon to catch this not-so-predictable April shower.

A couple decades ago, the only people who knew to watch for meteor showers were dedicated amateur astronomers. Now the public has caught on. *S&T* and others have been providing the news media with reliable predictions, clear instructions, and realistic descriptions of what watchers can expect, especially given most people's light pollution — and this has turned meteor showers into mass-participation events. The epochal Perseid and Leonid showers of the 1990s certainly helped. Most people are happy if they go out and see just a couple of nice shooting stars on schedule, if they've been primed to expect no more than one every few minutes rather than some kind of fireworks display.

Meteor showers are scarce in the first half of the year for mid-northern watchers, but an exception is the Lyrid shower.

This year the Lyrids ought to peak in the early morning hours of April 22nd.

During last year's shower, Pat Gaines of Fort Collins, Colorado, caught two Lyrids in one lucky exposure plunging away from the shower's radiant at the Lyra-Hercules border.

Unlike the Perseids, Geminids, and some others, the strength of this shower is not very predictable. In some years its rates don't reach more than 10 meteors visible per hour even in a dark, moonless sky in the pre-dawn hours when the shower's radiant in Lyra is near the zenith. Last year, observers making counts by standardized methods for the International Meteor Organization found the Lyrids peaking at about 25 per hour (as adjusted to the zenithal hourly rate).

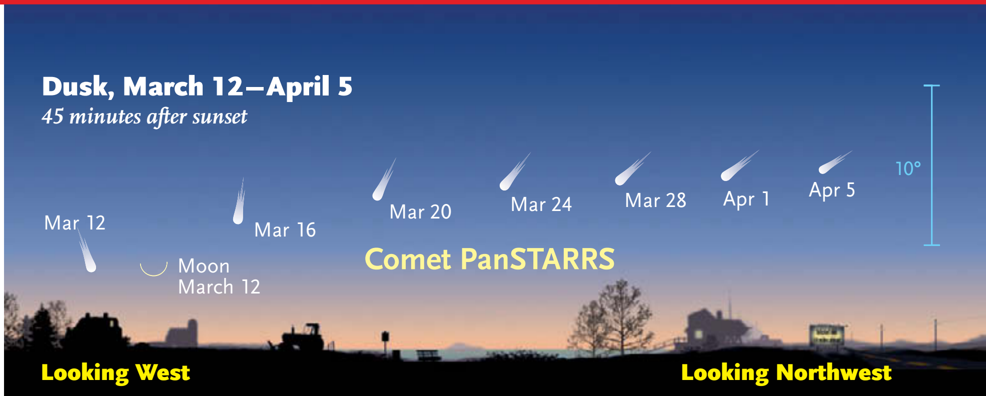
In 1982 meteor counters caught a brief outburst of 90 per hour. There have been other surprises, and there's a slim chance of a spectacle. In 1803 a newspaper in Richmond, Virginia, wrote of the Lyrids:

> *Shooting stars. This electrical [sic] phenomenon was observed on Wednesday morning last at Richmond and its vicinity, in a manner that alarmed many, and astonished every person that beheld it. From one until three in the morning, those starry meteors seemed to fall from every point in the heavens, in such numbers as to resemble a shower of sky rockets.*

And in 687 BC, a Chinese chronicler recorded that meteors from the shower "dropped down like rain."

This year, plan on some careful Moon-dodging. Light from the bright gibbous Moon washes the sky until moonset only about a half hour before the first glimmer of dawn on April 22nd. That's your best, if narrow, observing window.

Dress very warmly, and bring out a reclining lawn chair to a spot with an open view of the overhead sky and with no glary lights. If the Moon is still up, put it behind you. Lie back and be patient. A shower member may appear anywhere in the sky. But it will reveal its identity by traveling in a direction that, traced backward, points to a spot near Vega in Lyra.



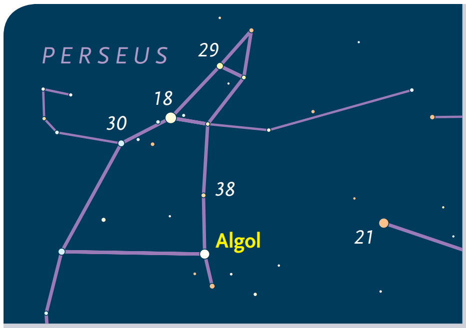
PanSTARRS update: **When most readers receive this issue, Comet PanSTARRS will be about to emerge from the glare of the Sun into twilight view very low in the west. The comet was originally predicted to reach magnitude 0 or brighter from about March 10–16, but late weakening suggests that it will be more like magnitude +3 at most. So bring binoculars! Full background is in the March issue, page 50. See continuing updates at skypub.com/panstarrs.**

Lunar Occultation

On the night of April 23–24 the Moon will be just short of full. If you're out with your telescope observing the shadowy detail on the terminator near the limb, you may notice that the Moon is creeping toward a star: Chi Virginis, magnitude 4.7. The invisible dark limb just beyond the terminator will occult the star for most of North America except the Northeast and north of the Great Lakes.

Some times: at Washington, D.C., 12:20 a.m. EDT; Miami, 11:58 p.m. EDT; Chicago, 10:47 p.m. CDT; Austin, 10:17 p.m. CDT; Denver, 9:07 p.m. MDT; Los Angeles, 7:52 p.m. PDT.

Maps and timetables for the year's occultations of brighter stars are on the International Occultation Timing Association site. See **www.lunar-occultations.com/iota/bstar/bstar.htm**.

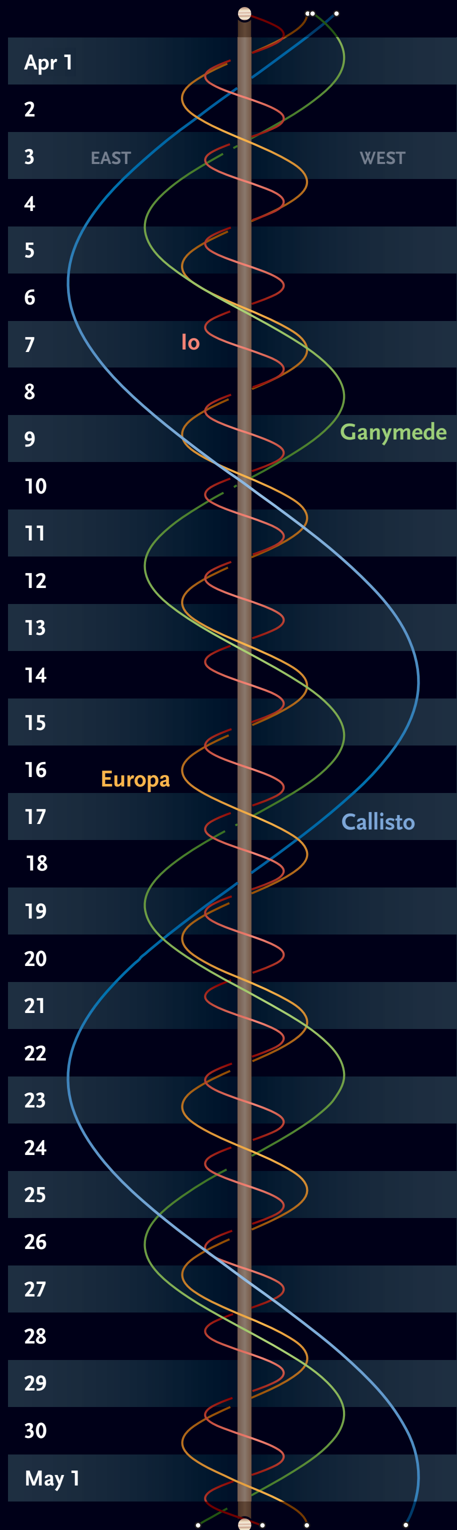


Algol, the prototype eclipsing variable star, fades every 2.87 days from its usual magnitude 2.1 to 3.4. It stays near minimum light for two hours, and takes several more hours to fade and to rebrighten. The change is obvious to the naked eye. Shown above are magnitudes of some comparison stars with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

Minima of Algol

Mar.	UT	Apr.	UT
2	9:19	2	22:21
5	6:08	5	19:11
8	2:58	8	16:00
10	23:47	11	12:49
13	20:36	14	9:38
16	17:26	17	6:28
19	14:15	20	3:17
22	11:04	23	0:06
25	7:54	25	20:55
28	4:43	28	17:44
31	1:32		

Jupiter's Moons



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

Action at Jupiter

Week by week, the largest planet is losing altitude in the southwest at dusk. Catch it while it's still high; set up your telescope around sunset, so the scope will have time to cool down by late twilight when Jupiter comes into good view.

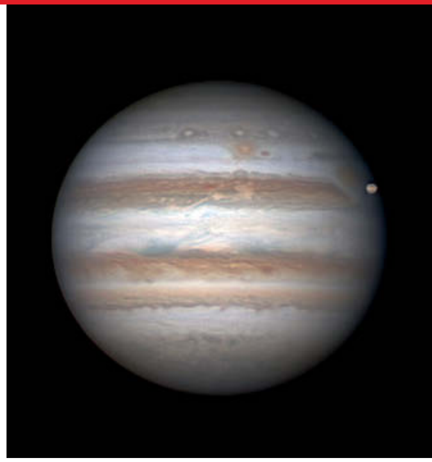
Nor does the giant planet appear so giant anymore, shrinking from 36″ to 34″ during April.

Even so, any telescope still shows Jupiter's four big Galilean moons. Binoculars usually reveal at least two or three. Identify them with the diagram on the previous page. Listed below are all of their many interactions with Jupiter's disk and shadow in April.

Jupiter's Great Red Spot is becoming harder to see as the planet shrinks. Following are the times, in Universal Time, when it should cross Jupiter's central meridian. The dates, also in UT, are in bold:

April 1, 5:09, 15:05; **2**, 1:01, 10:57, 20:53; **3**, 6:48, 16:44; **4**, 2:40, 12:36, 22:32; **5**, 8:28, 18:23; **6**, 4:19, 14:15; **7**, 0:11, 10:07, 20:03; **8**, 5:58, 15:54; **9**, 1:50, 11:46, 21:42; **10**, 7:38, 17:34; **11**, 3:29, 13:25, 23:21; **12**, 9:17, 19:13; **13**, 5:09, 15:04; **14**, 1:00, 10:56, 20:52; **15**, 6:48, 16:44; **16**, 2:40, 12:35, 22:31; **17**, 8:27, 18:23; **18**, 4:19, 14:15; **19**, 0:11, 10:06, 20:02; **20**, 5:58, 15:54; **21**, 1:50, 11:46, 21:41; **22**, 7:37, 17:33; **23**, 3:29, 13:25, 23:21; **24**, 9:17, 19:12; **25**, 5:08, 15:04; **26**, 1:00, 10:56, 20:52; **27**, 6:48, 16:43; **28**, 2:39, 12:35, 22:31; **29**, 8:27, 18:23; **30**, 4:19, 14:14.

The Red Spot appears closer to the central meridian than to the limb for 50 minutes before and after these times. ✦



Io had just crossed Jupiter's following (celestial east) limb and was almost on top of the Great Red Spot when Christopher Go took this image on January 5th at 12:12 UT. South is up. Closer to the central meridian, note the red ring of Oval BA in the South Temperate Zone and the row of four white ovals in the South South Temperate Belt.

Phenomena of Jupiter's Moons, April 2013

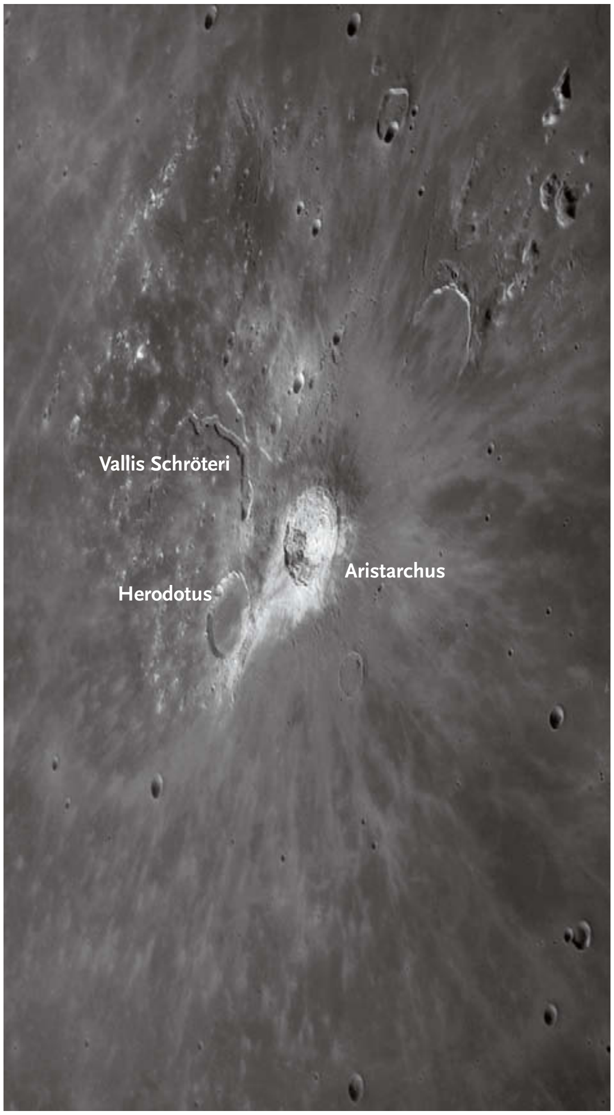
Date	UT	Event
Apr. 1	8:10	I.Oc.D
	8:22	II.Oc.D
	11:31	I.Ec.R
	13:14	II.Ec.R
Apr. 2	5:26	I.Tr.I
	6:35	I.Sh.I
	7:38	I.Tr.E
	8:46	I.Sh.E
Apr. 3	2:40	I.Oc.D
	3:04	II.Tr.I
	4:02	III.Oc.D
	5:18	II.Sh.I
	5:31	II.Tr.E
	6:00	I.Ec.R
	6:29	III.Oc.R
	7:45	II.Sh.E
	8:39	III.Ec.D
	11:06	III.Ec.R
	23:56	I.Tr.I
Apr.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

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

Hints of Vents

Track down the volcanic sources of the lunar maria.

