

Amateur's Award-Winning Asteroid Research p. 60

SKY & TELESCOPE

THE ESSENTIAL MAGAZINE OF ASTRONOMY

OCTOBER 2010

The Hunt for Super-Earths

*Astronomers are studying exoplanets
just slightly bigger than our home world. p. 30*

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S&T Test Report:
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On the cover:
Space artist Don Dixon portrays a hypothetical exoplanet that is not much larger than Earth (as seen from a low orbit).

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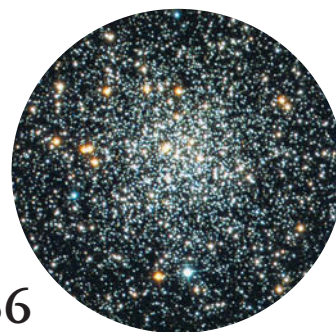
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Serving His Country

EVEN IF YOU'RE a casual *S&T* reader you've undoubtedly noticed the artwork of our talented illustrator, Casey Reed. After earning a bachelor's of fine arts degree in communication design from the Massachusetts College of Art, Casey came to *S&T* in 2003. Even though he started off at a high level, his work continues to get better and better.

Casey's space art, technical diagrams, and sky maps appear all over the magazine. He has created the art for many of our recent covers, and he often comes up with catchy coverlines and innovative cover concepts (see this year's January and April issues, or the February 2009 issue, for example). And with his considerable computer skills, Casey has helped us get off to a flying start on Facebook and Twitter.

Sadly, we're going to be losing Casey for about 14 months. Casey is a staff sergeant in the Massachusetts National Guard, and his unit is deploying to Afghanistan. We will keep Casey on our masthead while he serves his country overseas, and Casey is hoping that he'll occasionally be able to produce illustrations for *S&T*.

"During my time away I will certainly miss working with my friends and colleagues on the pages of *S&T*," says Casey. "While the coming year will be challenging both personally and professionally, it's comforting to know that even in a land of unrest and uncertainties, the night sky will remain constantly familiar."

We're going to miss Casey very much, and we look forward to his return next year. Please keep Casey and his fellow servicemen and women in your thoughts and prayers as we hope for a safe deployment in a troubled land.

To fill Casey's shoes while he's away, we have brought on board another extremely talented illustrator, Leah Tiscione, who has previously worked as a graphic artist for the *New York Post* and the *Arizona Daily Star*. You can look forward to seeing Leah's work in the months ahead.

I also want to let you know that Kristina Grifantini's cover story "Solar Impact" for our March 2009 issue earned the prestigious 2010 Popular Writing Award from the American Astronomical Society's Solar Physics Division. Congratulations Kristina!

Robert Naeye
Editor in Chief

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Skies to Explore

Robert Naeye wrote about the nice trip he had to Chile and discussed the pros of that country ("Astronomy's Best-Kept Secret," April issue, page 6). So I wanted to add that Mexico, just next door to the U.S., also has a great night sky to share.

Take the state of Zacatecas, for example: you just have to look at Google Earth in the evening to see the very dark sky we have. We are at about 2,500 meters above sea level, with very dry weather all year. Maybe we can't see the Magellanic Clouds, but we are able to see Canopus, Omega Centauri, and the Southern Cross. Zacatecas has short, direct flights to both Los Angeles and Chicago, and we have our clocks set to Central Standard Time. Southern Mexico can provide you with excellent dark skies, too!

Luis Díaz Santana
Zacatecas, Mexico

Big Bang Landmark in Trouble

I am writing about a historic landmark that has been left abandoned and in jeopardy.

On May 8th I traveled to New Jersey to see the horn antenna with which Arno Penzias and Robert Wilson discovered the cosmic microwave background in 1964, establishing the reality of the Big Bang. The horn is frequently mentioned and pictured in histories of science and astronomy, it's a registered National Historic Landmark, and I figured it was time I had a look at it. The experience left me disconcerted.

After driving up and down Crawford



Has Bell Labs' Horn Antenna, seen here in 2007, fallen into disarray?

BELL LABS / NATIONAL PARK SERVICE

Corners Road in Holmdel for more than an hour, I was unable to find it. I did find a small sign by the road that told me I was near the site where the cosmic microwave background radiation was discovered. This was, however, miles away from where I eventually found the antenna.

I was on the verge of giving up when I happened upon Lucent Technologies, which I knew had inherited the legendary Bell Labs where Penzias and Wilson worked. I drove around the Lucent campus until I found someone and explained my quest. He pointed me to a road up a hill. When I found what I was looking for, I

was shocked and disgusted.

This National Historic Landmark, which enabled one of the most monumental discoveries of all time, was dirty, rusted, and in dire need of restoration. Someone had been using it as a container to store equipment and left a stepladder leaning against the base. It was a far cry from the historic photographs.

When I returned home I wrote to the National Park Service. They have been cooperative and say they've directed that a modicum of restoration be done. But I'm not sure how seriously they are taking my complaint.

I thought *S&T* readers would be interested to know the state of this important landmark.