Dark lava flows of the lunar maria cover about 30% of the Moon's nearside. Geologists know from investigating volcanism on Earth that such lavas come from magma that melts at the top of a planet's mantle, which then rises to erupt at the surface. The process on the Moon is thought to be similar, and the lunar mantle is about the same depth as many places on Earth, perhaps 35 to 45 kilometers (22 to 28 miles) or more below the surface. Despite the vast extent of lunar lava flows, there are few easily observed vents where these lavas erupted.



ALAN FRIEDMAN

Best seen a day or two before full and new phases, the Aristarchus Plateau is the richest lunar volcanic source visible from Earth. Under steady conditions, many rilles can be seen in the area, including Vallis Schröteri, the largest on the Moon.

On Earth, volcanic eruptions pile lavas and ash around their source vents, building conspicuous volcanic cones and mountains. The existence of such mountains requires a substantial flow of magma, often occurring over tens of thousands to a few million years. The buildup occurs because terrestrial lavas and ash don't spread far beyond the vents, so many small eruptions concentrate volcanic materials around their source.

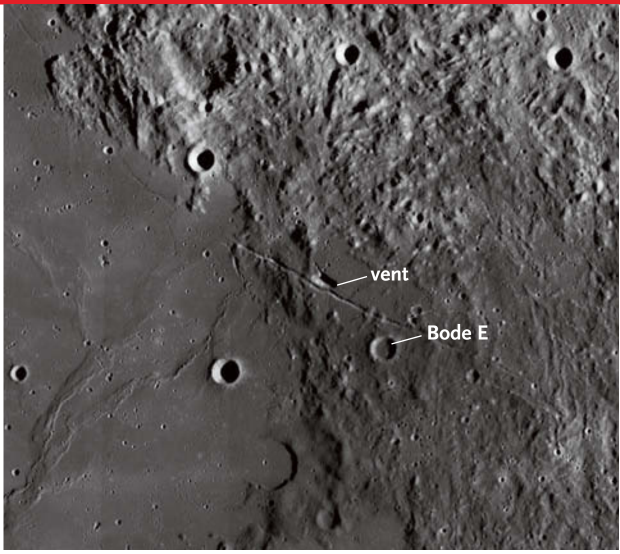
We know from studying lunar rocks collected by Apollo astronauts that lunar lavas were much more fluid than typical terrestrial analogs. This means that lunar lava flows traveled far from their vent sources, building few, if any, volcanic cones. Although the Moon lacks large volcanic mountains, many small hills and depressions mark the location of vents, a few of which are visible in a mid-sized amateur telescope.

One of the Moon's richest volcanic areas is the Aristarchus Plateau, an elevated rectangle about 180 km on a side with the **Aristarchus** impact crater on its southeastern corner. The plateau appears to have been uplifted, perhaps due to a huge underground intrusion of magma.

That suggestion is likely correct because the plateau is the source of a number of rilles, including Schröter's Valley (**Vallis Schröteri**), the largest on the Moon. The flow of lava away from a vent formed this valley. The lava built a channel that we see today as the valley's walls, and its source region is a 2-km-high broad volcanic mountain with a deep pit on its western flank. The 12-km-wide pit is known as the Cobra Head, because it's an entrance to a narrower, sinuous channel. Smaller rilles have their vents along the serrated eastern edge of the Plateau, and more appear north of the nearby ruined crater **Prinz**. These rilles start in vent areas 3 to 6 km wide that form oval, rimless depressions that are just visible telescopically.

In fact, the vents of most sinuous rilles are depressions, as if the eruption caused the roof to collapse as the source magma chamber was emptied to form the rilles. At **Rima Hadley** and other sinuous rilles, the vent area is a sickle-shaped trough, though we don't know why rille vents commonly appear this way. Rima Hadley's sickle is

Charles Wood (*lpod.wikispaces.com*) *is coauthor of the new book* 21st Century Atlas of the Moon.



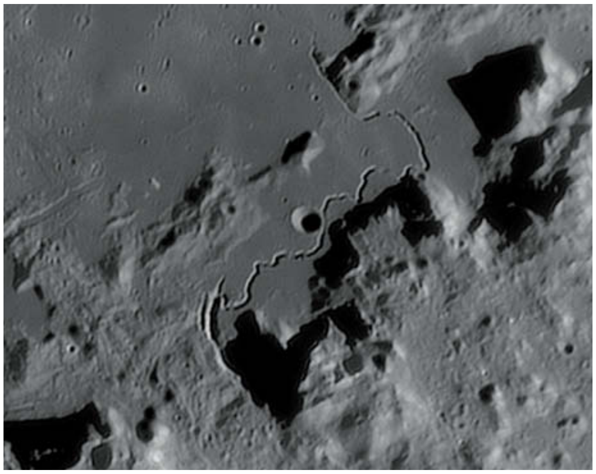
NASA / GSFC / ARIZONA STATE UNIVERSITY

The unnamed source vent that produced the dark pyroclastic material covering the region east of Sinus Aestuum can be spotted in amateur telescopes northwest of the minor crater Bode E.

difficult to spot; look for it at the southwest end of the rille in the foothills of Montes Apenninus.

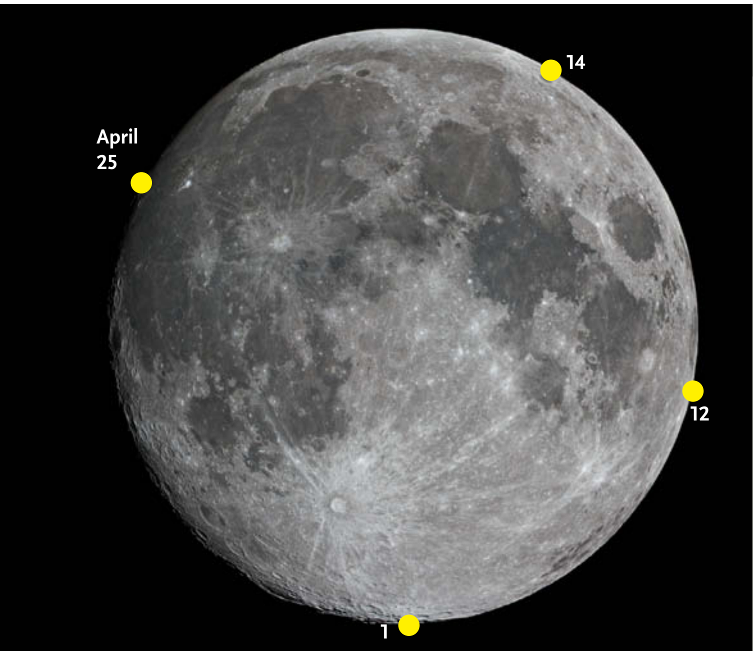
All of the vents described so far carried molten lava downslope, creating lava tubes, channels, and flows. Other vents hosted more explosive eruptions that scattered volcanic ash (known as *pyroclastics*) and rock fragments around them. Telescopic observers can see two kinds of ash deposits and associated vents. The more familiar ones are small circular collapse pits surrounded by haloes of dark ash, such as the famous dark spots on the floor of **Alphonsus**. Similar volcanic, dark halo craters also appear on the floor of **Atlas**. The best time to spot these dark halo craters is when the solar illumination is high, producing the greatest contrast between the dark ash and the brighter surrounding crater floor.

The second kind of pyroclastic eruption is less familiar to most observers. In these cases, ash erupted from a rille or a V-shaped depression with tapered ends. Two of the largest of these pyroclastic deposits appear as dark mantles over low hills east and south of **Sinus Aestuum**. The V-shaped vent that produced the eastern deposit is 7 by 3 km across, just northwest of the small crater Bode E; it is another challenging target for observers. Most other pyroclastic deposits are smaller, but two others are easy to find because of their darkness — the Taurus-Littrow landing site of Apollo 17, and **Rimae Sulpicius Gallus**, across the southern margin of Mare Serenitatis. ✦



DAMIAN PEACH

The sickle-shaped vent that produced Rima Hadley is briefly visible each month at the southwest end of the meandering channel.



The Moon • April 2013

Phases

LAST QUARTER	April 3, 4:37 UT
NEW MOON	April 10, 9:35 UT
FIRST QUARTER	April 18, 12:31 UT
FULL MOON	April 25, 19:57 UT

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

S&T: DENNIS DI CICCO

Distances

Apogee	April 15, 22h UT
251,568 miles	diam. 29′ 30″
Perigee	April 27, 20h UT
225,103 miles	diam. 32′ 59″

Librations

Cabeus (crater)	April 1
La Pérouse (crater)	April 12
Mare Humboldtianum	April 14
Eddington (crater)	April 25

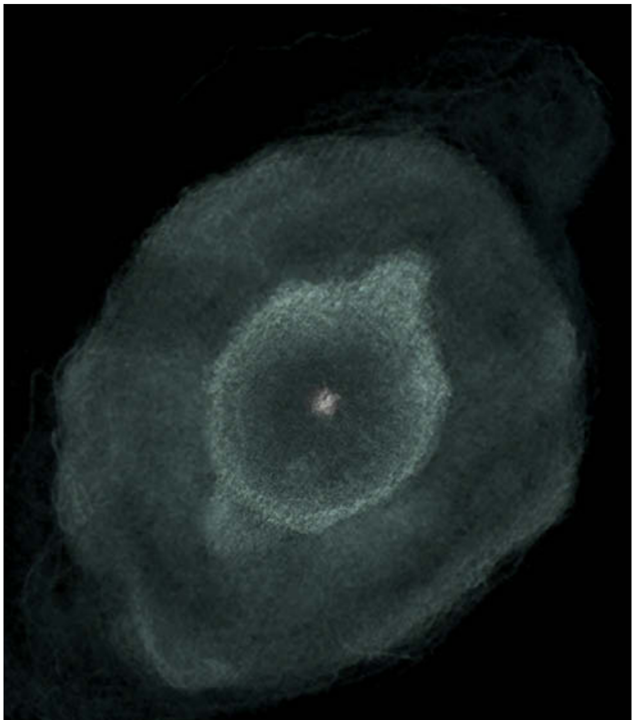
The Ghost of Jupiter

Hydra hosts an assortment of galactic and extragalactic objects.

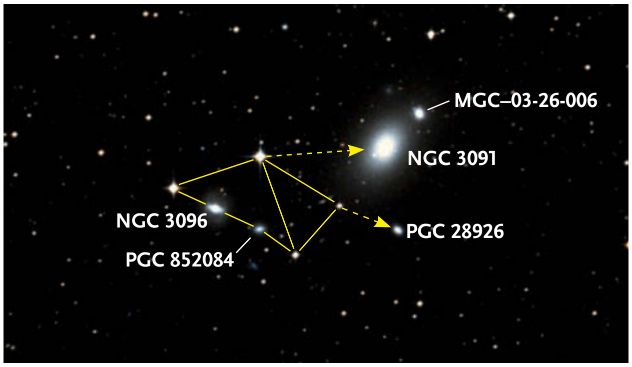
Call at will
Thine own ghost, or the ghost of Jupiter,
Hades or Typhon, or what mightier Gods
From all-prolific Evil, since thy ruin
Have sprung, and trampled on my prostrate sons.
— Percy Bysshe Shelley, *Prometheus Unbound*, 1820

According to mythology, Jupiter had Prometheus bound and tortured for long ages as punishment for favors that he bestowed on mankind and to make him divulge which of Jupiter's future sons was fated to dethrone him. In *Prometheus Unbound*, mother Earth offers guidance to captive Prometheus when he wants to recall the curse he hurled at Jupiter. The shades of all thinking beings remembered the curse, but Prometheus didn't want those words of hatred to be uttered again by himself or his shadow, so he summoned the "ghost of Jupiter."

The starry heavens hold their own Ghost of Jupiter, the



French stargazer Serge Vieillard sketched NGC 3242, the Ghost of Jupiter, on a superb night in Chile as seen at 575× through a 400-mm telescope.



POSS-II / CALTECH / PALOMAR OBSERVATORY

remarkable planetary nebula **NGC 3242** in Hydra. William Herschel discovered this nebula in 1785 and claimed that its light was the color of Jupiter, but the nebula's nickname was bestowed in 1882 by William Noble. In the periodical *Knowledge*, Noble wrote, "It will be seen as a pale-blue disc, looking just like the ghost of Jupiter."

Through my 105-mm refractor at 28×, NGC 3242 is a beautiful, small, round, vividly sky-blue disk. It maintains its color at 87×, while at 203× it appears slightly oval. My 10-inch reflector at 70× reveals a bright interior oval, which becomes a ring surrounding a faint central star at 320×. In my 14.5-inch reflector at 170×, the oval nebula and its interior ring lean northwest, and there's a bright patch on the ring's southeastern end. At 245× the bright patch is part of an arc along the ring, and another arc along the ring's opposite end holds a more subtle enhancement. The ring's northeastern flank shines brighter than the opposite side.

Now we'll move westward to visit the challenging, compact galaxy group Hickson 42. **NGC 3091** (Hickson 42a) is the brightest member, and it's plainly visible as a little smudge through my 130-mm refractor at 23×. It forms a line with a pair of 11th-magnitude stars roughly 3′ and 5′ east and slightly south of the galaxy. At 63× NGC 3091 becomes an oval glow, tipped northwest, that grows brighter toward the center. At 164× two of its companions make an appearance. The most obvious one is **NGC 3096** (42b). The 11th-magnitude stars team up with a dimmer star 3′ southwest to make a right triangle. Starting at the easternmost star, NGC 3096 lies about one-third of the way along the triangle's hypotenuse. Considerably tougher, **MCG–03-26-006** (42c) is a little round spot just off NGC 3091's northwestern tip.

Through my 10-inch reflector at 231×, NGC 3091 covers 2′ × 1¼′ and displays an oval core enwrapping a round nucleus. NGC 3096 is a ½′-long oval nearly aligned with the triangle's hypotenuse.

An extremely faint star off NGC 3091's southeastern tip forms a trapezium with the three triangle stars. The northwestern side of the trapezium points to a small and very faint smudge, as shown on the facing page. This is **PGC 28926** (42d), the final member of the group.

With averted vision, I also catch glimpses of a tiny faint spot about two-thirds of the way along the triangle's hypotenuse. This galaxy doesn't bear a Hickson designation and is known as **PGC 852084**. I can hold it steadily in view with my 15-inch reflector at 216×. The part of NGC 3096 that was visible in the 10-inch is now enshrouded in a gauzy halo tipped south-southeast, and MCG–03-26-006 gains an elusive, starlike nucleus.

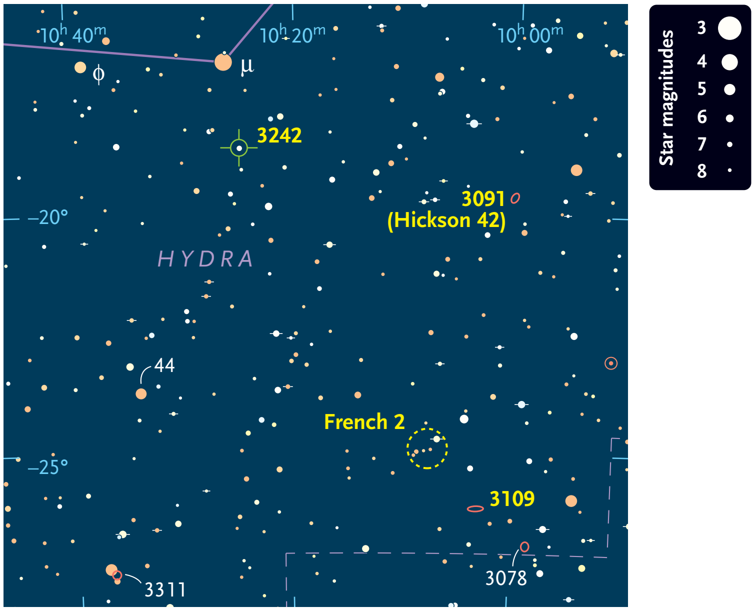
PGC 852084 and the Hickson group are both about 200 million light-years away from us, and they may be physically related.

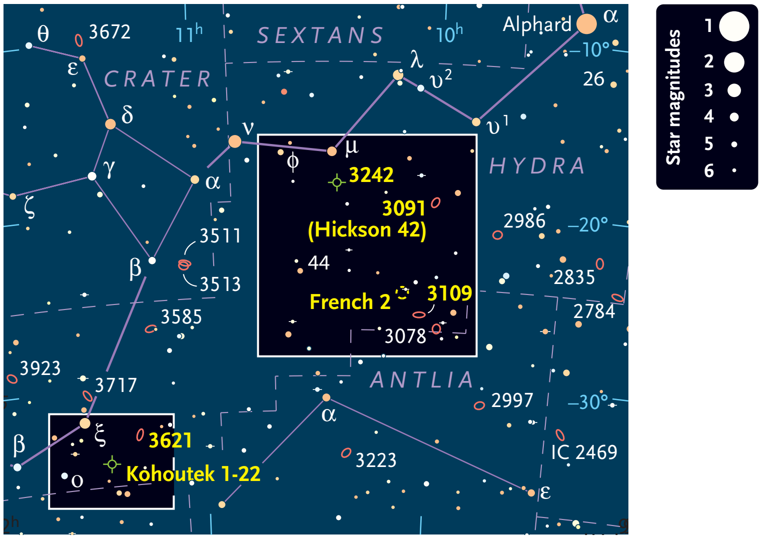
Let's drop 6½° southward to the galaxy **NGC 3109**, which covers more sky than all of the Hickson 42 galaxies combined. It's only 4 million light-years away and appears to be part of a small, dynamically distinct association of galaxies nosing the outer boundaries of our Local Group.

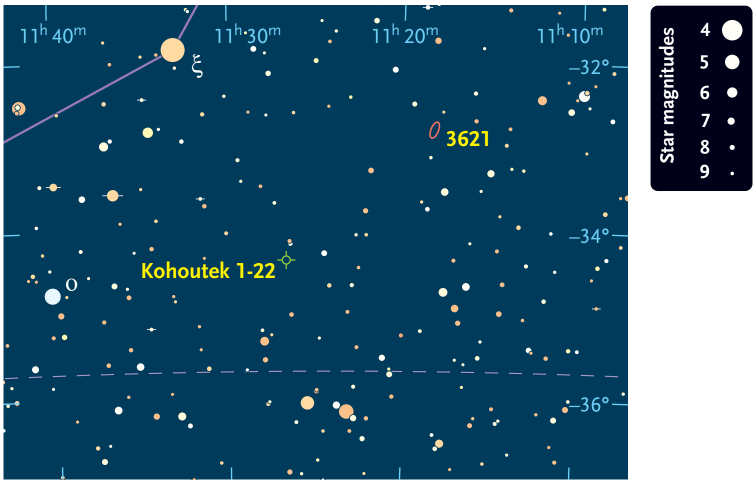
In my 105-mm refractor at 28×, NGC 3109 is highly elongated east-west with a somewhat brighter area in the center. Several faint stars watch the galaxy's southern flank and eastern end. To the south, a shallow, 1.2°-long S curve of eight 7th- to 9th-magnitude stars snakes northwest across the field. Although the galaxy's surface brightness appears low at 87×, it's intriguingly irregular. NGC 3109 covers about 14′ × 2½′, with its eastern end sandwiched between a star pair north and a single star south.

NGC 3109 looks very unusual in my 10-inch reflector at 113×. The center of the galaxy is brighter, but in a pattern quite unlike the typical round or oval core of most galaxies. In the north, this bright region lines more than one-third the galaxy's length and then quickly narrows to a blunt point in the south. It nearly spans the galaxy's width and is unevenly bright. A faint star is superposed on its western side, and another hovers just above (north of) its eastern end. In and around the rest of the galaxy, very faint stars pop in and out of view, while numerous brighter ones adorn the field.

While observing NGC 3109 with my 105-mm scope, I noticed a cute asterism 1.6° northeast of the galaxy. At 17× I see 11 stars, magnitudes 7 to 11, forming an improbably long-necked dromedary camel headed west. The brightest star marks the top of his head, and he spans nearly 40′ nose to tail. Learning of my "discovery," the Deep Sky Hunters' Yahoo group included this in its catalog of asterisms as **French 2**.







Moving to Hydra's southernmost bend, we see the 4.7-magnitude star Omicron (ο) Hydrae. Look 2.8° west and 22′ north of that star for a planetary nebula known as **Kohoutek 1-22** (PN G283.6+25.3), or the Southern Owl. The nebula is faintly visible at low power with my 130-mm refractor, but after trying lots of eyepiece and filter combinations, I settled on a filterless, 102× view as the most pleasing. The planetary looks round and fairly large at 2½′, with low surface brightness that hints at being uneven. The best image through my 10-inch reflector comes at 115× with a narrowband nebula filter. The nebula shows subtle brightness variations and is brightest in the northeast and southwest.

The Southern Owl gets its nickname from its close photographic resemblance to the Owl Nebula (M97) in Ursa Major. Both look somewhat like a round face with two large eyes. The bright areas seen with my 10-inch scope correspond to the owl's forehead and lower face, while the dark patches southeast and northwest are his eyes.

Our tour's finale features the big, bright spiral galaxy **NGC 3621**. It's readily visible in my 105-mm refractor at 17× as an oval glow that leans north-northwest and grows brighter toward the center. A star is pinned to the galaxy's western flank, and a fainter one is affixed to its south-southeastern tip. At 87× a total of four stars frame the brightest part of NGC 3621, inscribing it in a kite flying south-southeast. The 4½′ × 1¾′ outer core appears woolly with a dark area along its western side, while the galaxy as a whole reaches 8′ × 3½′. With my 10-inch scope at 170×, both sides of the core are lined with darker bands and dim haze beyond.

NGC 3621 is relatively nearby at 20 million light-years. Its stellar disk spans roughly 100,000 light-years, making it comparable in size to the galaxy we call home. A 2009 study by Mario Gliozzi and colleagues published in *The Astrophysical Journal* indicates that NGC 3621 may contain a central black hole with 20,000 times our Sun's mass closely flanked by two other black holes, each harboring a few thousand solar masses. ✦

Sky & Telescope **contributing photographer Robert Gendler captured the magnificent spiral galaxy NGC 3621 with 12 hours of exposure through a 14.5-inch telescope.**

Nebulae and Galaxies in South Central Hydra

Object	Type	Mag(v)	Size/Sep	RA	Dec.
NGC 3242	Planetary nebula	7.7	42″ × 38″	10^h 24.8^m	–18° 39′
NGC 3091 (42a)	Galaxy	11.1	3.0′ × 1.9′	10^h 00.2^m	–19° 38′
NGC 3096 (42b)	Galaxy	13.1	1.0′ × 0.8′	10^h 00.6^m	–19° 40′
MCG–03-26-006 (42c)	Galaxy	13.4	0.4′ × 0.4′	10^h 00.2^m	–19° 37′
PGC 28926 (42d)	Galaxy	14.9	0.44′× 0.36′	10^h 00.2^m	–19° 40′
PGC 852084	Galaxy	15.0	0.5′ × 0.4′	10^h 00.5^m	–19° 40′
NGC 3109	Galaxy	10.8	19.1′ × 3.7′	10^h 03.1^m	–26° 10′
French 2	Asterism	—	39.6′	10^h 07.7^m	–24° 55′
Kohoutek 1-22	Planetary nebula	12.1	3′	11^h 26.7^m	–34° 22′
NGC 3621	Galaxy	9.6	12.3′ × 7.1′	11^h 18.3^m	–32° 49′

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

DID YOU KNOW?

The interactive observing tools at skypub.com/tools include such diverse functions as a daily almanac, a telescope eyepiece calculator, predictions of Algol minima, an artificial satellite tracker, and tools to predict the visibility of all the major planetary satellites as well as surface features on Jupiter and Mars.


Sky & Telescope's
SkyWeek
Take the guesswork out of finding the best celestial sights. It's a daily diary of the most interesting astronomical happenings.
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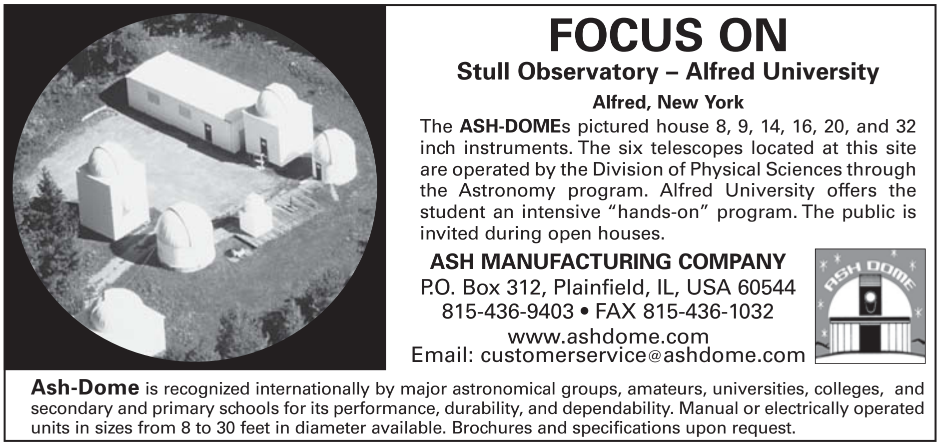
FOCUS ON
Stull Observatory – Alfred University
Alfred, New York
The ASH-DOMEs pictured house 8, 9, 14, 16, 20, and 32 inch instruments. The six telescopes located at this site are operated by the Division of Physical Sciences through the Astronomy program. Alfred University offers the student an intensive "hands-on" program. The public is invited during open houses.
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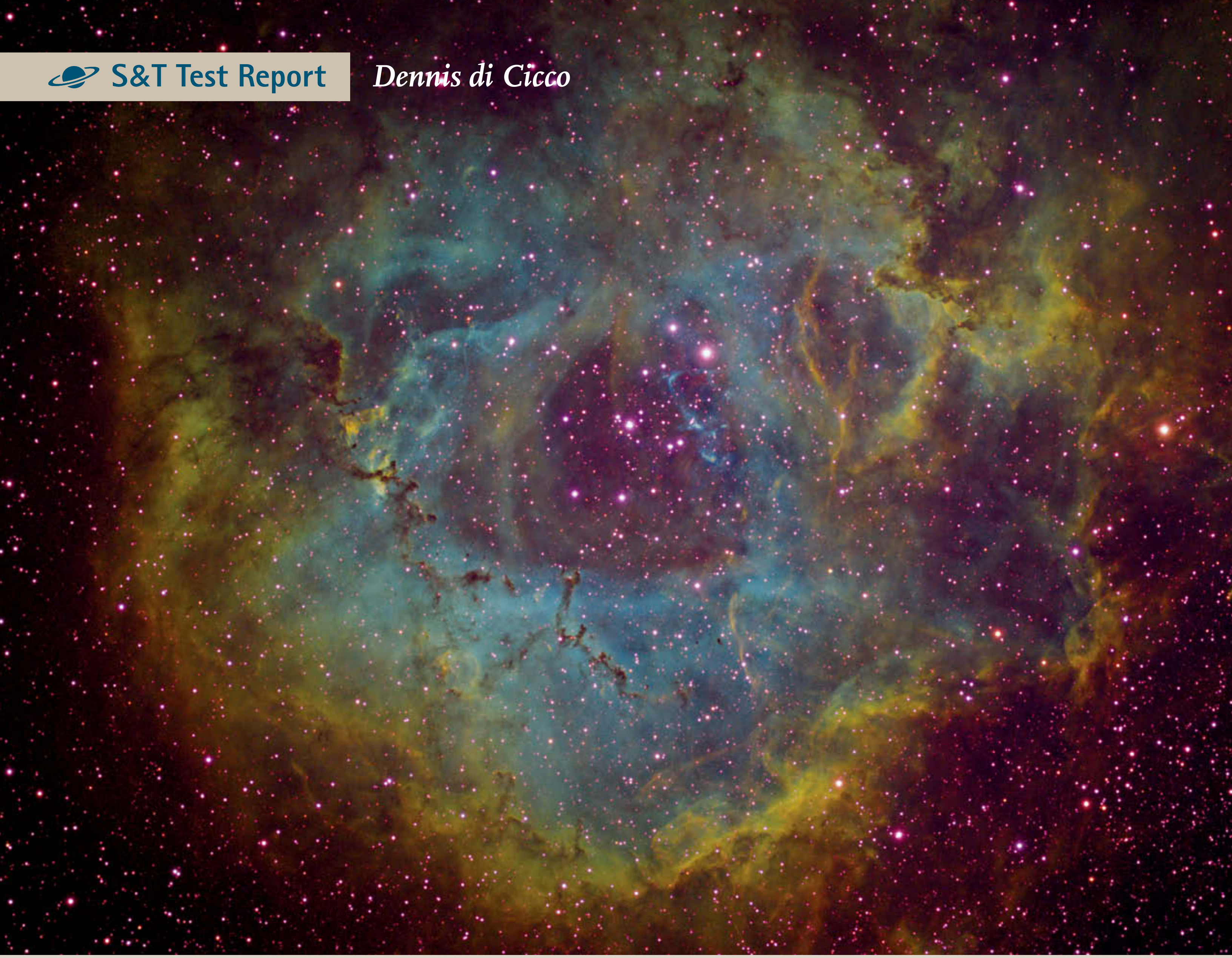
Dennis di Cicco