Arthur Haspoja
Mount Prospect, Illinois

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

Help a Fellow Subscriber

Much of the year I am hostage to cloudy, rainy, light-polluted skies, including the Everett and Seattle nebulae to my south and all the smaller nebulae (cities) around Puget Sound.

My ambition is to observe as many of the Caldwell objects as possible from the United States. So far I have observed 64. My goal is to reach 80!

This will require a trip to the Southwest in early fall. Can readers suggest sites in southern Arizona or New Mexico where



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Astro-Tech, Celestron, and the night sky . . . meant for each other.



Some things are just meant to go together: peanut butter and jelly; apple pie and ice cream; Astro-Tech, Celestron, and the night sky. Here's another of those combos: a Celestron CG-5 go-to mount and an Astro-Tech AT8IN 8" f/4 Imaging Newtonian. The background photo shows the kind of image the \$449 AT8IN can produce in the hands of a talented hobbyist. Ready to take your own images? We have your scope.



AT8IN image of the Horsehead and Flame nebulae in HaRGB by astronomy hobbyist David Rosenthal (<http://pbase.com/djrlx90>).

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Letters

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Sun Size

In the "Martian Solar Eclipses" blurb in your Astro Q&A department (August issue, page 70), Alan MacRobert writes that the Sun appears only two-thirds as big from Mars as it does from Earth. To be more specific, wouldn't it be the Sun's diameter that appears two-thirds as large? Wouldn't the Sun's disk appear some four-ninths (about 44%) as large?

Bruce McClure

Norwood, New York

Editor's note: In astronomy and science, an object's "size" is usually assumed to mean its linear size (radius or diameter), not its area or volume — in other words the unit with one dimension, not two or three.

Further Reading

Thanks to Leif Robinson for mentioning in 50 & 25 (September issue, page 9) the article I wrote for the September 1985 issue. The advice I gave on choosing exit pupils is still generally valid, but if your readers check my May 1991 issue article "magnification," they'll see how my thinking has evolved. My TVO website essay "majesty factor" goes a little further in trying to technically explain how the "wow" factor increases with increasing apparent fields.

Al Nagler / CEO, Tele Vue Optics, Inc.

Chester, New York

75, 50 & 25 Years Ago

Leif J. Robinson

September/October 1935

Nearby Galaxies "The nearest external galaxies, according to Mount Wilson and Harvard estimates, are, in order of increasing distance, the Large Magellanic Cloud, the Small Magellanic Cloud, the Magellanic type system N. G. C. 6822, the spiral nebula Messier 33, and the Andromeda Nebula with its two companions. These objects, together with our own galactic

system, its globular clusters, and possibly two or three other neighboring galaxies, compose what Dr. [Harlow] Shapley calls the local supergalaxy."

Today their distance order is nearly what it was 75 years ago; only the Andromeda galaxy and M33 have switched rank

(slightly). The number of galaxies in what is now called the Local Group has risen to more than 40. The nearest is the sparse, recently discovered Sagittarius dwarf merging with the Milky Way.

October 1960

Echo of Echo "The brightest artificial satellite yet launched, Echo I has attracted unusually wide public interest. Despite its thousand-mile orbital height, the 100-foot aluminized balloon rivals 1st-magnitude stars, catching the attention of even casual watchers.

"Sent up from Cape Canaveral on August 12th . . . Echo I is the first inflatable structure to go into orbit. Three earlier attempts with smaller balloons had miscarried."

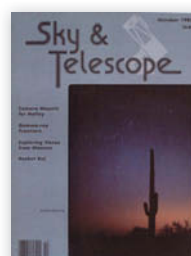
Echo I was an inspiring sight whenever it crossed the night sky in the early Space Age. The number of failures incurred in this single program is indicative of the poor state of the United States' space program at the time.

October 1985

High-Energy Sky "Now that we have a feeling for the low angular resolution of present-day detectors we can study the appearance of the gamma-ray sky. When data from all observations (essentially the 200,000 photons detected by COS-B during its seven years in orbit) are plotted in galactic coordinates, the plane of our galaxy is clearly delineated. . . ."

Gamma-ray studies continue to be one of the

most active and exciting fields of astronomy, with many satellites launched to achieve higher resolution both in space and time. Some hot topics include the nature of pulsars, active galactic nuclei, gamma-ray bursts, and dark matter.