Officina Stellare's Veloce RH200 Astrograph

This 8-inch f/3 catadioptric system hits a lot of sweet spots for today's astrophotographers.

The Veloce RH200's f/3 focal ratio makes it a superb astrograph for imaging nebulae with narrowband filters. The author made this view of the Rosette Nebula using SBIG's new STT-8300 camera; H-alpha, SII, and OIII filters; and approximately 2 hours of exposure through each filter.

ALL PHOTOS BY THE AUTHOR WITH ADDITIONAL IMAGE PROCESSING BY SEAN WALKER

WHAT WE LIKE:

- Ideal system for medium-field deep-sky imaging
- Superb image quality across large CCD chips
- Stable focus in changing temperatures

WHAT WE DON'T LIKE:

- Unusually heavy for its size; requires substantial mount

While reviewing imaging equipment a few years ago, I envisioned an astronomical Rip Van Winkle awakening from his 20-year snooze to discover a world of astrophotography unlike anything that existed when he dozed off. Digital cameras, computerized image processing, and new telescopes made specifically for astrophotography were just some of the wonders he'd encounter. Well, it's time to dust off that literary conceit for use again, because today's awakening Rip would have even more new wonders to behold. And one that would surely boggle his mind is Officina Stellare's new Veloce RH200, a Riccardi-Honders 200-mm (8-inch) f/3 astrograph.

Indeed, old Rip could have taken a mere catnap and been surprised by the Riccardi-Honders design, since it was barely a blip on astrophotography's radar five years ago. New designs, not to mention new names for variations on older designs, continually turn up in the imaging marketplace. But the Riccardi-Honders design stands out from the others. Writing in their new book *Telescopes, Eyepieces, and Astrographs* (Willmann-Bell, 2012), Gregory Hallock Smith, Roger Ceragioli, and Richard Berry, state that "In principle, [the Riccardi-Honders design] is better than any other astrograph we know." That's a pretty powerful statement given the wide range of high-end imaging systems currently available.

These authors also note that while the Riccardi-Honders moniker is relatively new, the design has roots extending as far back as the early 19th century. Furthermore, during the latter half of the 20th century, systems "practically identical" to the Riccardi-Honders were proposed by various optical designers. For astrophotographers, however, the ball started rolling soon after the turn of the millennium when Klaas Honders introduced amateur telescope makers to a Newtonian variant of earlier designs. A few years later, Italian optical designer Massimo Riccardi worked Honders's system into the Cassegrain configuration found in today's astrographs.

With its dew cap retracted, the RH200 is not much longer than it is wide. But the dew cap must be fully extended (seen below) when the astrograph is used, since the dew cap's front aperture forms an integral part of the imaging system.

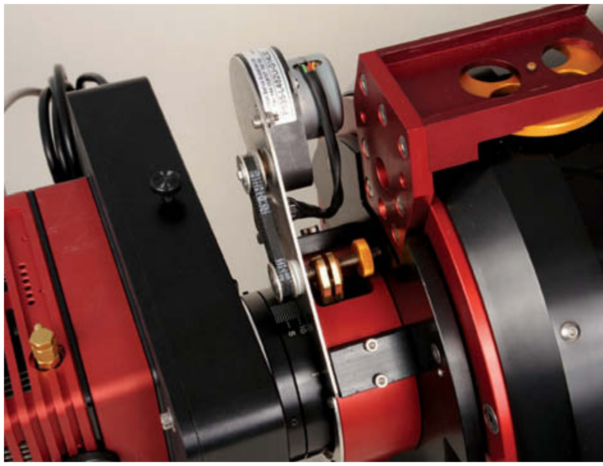
In a nutshell, these astrographs have a full-aperture, single-element meniscus objective, a Mangin-type primary mirror (basically a meniscus lens that light passes through twice due to a reflective coating on the *back* side of the glass), a convex Cassegrain secondary mirror, and a corrector lens near the focal plane. The system produces tight, round star images on a large, flat focal surface through a wide range of wavelengths. And it can be made with large apertures and very fast f/ratios. In other words, the Riccardi-Honders design has the qualifications required to make it the Holy Grail of astrophotographers.

We borrowed the Veloce RH200 from its Italian manufacturer for this review. The most basic form of the Veloce RH200 is the optical tube assembly with a Vixen-style dovetail mounting bar, but without a focuser. The model we borrowed came with Officina Stellare's robust Crayford-style focuser (a $200 option), which has precision

Although tested with several cameras, the RH200 astrograph worked particularly well with SBIG's STT-8300 CCD camera and autoguiding filter wheel pictured here. Officina Stellare makes an 80-mm guide scope that fits on the astrograph's top bracket.

RH200 Astrograph

U.S. price: from $8,395
Available from Officina Stellare dealers worldwide
officinastellare.com



Left: **As explained in the text, full-frame DSLR cameras work best when used with special adapter rings.** ***Center:*** **The Riccardi-Honders optical design in the RH200 has a full-aperture corrector with an aluminized spot on its back side forming the Cassegrain secondary mirror.** ***Right:*** **Some camera setups have limited clearance with the optional RoboFocus system (see the accompanying text for details).**

tip-tilt adjustments for squaring it to the scope's optical axis. The focuser was also fitted with an optional RoboFocus motor drive that has a starting price of about $400 and can run upward of $600 depending on the electronic package ordered with it.

Multiple Sweet Spots

The Veloce RH200 has a lot going for it. The one thing that immediately catches the eye of even casual astrophotographers is its unusually fast f/3 focal ratio, which makes it an ideal instrument for recording faint nebulosity. It also has 8 inches of aperture, and it is aperture, not f/ratio, that is the critical factor for imaging faint stars. Next on the list is its 600-mm focal length and corresponding image scale of 344 arcseconds per millimeter, which is enough to resolve fine detail in nebulous objects. And then there's field coverage. The RH200 is spec'd to cover a 43-mm imaging circle (spanning a 4.1° diameter field). This imaging circle is big enough to cover a full-frame DSLR or the popular Kodak KAI-11000 "full-frame" sensor used in many astronomical CCD cameras. But, as some of the images with this review show, I also had excellent results shooting with an even-larger-format KAF-16803 CCD camera, which requires an imaging circle 52 mm in diameter for full coverage. When I shot pictures with the RH200, only the very corners of the large-format chip had degraded star images.

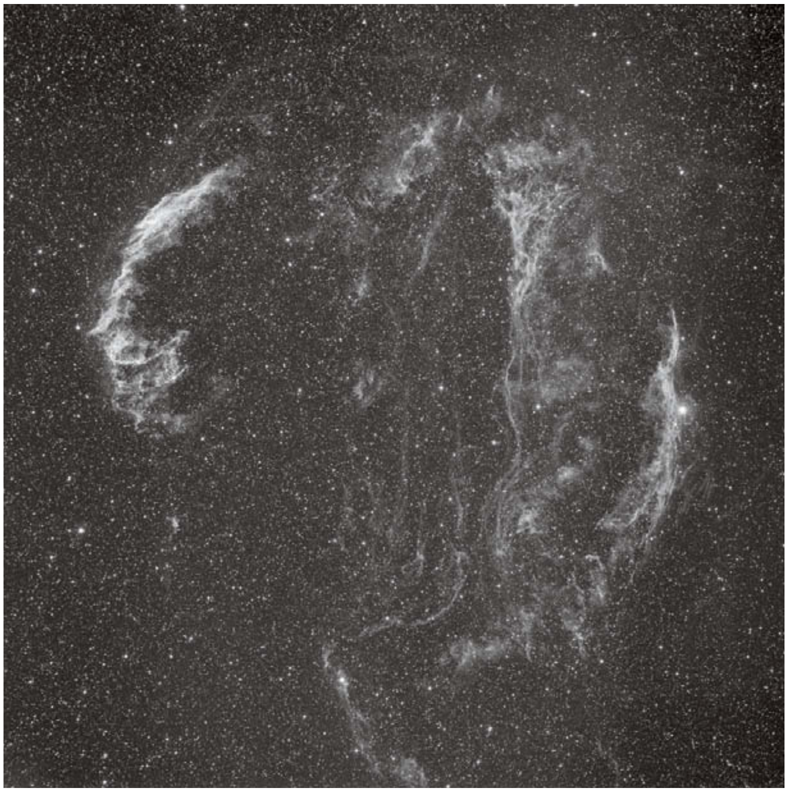
In my opinion, the real "sweet spot" for the RH200 is when it's connected to an astronomical CCD camera having the highly popular KAF-8300 chip. The result is a system with an image scale of 1.86 arcseconds per pixel and a very uniformly illuminated field of view covering 1.7° by 1.3°. In the interest of full disclosure, such a setup is ideal for the medium-field, deep, narrowband imaging that I like to do. But as much as I'm attracted to the RH200 because of these numbers, they are meaningless if the astrograph doesn't perform well under the stars. And that's where the RH200 really showed its mettle.

Left: **An unprocessed snapshot of the Pleiades in strong moonlight shows that only modest vignetting occurs when a full-frame DSLR camera is fitted with the large-aperture adapter shown above.** ***Right:*** **Even the brightest stars, such as Zeta Orionis in this 2-hour H-alpha exposure of the Horsehead Nebula, produce relatively small halos and no ghost images when recorded with the RH200.**

I tested the astrograph with a Nikon D700 full-frame DSLR; an FLI ProLine 16803 CCD camera, and the new SBIG STT-8300 CCD camera pictured on page 61 (which will be reviewed in an upcoming issue). Officina Stellare provided me with adapters for the Nikon and FLI cameras, and, because of its newness, I machined my own adapter for the STT-8300. However, I'm sure these will become commercially available very quickly. Although it's possible to use standard T-thread adapters to mount DSLRs to the RH200, these are only suitable for cameras with APS-size chips. Using full-frame cameras with T adapters will vignette the corners of the frame due to the restricted clear aperture of T-thread fittings. There are several sources, including Borg and Teleskop-Service, that offer large-aperture adapters made specifically for astrophotography with full-frame DSLR cameras.

Another caveat that goes with mounting cameras to the RH200 is its fixed backfocus, which falls about 60 mm beyond the astrograph's fully retracted focuser. That can be rather tight spacing for some setups. For example, the STT-8300 and its self-guiding filter wheel reached focus with less than a millimeter to spare between the plug on the RoboFocus electrical cable and the front of the filter wheel. And my Nikon would only reach focus when the camera body was turned such that the protruding front of the camera avoided the RoboFocus mechanism.

The last item worth mentioning is the RH200's weight. There's a lot of glass in the system, and despite its very compact appearance, it weighs almost 20 pounds (9 kg) without a camera attached. It thus requires a relatively substantial mount for astrophotography.



Although the detector in the FLI ProLine 16803 CCD camera used for this 200-minute H-alpha exposure of the Veil Nebula covers a greater field than spec'd for the RH200, star images are excellent in all but the corners of the frame.

Another 200-minute H-alpha exposure made with the FLI ProLine 16803 CCD camera captures a 3.5°-wide field and the brightest portions of the well-know emission nebula IC 1396 in Cepheus.

Overall, the RH200 performed superbly. Ghost images were never a problem, and halos around very bright stars were acceptable (see, for example, the image of the Horsehead Nebula on the facing page). The focus was remarkably stable over the temperature variations I experienced on most nights this past winter. During one 7-hour imaging sequence last January, I measured star diameters that tracked perfectly with my target's changing altitude despite a temperature drop of 10°F (5.6°C) from start to finish. I also found no need to refocus the telescope when I switched color filters while shooting broadband red, green, and blue images or narrowband images using H-alpha, SII, and OIII filters. When shooting multi-wavelength image sets, I'd always focus the RH200 using the filter closest to the middle of the wavelength range.

The accompanying photos pretty much speak for the imaging quality of the RH200. As I mentioned above, because the astrograph is ideally suited for the kind of imaging I most enjoy doing, I had very high expectations for the scope before it arrived. And there's no question that it lived up to all of them during the time I spent shooting with it. That, in my opinion, says a lot. ✦

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*Senior editor **Dennis di Cicco** needed more than a few catnaps to catch up on all the sleep he lost while shooting images with the Veloce RH200 astrograph.*

A Box of Bino Fun

Big binoculars open up a universe of observing opportunities.

Bill Faatz's 5-inch "bino box" provides stunning views of the night sky. It's built with mostly commercially available components.

BEING AN AVID binocular observer and equipment nut, I'm very fond of telescope-making projects involving binoculars. This is especially true when the instrument is nicely crafted and relatively easy to build, such as the one described here by northern California amateur Bill Faatz.

Telescope makers are motivated by many factors, but one of the most common is the desire to obtain equipment that isn't commercially available. Bill owned 25×150 Fujinon binoculars, and though the views through them were excellent, they weighed 150 pounds (68 kg) with the mount. He also found that the straight-through viewing angle and fixed magnification were limiting.

So Bill set out to build his own big binoculars. What I find very appealing about his design is that there are very few tricky parts to make. The main component is a plywood box measuring 20 by 15 by 8 inches. Everything else is available off the shelf.

The heart of the system is a pair of Istar 127-mm (5-inch), f/5.5 achromatic objective lenses from **www.istar-optical.com**. The remaining optical parts are mirrors and eyepieces. "Because my bino box uses three mirrors, the odd number of reflections yields the same image orientation as a refractor or Cassegrain used with a star diagonal," Bill explains. Inside the box, a pair of standard 3.1-inch (minor-axis) Newtonian secondary mirrors feed 2-inch star diagonals. These, in turn, direct light to 1¼-inch star diagonals that hold the eyepieces. As Bill reports, "The helical focusers allow inter-ocular spacing adjustment of the eyepieces, and the star diagonals provide a 90° viewing angle."

ALL PHOTOS BY BILL FAATZ

Each half of the binocular uses a pair of star diagonals — a 2-inch model and a 1¼-inch that holds the eyepieces. Inter-ocular spacing and rough focusing is done with helical focusers, while fine focus is achieved by sliding the eyepieces in and out of the star diagonals.

In addition to cost savings, the optical configuration of the bino box yields two advantages over many commercial big binoculars. The first is the ability to vary the magnification using different eyepiece pairs. The other involves the use of first-surface mirrors rather than prisms, which helps ensure excellent image contrast and good illumination across the field of view. "By ray-tracing the design and carefully positioning the mirrors," Bill explains, "I was able to achieve nearly 80% illumination at the edges of my low-power eyepieces."

Those of us who routinely use 10×50 binoculars can imagine how great the views in 5-inch binos are. Bill doesn't have to imagine. "Last summer I tried the bino box on the Veil Nebula using 24-mm (29×) and 19-mm (36×) Tele Vue Panoptic eyepieces equipped with ultra-high-contrast nebula filters," Bill recalls. "I saw lots of detail in the main halves of the Veil and all kinds of bits and pieces of bright nebulosity in between, including a well-defined Pickering's Wisp."

Dark nebulae dotting the summer Milky Way are another prime target. "The area around Gamma Cygni clearly shows a wealth of bright and dark nebulae, and Barnard's 'E' in Aquila stands out boldly," says Faatz.

Readers can learn more about Bill's binoculars by e-mailing him at **bfaatz@windjammercable.net**. ✦

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*Contributing editor and avid telescope maker **Gary Seronik** writes our Binocular Highlights column (page 45). He can be contacted through his website, **www.garyseronik.com**.*

Top 10 Neglected

So many familiar deep-sky objects fill the night sky that quite a few equally worthy and exciting ones suffer observer neglect. Here's my personal roster of the 10 most fascinating of these, drawn from my more than 20,000 hours of stargazing with hundreds of amateur telescopes over the past 50 years.

For each, I suggest an explanation for why it's largely overlooked. Many of the nicknames I coined myself, in hopes of giving these objects a little more flair and vitality. After viewing them, you'll surely want to expand your skills (and thrills!) by seeking out other examples and compiling a list of your own.

All are plotted on major star atlases. Numbers 1, 2, 3, 5, 7, and 8 are in good early-evening view right now.

James Mullaney, F.R.A.S.

Hidden in plain sight, why aren't these familiar old favorites?

1. NGC 2477: Puppis Supercluster. Famed observer Steve O'Meara calls this superb open cluster the best non-Messier object in the sky. Yet it remains little known and rarely observed. So what's wrong with it? It's fairly far south, at declination –39° in Puppis, causing William Herschel to miss it in his pioneering sweeps of the heavens. It's also just 1.4° from larger, brighter, but much sparser NGC 2451, as seen at right. But when they're on the meridian after nightfall in March, they're a good 10° high even as seen from latitude 41° north (New York, Denver, Madrid), readily visible in binoculars and grand in a telescope.

Backyard scopes show NGC 2477 with at least 300 stars crowded into a slightly irregular pattern some 0.5° wide, about the apparent diameter of the Moon. It's a beautiful sight in a 4-inch reflector at 45×, and the star density holds up well enough to make it spectacular even in the largest of amateur instruments despite overflowing the field of view. More on the spectacular odd couple of NGC 2477 and 2451 is in last month's issue, page 57.

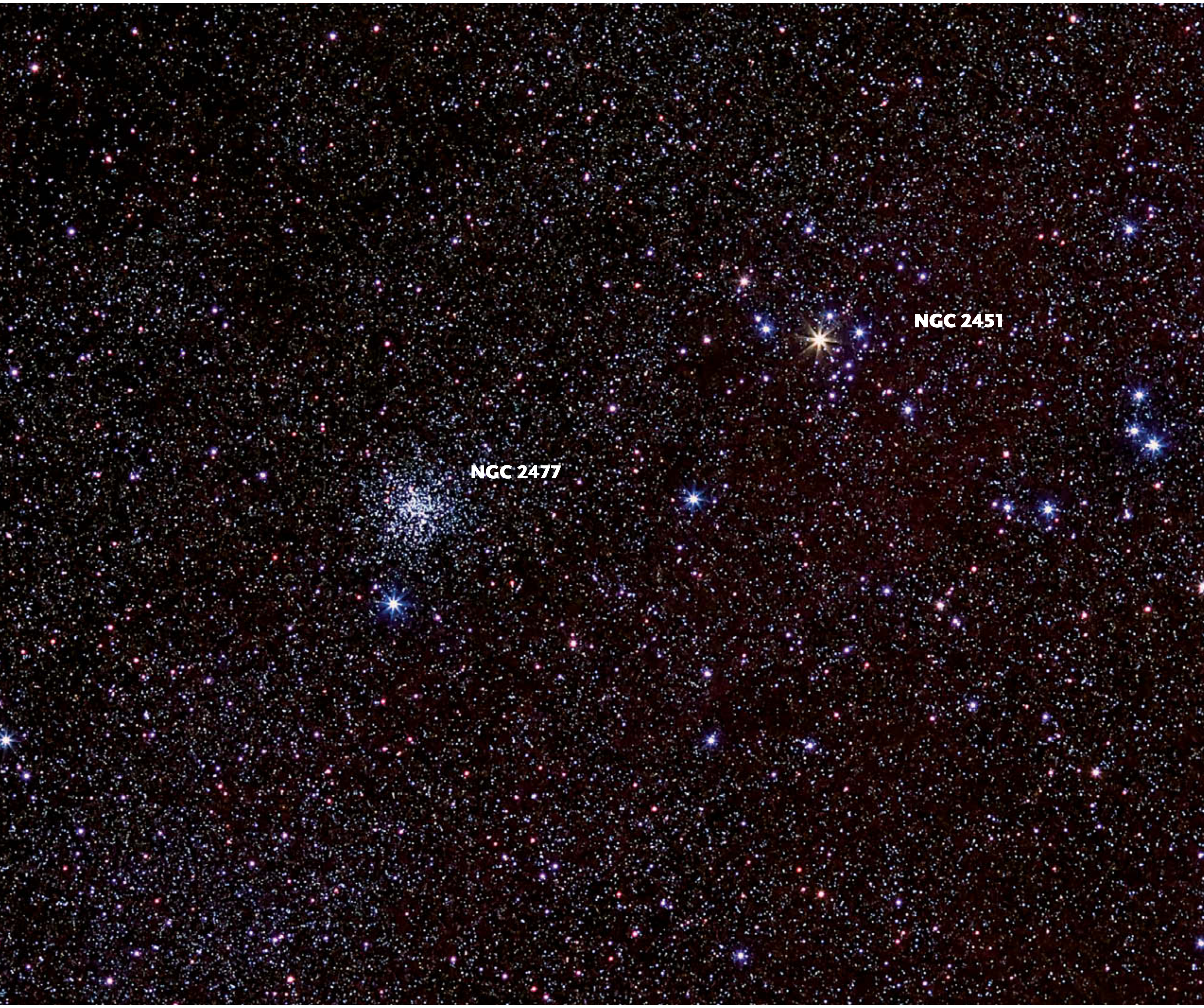
Puppis Supercluster

NGC 2477
Open cluster in Puppis
Magnitude 5.8
Size: 20′
R.A. $7^h\ 52.3^m$
Dec. –38° 33′

In southern Puppis, use bright but sparse NGC 2451 as your starting point for spotting much richer NGC 2477.

ALAN DYER

Deep-Sky Wonders



Eight-Burst Nebula

NGC 3132
Planetary nebula in Vela
Magnitude 9.2
Size: 84″ × 52″
R.A. 10^h 07.0^m
Dec. –40° 26′

SERGIO EGUIVAR

Catch NGC 3132, a southern ring nebula on the border of Vela and Antlia, when it transits in the evening at this time of year.

2. NGC 3132: The Eight-Burst Planetary. Like the previous object, this amazing planetary nebula is largely unknown to most northern observers, due to its declination of –40° on the Vela-Antlia border. Yet it too is an easy catch when on the meridian. Sometimes called the “Southern Ring Nebula,” it’s not only brighter than the famed Ring in Lyra (M57) but has an obvious central star of 10th magnitude.

Moreover, it shows structure in amateur instruments. The elliptical nebulosity, gray to the eye with a hint of blue, is readily seen in a 5-inch at 50×. A 10-inch at 100× shows intriguing structure suggesting overlapping oval rings (thus the “eight-burst” name). Whatever telescope you’re using, if you love the Ring Nebula (and who doesn’t?), I guarantee you’ll be asking yourself why you never bothered to seek out this neglected southern version once you’ve laid eyes on it!

Herschel’s Wonder Star

Beta Mon
Triple star
Mags. 4.6, 5.0, 5.4
Seps. 7.3″, 9.3″, 2.9″
R.A. 6^h 28.8^m
Dec. –7° 02′

3. Beta Monocerotis. William Herschel (1738–1822) is best remembered for discovering Uranus and for cataloging 2,500 star clusters and “nebulae” (mostly galaxies) by 1802. His son John published these in the *General Catalogue of Nebulae and Clusters of Stars,* which in 1888 became the foundation of the *New General Catalogue (NGC).*

But William Herschel also discovered more than 800 double and multiple stars. Beta Mon thrilled him so much that he named it the “Wonder Star.” Despite its beauty as perhaps the finest triple of its class, and despite being the brightest star in Monoceros, it’s largely ignored — undoubtedly due to the overpowering majesty of Orion to the west and the hoard of clusters in the Monoceros-Puppis Milky Way to the east.

Beta Mon’s three components, fairly similar in brightness and all bluish white, form a flat triangle about 10 arcseconds long. The fainter two form the closest pair. All are highly luminous stars of spectral type *B*. My 5-inch Schmidt-Cass shows an elongated, triangular mass at 50× and splits them cleanly at 100×. Seen in a 10-inch or larger scope at 150×, Beta Mon is definitely a most beautiful stellar triple play.

South Double Double

Nu Scorpii
Quadruple star
Mags. 4.4, 5.3 / 6.6, 7.2
Separations 1.3″ / 2.4″
R.A. 16^h 12.0^m
Dec. –19° 28′

4. Nu Scorpii: A Tinted Double Double. Telescope users often look in on “the Double Double,” Epsilon Lyrae near Vega. Here’s another in a different well-known area: the head of Scorpius. Many who’ve looked at this object think it’s just a fairly wide pair (41″), unaware that each star itself is two!

A 3-inch glass at 30× on an average night shows it only as a pair. But a 3-inch at 100× in good seeing splits the wider of the two stars and elongates the other. A 5-inch at 100× resolves both doubles. Subtle color contrasts within each become evident in 6- and 8-inch apertures. Nearly a century ago William Tyler Olcott wrote in his classic *Field Book of the Skies,* “Nu Scorpii is said to be the most beautiful quadruple star in the sky.” Indeed, viewing it in a 13-inch refractor at 180×, I rated it just that.

Tau CMa Cluster

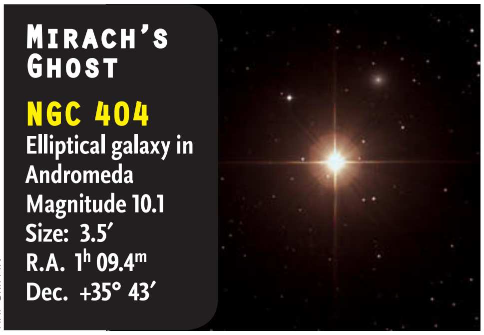
NGC 2362
Open cluster in Canis Major
Magnitude 3.8
Size: 6′
R.A. 7^h 18.8^m
Dec. –24° 57′

SERGIO EGUIVAR

Surrounding 4th-magnitude Tau Canis Majoris is the tight little triangular cluster NGC 2362. North is up in all images.

5. NGC 2362: The Tau CMa Starburst. Here’s a celestial surprise package if ever there was one! Yet I’ll bet most readers have never laid eyes on it. This glittering jewel box of 60-some stars is less than 2° south-southeast of h3945 on the facing page. It’s found easily enough, being centered on 4th-magnitude Tau Canis Majoris (itself a cluster member). But it’s so compact, about 6′ wide, that the cluster symbol is barely noticeable on most atlases due to the star’s big dot right on top of it. As a result, those sweeping for treasure using an atlas often pass right by this tiny clan.

But once spied, it’s a different story. A 2.4-inch refractor or 3-inch reflector at 30× shows something unusual about the star, as if it has a halo of sorts. A 4-inch at 60× reveals the halo to be a close-knit cluster of blue-white suns, and as aperture increases they become ever more spectacular. In an 8-inch at 80× it truly lives up to its “starburst” name, reminding me of fireworks frozen in space, or perhaps an exquisite piece of celestial jewelry with Tau set in a ring of diamonds. To fully sense its rare beauty, gaze upon it with the largest scope you can get your hands on.



HAP GRIFFIN

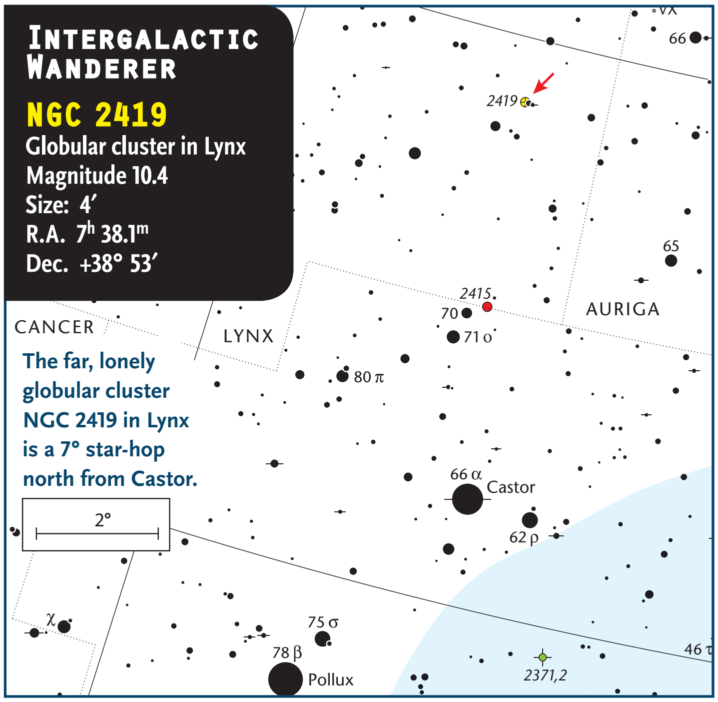
Dazzling Beta Andromedae, or Mirach, fails to overwhelm 10th-magnitude NGC 404 in this image by Hap Griffin of South Carolina.

6. NGC 404: The Comet Impostor. I've been credited with saving an entire galaxy from oblivion! Although NGC 404 in Andromeda isn't bright at 10th magnitude, it's one of the easiest galaxies in the sky to find — and overlook. That's because it lies in the same field as 2nd-magnitude Beta Andromedae (Mirach). Look for a faint, round glow 0.1° north-northwest of the dazzling orange star. In atlases it was hidden under the star symbol — until I called Walter Scott Houston's attention to it, and he wrote about it in his *S&T* column for December 1968. As a result, later atlases began showing the galaxy cut into Beta's big symbol.

Easy to find but hard to see, the galaxy looks much fainter than its magnitude due to contrast with Beta. Those who chanced upon it often mistook it for a comet they'd just discovered, since it wasn't on their maps. A 3-inch glass at 60× will show it, and it's fairly obvious in a 6-inch at 90× on a transparent night. Higher power helps with "Mirach's Ghost," as does moving Mirach out of the field.

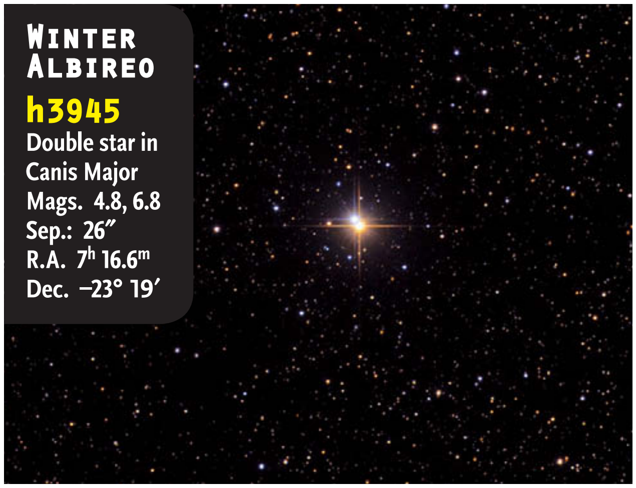
7. NGC 2419: Intergalactic Wanderer. Dim and tiny for a globular star cluster, this remote stellar mass hardly seems like a worthy specimen of its exalted class and thus goes ignored in favor of more exciting starballs. But its very remoteness is what makes it fascinating, if a bit challenging, in small scopes. At a distance of some 300,000 light-years (nearly twice as far as the Large Magellanic Cloud), it's the most distant globular cluster known to attend our galaxy. It's in the northern constellation Lynx, nowhere near most globulars.

There's something alluring about seeing so distant and unusual an object. Celestial objects seem to have personalities, and to me this one looks lonely out there by itself. Two 7th-magnitude "sentry stars" just to its west form an equal-spaced straight row with it, 8′ long in total. At magnitude 10.4, it's visible in a 3-inch refractor at 45×. But a 6-inch is really needed to appreciate the view. Seen in bigger scopes, this distant swarm is indeed a showpiece. It sparkles in a 14-inch Dobsonian at 200×, and Walter Scott Houston called it "a beautiful object for a 17-inch."



The far, lonely globular cluster NGC 2419 in Lynx is a 7° star-hop north from Castor.

SKY ATLAS 2000.0



The "Winter Albireo" is a never-to-be-forgotten stellar trophy over Canis Major's back. For this shot, Sergio Eguivar of Buenos Aires, Argentina, combined 12 minutes of exposures made with a 6-inch f/5 Newtonian reflector.

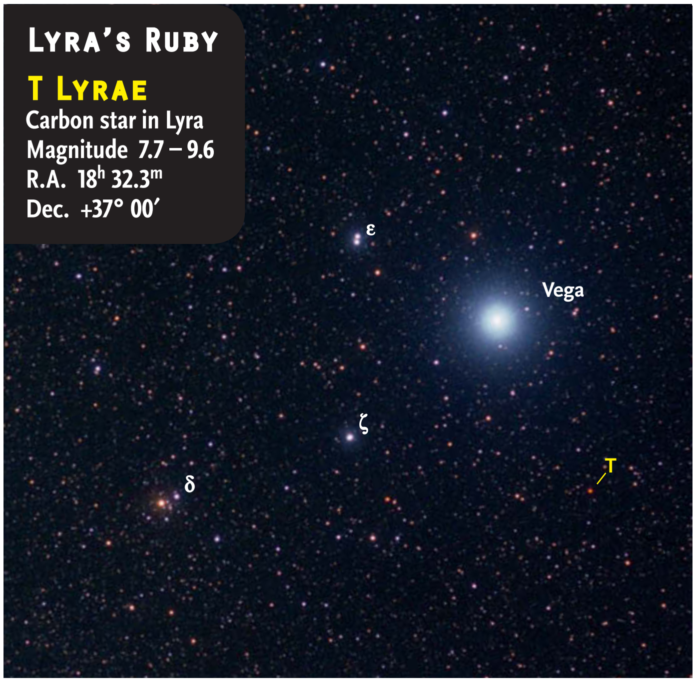
8. h3945: The Winter Albireo. Were I to pick one object that epitomizes a neglected wonder, it would be this lovely double 2° from the Tau Canis Majoris cluster. Its ruddy-orange and greenish-blue components, magnitudes 4.8 and 6.8, are more than a magnitude fainter than Albireo's, but they seem more intensely hued to some observers, including me. Indeed, the primary appears a fiery red at times, apparently depending on atmospheric conditions. Its spectral type is *K3* II; the secondary star is *A5*. Well separated at 26″, the pair is striking even in a 2-inch glass at 25× and absolutely superb in a 6-inch reflector at 50×.

So why the neglect? Overshadowing by radiant Sirius 10° to its northwest may be one reason. But I suspect the real cause is its intimidating, and often absent, designation. Having neither a Bayer Greek letter nor a Flamsteed number on atlases — not even a Struve (Σ) or other obvious double-star label — causes most observers to assume that it's insignificant. The "h" prefix indicates that it's one of the double-star discoveries of John Herschel, William's famous son. In any case, the Winter Albireo deserves to be on every showpiece list.

9. T Lyrae: Lyra's Ruby. So you think you know what's to be seen near Vega? Have you turned countless times to the Double Double, Zeta and Delta Lyrae, and the Ring Nebula? Hidden in the dark 2° southwest of Vega is one of the reddest stars in the heavens. I enjoy showing this gem to experienced observers who think they know the sky's wonders well, only to hear exclamations of surprise and delight upon seeing it.

T Lyrae is a type-*C*5 carbon star, and like many red giants it varies substantially in brightness — in this case between magnitude 7.7 and 9.6, irregularly. Its red hue is quite striking in a 6-inch at 50×, and being a bit on the dim side, it gets better with aperture. As always when viewing star colors, stare directly at it for maximum effect (as opposed to using averted vision, good for faint targets but not color).

Its proximity to Vega and the other wonders of Lyra probably accounts for its obscurity. So too does its lack of a popular name, unlike Herschel's Garnet Star (Mu Cephei), Hind's Crimson Star (R Leporis), and La Superba (Y Canum Venaticorum).

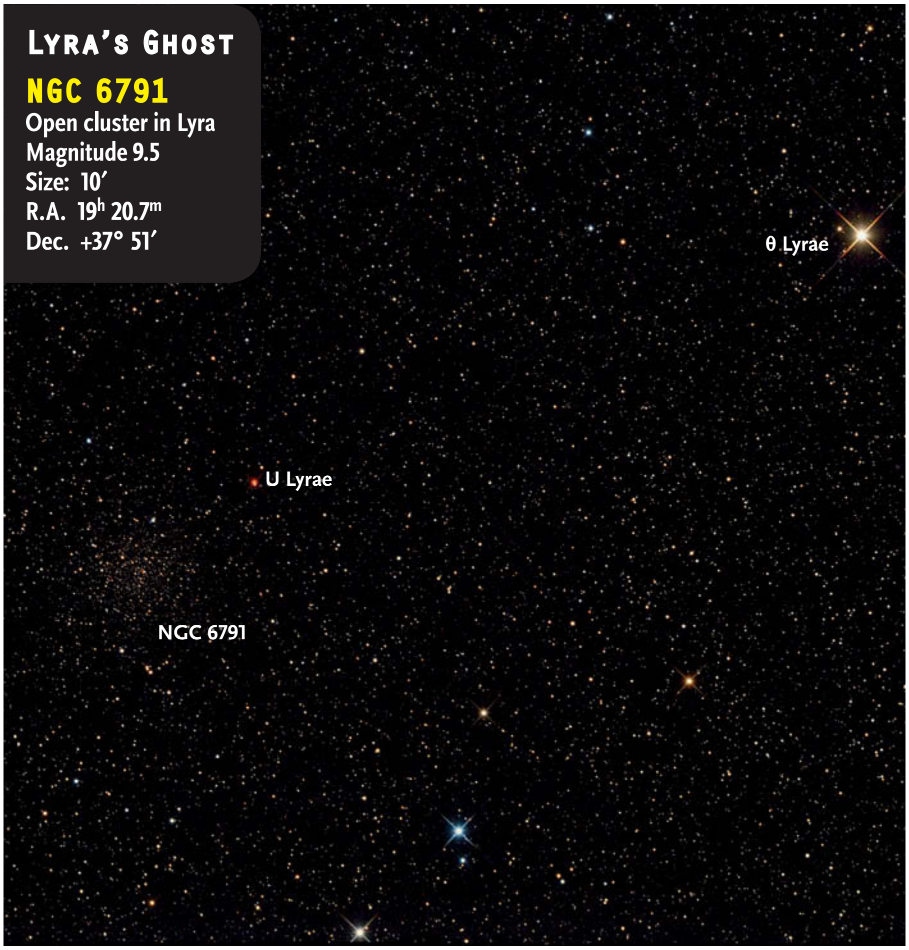


The most colorful stars in the sky are carbon stars such as T Lyrae near Vega. These red giants get their extra hue from carbon compounds in their atmospheres, which act as red filters.

10. NGC 6791: Lyra's Ghost Cluster. It's easy to see why this object is neglected. Most observers pass right over it without realizing it's there, as did the Herschels in their sweeps of the sky. So did I several times. So do some variable-star observers checking U Lyrae close by (another carbon star, dipping from magnitude 9.5 to 12.5 and back every 15 months). It's also absent from most atlases.

NGC 6791 is an easy star hop 1° east-southeast of Theta (θ) Lyrae east of Vega. So its position is a snap to locate. But it has a low surface brightness, with most of its stars 12th or 13th magnitude, giving it a decidedly ghostly appearance. Once people recognize it, however, they use superlatives: "A glorious sprinkle of over 300 stars!" "Exceedingly rich!"

Although classified as an open cluster, it seems to be a borderline globular with its richness, its stars' great age (they consist of three populations aged 4, 6, and 8 billion years), and its distance both from us — 13,000 light-years — and from the Milky Way's plane. Big, dim, and softly sparkling, it surprises you only after you realize you're looking right at it. A 6-inch at 50× shows it with averted vision on a dark, transparent night, while the view in 10-inch and larger apertures will leave you wondering how the Herschels missed it! ✦



Often overlooked, Lyra's "Ghost Cluster" is another unusual find near Vega.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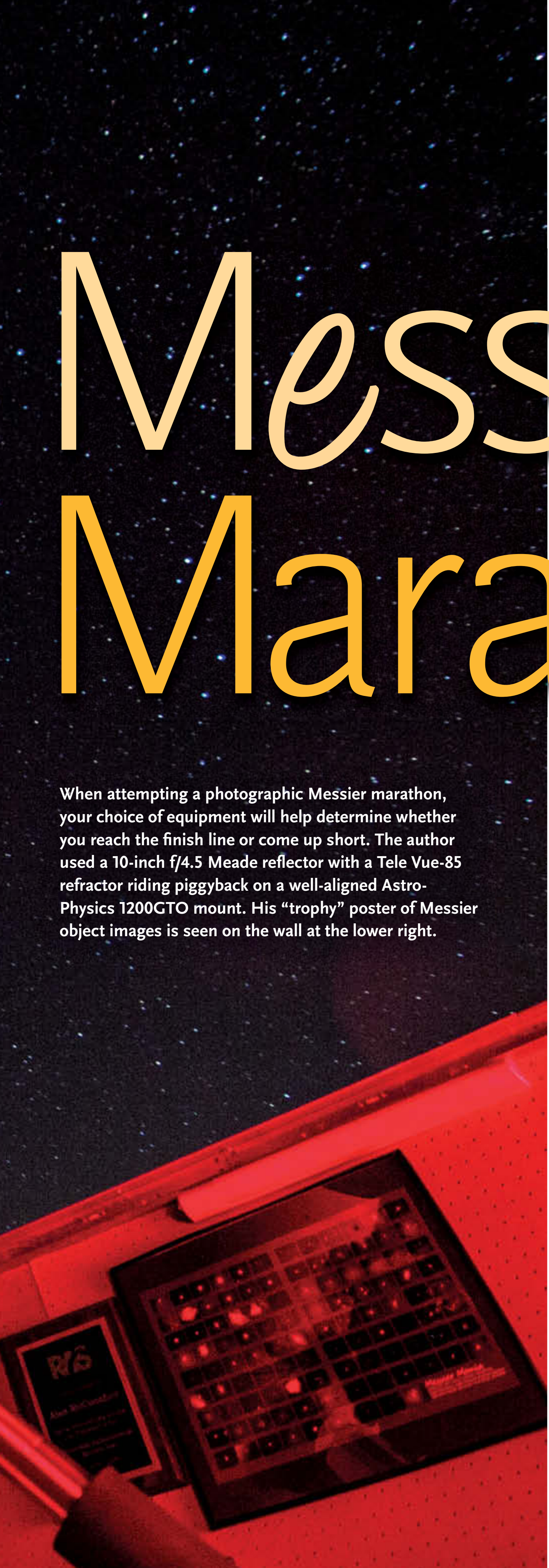


Messier Marathon

2 telescopes, 110 targets, and 1 night to shoot them all.

By Alex McConahay

When attempting a photographic Messier marathon, your choice of equipment will help determine whether you reach the finish line or come up short. The author used a 10-inch f/4.5 Meade reflector with a Tele Vue-85 refractor riding piggyback on a well-aligned Astro-Physics 1200GTO mount. His "trophy" poster of Messier object images is seen on the wall at the lower right.

ALL IMAGES COURTESY OF THE AUTHOR

A MESSIER MARATHON is an exhilarating challenge where observers spend a single night tracking down every object on Charles Messier's famous list of "non-comets." Although hunting down each of these targets visually is hard enough, last year I resolved to kick it up a notch and take on the Messier marathon photographically.

An imaging marathon is not a new idea — others have tried it. But much like its visual counterpart, an imaging marathon tests your skills as an amateur.

The Best-Laid Plan

The first thing you need for an imaging Messier marathon is a well-thought-out plan. Since the goal is to record every object in a single night, time management is critical. Although many astrophotographers might find it difficult to shoot all the Messier objects during the course of a year, it's a whole different story to catch them all in one night, which is only possible at the end of March through early April. You have to wait until "dark" to start, and you must be done before the Sun brightens the eastern sky. At the end of March my observatory experiences 12 hours of darkness. But twilight robs me of almost three of those hours. I calculated that there were only 574 minutes of true darkness on the night I chose to attempt my marathon. Dividing that by 110 objects, I had only 313 seconds to aim my scope, take a picture, and move on to the next target. And this does not count time for getting the equipment ready, for focusing, and for any unanticipated problems!

Typical deep-sky astrophotos require long exposures to accumulate enough signal to reveal galaxies, nebulae, and star clusters

When pursuing a photographic Messier marathon, having a wide-field instrument allows you to photograph some of the close groupings of targets on the list, including M84/86 and M65/66, in a single image, freeing up precious time for other targets throughout the night.

in all their glory. But in an imaging marathon, the ultimate goal isn't to produce 110 masterpieces. My goal was a photomontage of all 110 objects for a single poster. This eases quality tolerances quite a bit, since small images hide modest mistakes such as graininess, less-than-perfect focus, tracking errors, and other problems that are distracting in large-scale images.

The small size of my final images also allowed for faster shooting. My QSI 583 CCD camera has 3,326 pixels across the frame. But for the small final images, it made sense to shoot in binned mode (combining groups of pixels together to function as a single, large pixel). As such I could tolerate relatively large tracking errors, essentially eliminating the need for guiding while imaging. Additionally, larger pixel groups are more sensitive, enabling the camera to capture more photons in less time. And, with far fewer pixels to download, this cuts the overhead of getting the information from the camera to the computer. A full-size image takes 29 seconds to download from my camera, but an image with the pixels binned 4×4 takes only about three seconds.

Another consideration for an imaging marathon is that each picture has to have enough image scale to show detail and also cover enough field of view to capture each object in a single shot. This can be a challenge with the Messier list, since objects vary in size from the Andromeda Galaxy (M31), which is more than 2° wide, to M40, a tiny double star separated by about 50 arcseconds.

Because of this, I decided I needed two imaging setups to record everything — a wide-field instrument and another with longer focal length and greater image scale. For the long-focus scope I ultimately settled on a Meade 10-inch f/4.5 Newtonian reflector with my QSI 583 CCD camera. It covers a field 35 by 47 arcminutes and is perfect for small galaxies and planetary nebulae. Riding piggyback on this scope was my wide-field imaging system, a Tele Vue-85 refractor coupled to a Canon Rebel EOS 450 modified DSLR. It covers a field 85 by 128 arcminutes.

One of the unofficial rules of a visual Messier marathon is that a scope with Go To pointing can't be used, but I decided that constraint wasn't practical in an imaging marathon. I needed excellent robotic pointing to afford more time for imaging. So my Astro-Physics 1200GTO German equatorial mount was certainly put through its paces on my marathon night.

The next step in my planning was to prioritize the objects. Targets in the west during evening twilight needed to be imaged first, but there are a few other considerations. Can multiple objects be grouped into a single image, and which telescope is needed for which object? Combinations such as M42/43, M81/82, M65/66, and M95/96 fit on one frame of my narrow-angle rig, while capturing other pairs of Messier objects in the Virgo Cluster of galaxies and M20/21 required the wide-field setup.

Once I settled on my equipment and game plan for the big night, I set out practicing my techniques. Methodically cranking out a series of images one after the other with no time for errors required familiarity with everything involved in the process. On several evenings spread over the months before my marathon night, I performed dress rehearsals. Using the same checklist, the same configuration of camera, equipment, software, and physical settings, I tried to gather a dozen images in an hour. During these practice sessions I learned it was easier to coordinate everything using two computers (one to control the CCD camera, the other for the DSLR) rather than to switch back and forth between different software packages on a single computer.

Marathon Night

With all assumptions assumed, decisions decided, and a few nights of practice, the night of the marathon should have no surprises. I had planned to do my marathon on a Friday night, so the Wednesday before started out as a final practice run, but everything was going so well that I just kept on going. By the time the Sun rose the next morning, I had met my challenge!

Here's how the night unfolded. I turned on the system at 6:30 p.m., started the CCD camera's cooler, and made sure my two scopes were aligned on the same point in the sky. I defined a series of exposure parameters for the DSLR using *Backyard EOS* and programmed the autosave function in *MaxIm DL* to control the CCD.

I found brilliant Sirius in the deepening twilight and had both scopes focused and the Go To mount synced on the sky by 7:30. Then, at 7:45, I was off to hunt down the first object of the night — M74. I could still see a glow in the sky overhead, and a series of 30-second test exposures with the CCD camera didn't reveal anything except a few stars rising above the background illumination. Finally, at about 7:54, I saw the galaxy emerging from noise in the test images. I started my preset autosave sequence using 90-second exposures (with 3×3 binning) for luminance frames and 40-second exposures (binned 4×4) for each color filter. When the first luminance image came down from the camera, a histogram stretch showed an obvious galaxy in the upper right of the frame — I had my first object, one of the two most difficult on the list — and my marathon had begun.

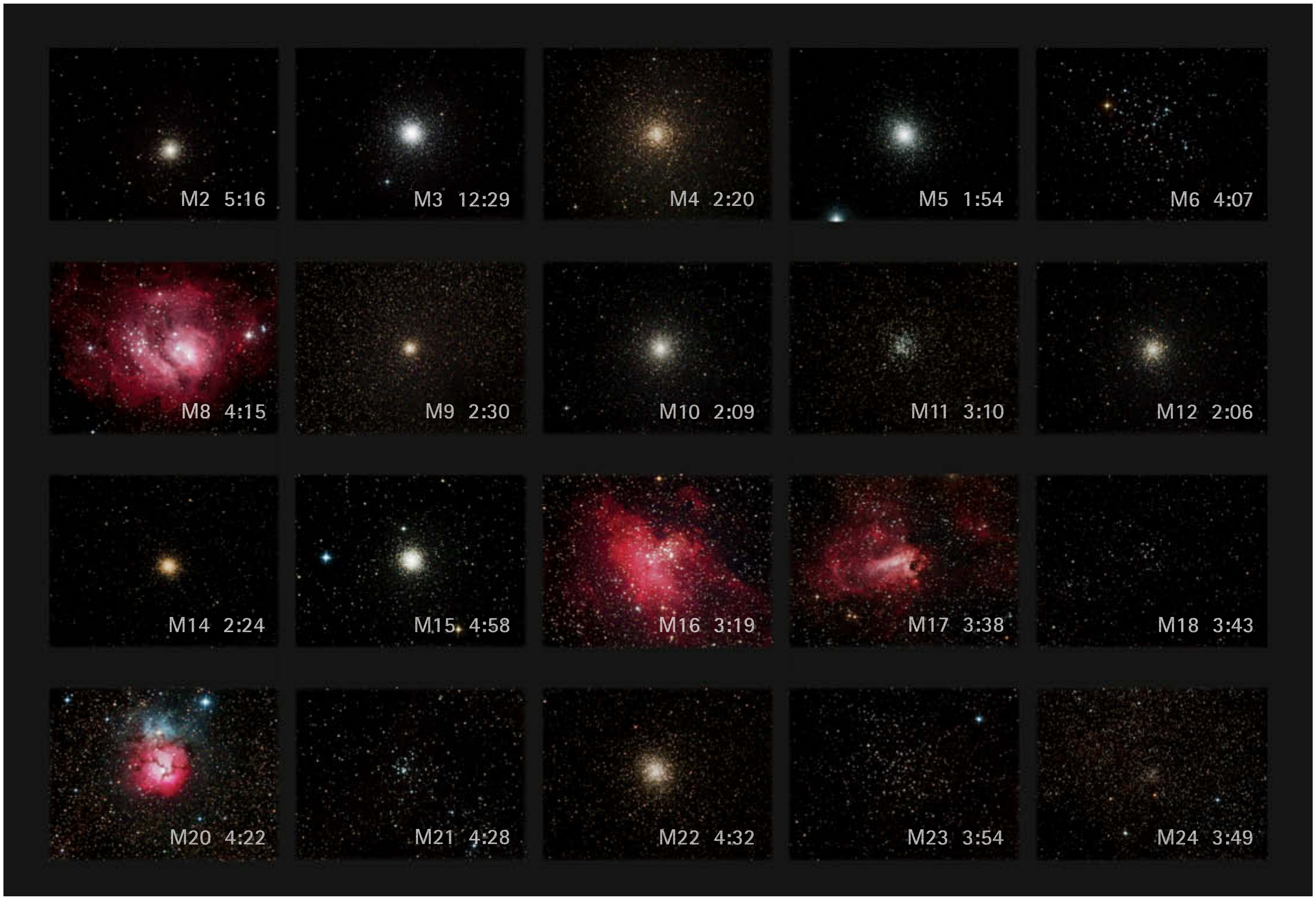
As the camera was busy taking exposures, I jotted down the time in my notes and readied for the next object on the list. As soon as the last of M74's exposures was finished, I pushed the buttons, sending the mount whirring over to M77.

My third target, the Andromeda Galaxy and its companions M32 and M110, was going to be more of a problem. They were sinking low in the northwestern sky, so I expected them to be hidden by my observatory's wall. But I hadn't taken into account the added height of my wide-field scope perched atop the 10-inch. Feeling heady,

I started exposures with both cameras (the 10-inch was only partially blocked by the wall). The DSLR finished its one exposure just as the last of the CCD sub-exposures ended. I was feeling good about my progress until I realized that I was already behind schedule. M33, which my plan called for imaging at 8:15, was not begun until 8:37.

By about 9:00 I was able to calibrate *MaxIm DL*'s telescope-control function and began using it to slew the mount. This meant that if an object didn't appear centered in my camera's field, the software could correct the aim automatically. This picked up the pace greatly, but by about 1:00 a.m. I realized that if I didn't work even faster I would miss about 10 objects by morning twilight. To regain some lost time, I reduced my individual exposures for my CCD camera from 90 to 60 seconds in luminance and from 40 to 20 seconds for each color filter.

So it went until the rosy fingers of dawn started to spread across the eastern sky. Exposures of M2 had started at 5:16 a.m., and unless I had absent-mindedly forgotten something, I had just one more object to go. I commanded the scope to point at the globular cluster M30. To my surprise it appeared to be pointing at the observatory's wall. I quickly took a test exposure, which confirmed my fears. Although M30 had cleared the horizon, it hadn't cleared the wall. I continued taking test exposures in the brightening twilight until, at 5:34, I saw something that was not a blurry star in the frame. I then started the last of the planned exposures. Five minutes later it was finished, and I could see a dim, trailed globular buried in the upper right corner of a hazy glow. Success!



The author managed to capture these colorful images despite spending just minutes on each target. See his entire poster of the best 103 results at www.skypub.com/messier-poster.jpg.

I set my camera to take some calibration frames and went to bed. The next day I began the daunting task of processing the images. Fortunately, much of the processing, particularly image calibration, could be automated. I didn't do any extensive processing to reduce noise, sharpen details, or remove gross imperfections in the final pictures. There simply wasn't enough data to work with, and, furthermore, I liked the somewhat "raw" appearance. This was, after all, a marathon (think sweat, blisters, and exhaustion) and not a pretty-picture event.

Lessons Learned

Hindsight is 20/20, and there are always lessons learned from a big project like this. My target list had emphasized the relative proximity of the objects to one another. This makes sense if I were visually star hopping to get to each object, particularly when using a Dobsonian or a scope without Go To pointing. One hop leads to another. However, when using an equatorially mounted Go To setup, this can slow you down. Crossing the meridian with a Dob means nothing. But with a German equatorial mount, this requires a meridian flip — the scope must twist 180° in right ascension and declination. This can be a challenge with all the cables from cameras, and it can take a couple of minutes.

With different equipment and more experience, it would have been easier for me to pull this off. A one-shot color camera could have eliminated the intricacies of multiple sub-exposures with the monochrome CCD and color filters. Also, some software packages allow you to program targets for an evening and run the camera and scope all night automatically. But that automation defeats the purpose of a marathon.

In the end, it was a pleasant night. The weather was perfect, though quite cold. All the equipment worked — no snagged cables, no power failures, no software bugs stopping the process. It was somewhat like running a marathon. Just put one foot in front of the other, follow the course, avoid blisters and broken shoelaces, drink plenty of fluids, and don't fall down. Sure, no problem! ✦

Alex McConahay *helps organize PATS, RTMC, and the Riverside AstroImaging Conference each year in Pasadena, California. See more of his work at* ***www.alexastro.com****.*

◀ **GEMS OF AURIGA**

Gerald Rhemann

The reddish star-forming regions IC 410 (left) and IC 405 are the brightest knots of a much larger molecular cloud that permeates the southern extent of the constellation Auriga. **Details:** *ASA astrograph H f/2.8 with FLI ProLine PL16803 CCD camera. Total exposure was 13 hours through color filters.*

▼ **A CLOSE PASS**

Jamie Cooper

Jupiter with its bright Galilean moons Europa, Io, and Callisto were easily visible as they briefly joined our Moon in a picturesque conjunction on the evening of November 28, 2012. **Details:** *105-mm refractor with Canon EOS 550D DSLR camera. High-dynamic-range composite of three short exposures.*

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▶ **DIAMONDS IN THE SKY**

Taha Ghouchkanlu

This wide-field photo captures two well-known galaxy groupings in Pegasus: Stephan's Quintet (bottom left) and the Deer Lick Group near the large spiral galaxy NGC 7331 (upper right). North is at right.

Details: *Astronomy Technologies AT8RC Ritchey-Chrétien telescope with Orion Parsec 8300 CCD camera. Total exposure was 4.5 hours through Orion color filters.*

▼ **GATHERING STORMS**

Dan Llewellyn

Jupiter's Great Red Spot was joined by Oval BA, also known as Red Spot Junior, and a small dark storm, near opposition in late 2012. South is up.

Details: *Celestron C14 with Point Grey Research Flea3 color video camera. Stack of multiple frames captured on the evening of October 22, 2012.*

▶ **NEBULOUS HOLLOW**

Larry Van Vleet

This false-color narrowband image of M16 hints at the cavernous space cleared out in the nebula by the hot, young stars of the newborn cluster. The famous "Pillars of Creation" (lower right) are thick columns of gas and dust that contain dozens of embryonic stars.

Details: *RCOS 16-inch Ritchey-Chrétien telescope with Apogee Alta U16M CCD camera. Total exposure was 29 hours through Astrodon narrowband and broadband color filters.*

A FLASH IN THE DARK
Babak Tafreshi
A bright sporadic meteor streaks between the horns of Taurus, while Jupiter blazes to its right near the Hyades star cluster.
Details: *Canon EOS 5D DSLR camera with 15mm f/2.8 fisheye lens. Total exposure was 55 seconds at ISO 1600.*

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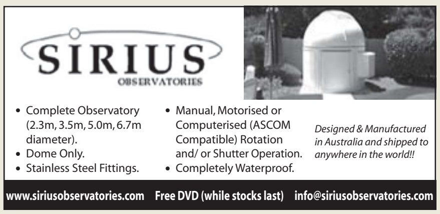

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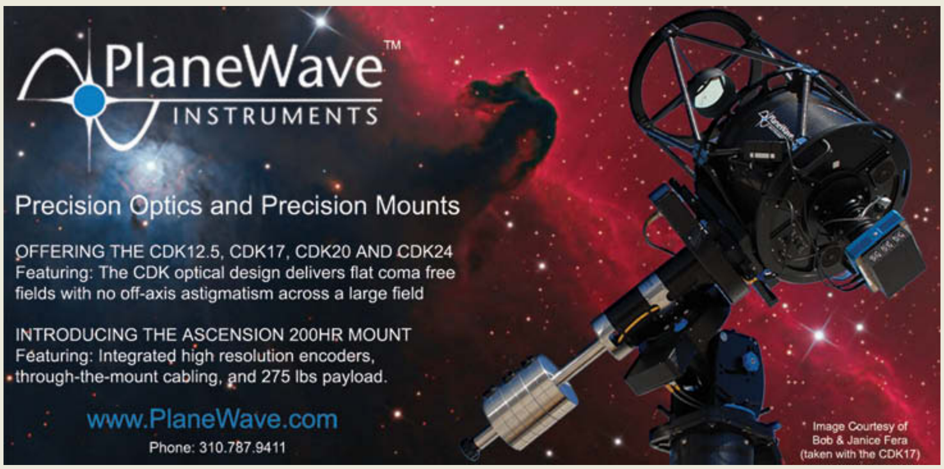

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FOR SALE: Items from the estate of the late William Shawcross, past President of Sky Publishing Corp. Items include Lunt Solar Systems H-alpha LS60THa scope with additional LS50F Ha filter and BF600, Lunt Calcium LS60T CaK scope, Orion 127, 8-inch Cassegrain from TAL, 4-inch f/10 TAL refractor, plus various eyepieces and accessories. For complete descriptive list send email to ads@skyandtelescope.com.

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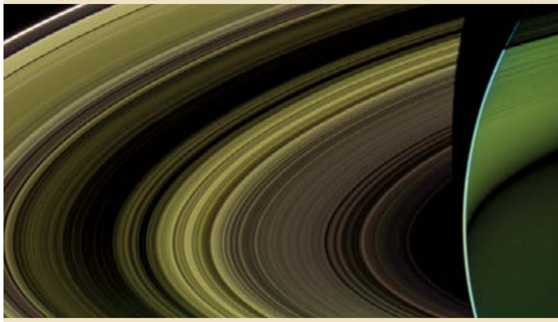

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Why do we think we're so small when we're actually big?

When contemplating the vastness of the cosmos, humans commonly feel physically miniscule — tiny creatures adrift in the vastness of space. But is this sense of physical inconsequentiality justified on a comparative basis?

Our universe is populated by objects of various sizes. The largest object we're aware of is the observable universe. Ignoring its continual expansion and the fact it might be part of a much larger universe, astronomers estimate that its current diameter is roughly 10^{27} meters (92 billion light-years). The smallest object is thought to be the incomprehensibly tiny "string" of energy, estimated as 10^{-35} meter in length. Assuming a continuity of object sizes between these extremes, the universe's size continuum spans 63 orders of magnitude.

On an absolute basis, humans certainly are tiny. But comparatively, the situation differs. Humans are roughly 3 to 7 feet in length, or roughly 10^0 meter. Humans are 35 orders of magnitude larger than the extreme small end of the size scale, but "only" 27 orders of magnitude smaller than the extreme large end. Surprisingly, the positioning of humans on this continuum is more than halfway to the large end. Employing the powers-of-ten system that scientists use, we are comparatively very large entities! Why are we blissfully unaware of this reality?

We gather information about our comparative size by our sense of sight. We look at ourselves, compare our size to that of objects of various sizes around us, and gain some sense of our relative ranking. But our sense of sight is a limited and biased representation of the underlying physical universe.

Our sense of vision extends from the width of a hair (10^{-4} meter) to the distance of the Andromeda Galaxy (10^{22} meters, or 2.5 million light-years). In other words, the universe "visible" to humans spans 27 orders of magnitude of size. We can thus visualize an impressive 43% (27 of 63) of the orders of magnitude of size in the physical universe.

But such visual efficacy is skewed toward the large end. From the smallest thing we can see (10^{-4}) to the unseen string at the small end of the size continuum, there are 31 orders of magnitude of sizes. On the large end, there are only five orders of magnitude unseen from the distance of Andromeda to the edge of the observable universe.

In our biased subset of the physical universe, humans are only 4 orders of magnitude larger than the small end, but a robust 22 orders smaller than the large end. In that sense, we are indeed minuscule. We see vastly more of the physical universe larger than our body size, compared with what we see that's smaller than ourselves.

Humans therefore reasonably, but erroneously, infer from our biased visual limitations that we're tiny entities adrift in a huge, unending cosmos. This is true on an absolute basis, but not on a comparative basis. Assuming that there is no comparable extension of size at the small end of the continuum, ongoing cosmic expansion insures that at some time in the future, we will indeed be comparatively minuscule creatures. But for now, we are creatures of comparatively consequential size. ✦

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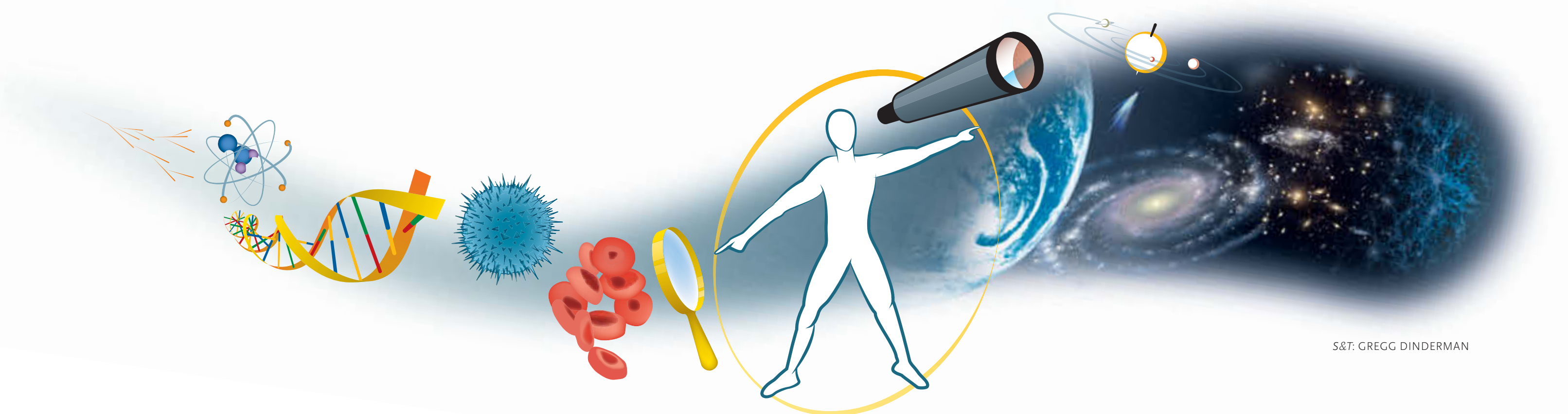

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