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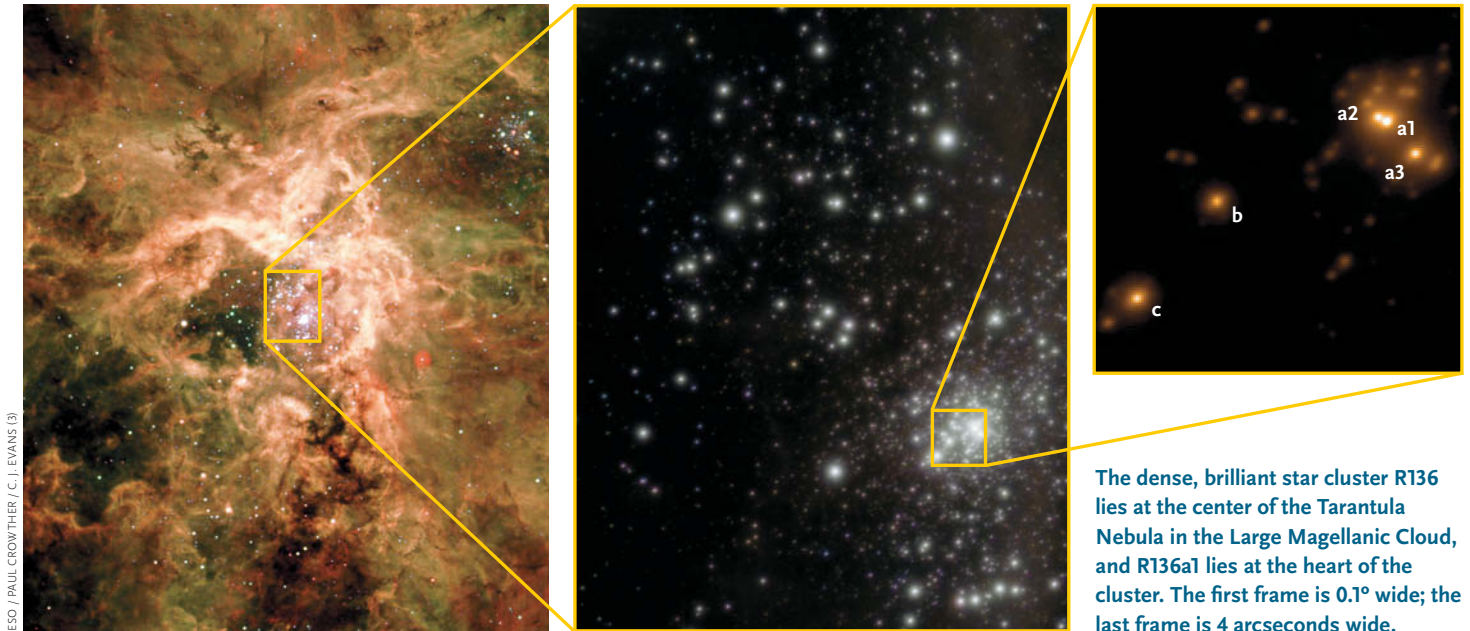
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A 320-Solar-Mass Star. . . Really?



ESO / PAUL CROWTHER / C. J. EVANS (3)

The dense, brilliant star cluster R136 lies at the center of the Tarantula Nebula in the Large Magellanic Cloud, and R136a1 lies at the heart of the cluster. The first frame is 0.1° wide; the last frame is 4 arcseconds wide.

ASTRONOMERS SINCE THE 1920s have thought that no star can have a mass much greater than about 100 to 120 times the mass of the Sun. As Arthur Eddington worked out in 1924, a star more massive would generate so much energy that its radiation pressure would overpower its gravity and drive off the star's outer layers — a self-regulating arrangement.

Later refinements bumped the “Eddington limit” up a bit. In recent years physicists realized that the limit was *much* higher for the pure hydrogen-and-helium stars born in the first generation after the Big Bang. Their top layers were more transparent to their radiation, so some could have had many hundreds of solar masses.

But those are long gone. In today's universe, the two heaviest stars with masses that have been measured directly (by the strength of their gravity in spectroscopic eclipsing binaries) may be HD 15558 in Cassiopeia, with 152 ± 51 solar masses, and R145 in the Large Magellanic Cloud,

with 140 ± 37 . But the values are controversial, and the list of most-massive stars is constantly changing with new challenges and revisions (May issue, page 22).

So when a group of astronomers claimed in July to have found a star weighing 265 Suns — and that it must have been born with about 320 — the news generated headlines in the mainstream media worldwide.

The star is R136a1, the brightest in the superdense R136 cluster at the heart of the Tarantula Nebula in the Large Magellanic Cloud. Shining with 9 million times the Sun's luminosity, this star has been studied for decades. Paul Crowther (University of Sheffield, England) and his colleagues used high-quality spectral data from Hubble and from Europe's Very Large Telescope to derive their new mass estimate. The team also announced that three other hypergiants in R136 range from 135 to 195 solar masses. Together, the four emit nearly half the radiation and stellar wind in the 100,000-member clus-

ter, they write in the July *Monthly Notices of the Royal Astronomical Society*.

Other massive-star experts are skeptical, however, both because the claim is extraordinary and because the mass was inferred indirectly: from the star's luminosity and temperature and the rate at which it's blowing off a thick stellar wind. The behavior of stars this bright is not reliably known, and the gold standard for stellar masses is still a “dynamical” measurement of gravitation in a binary. Super-massive-star expert Don Figer (Rochester Institute of Technology) says, “History is full of claims in this field that turn out not to be true, because so many things can go wrong.” (For instance, there's still some room for R136a1 to be not a single star but an unresolved binary pair.) Fellow expert Yaël Nazé in Belgium calls the new high-mass estimate “still unsure.”



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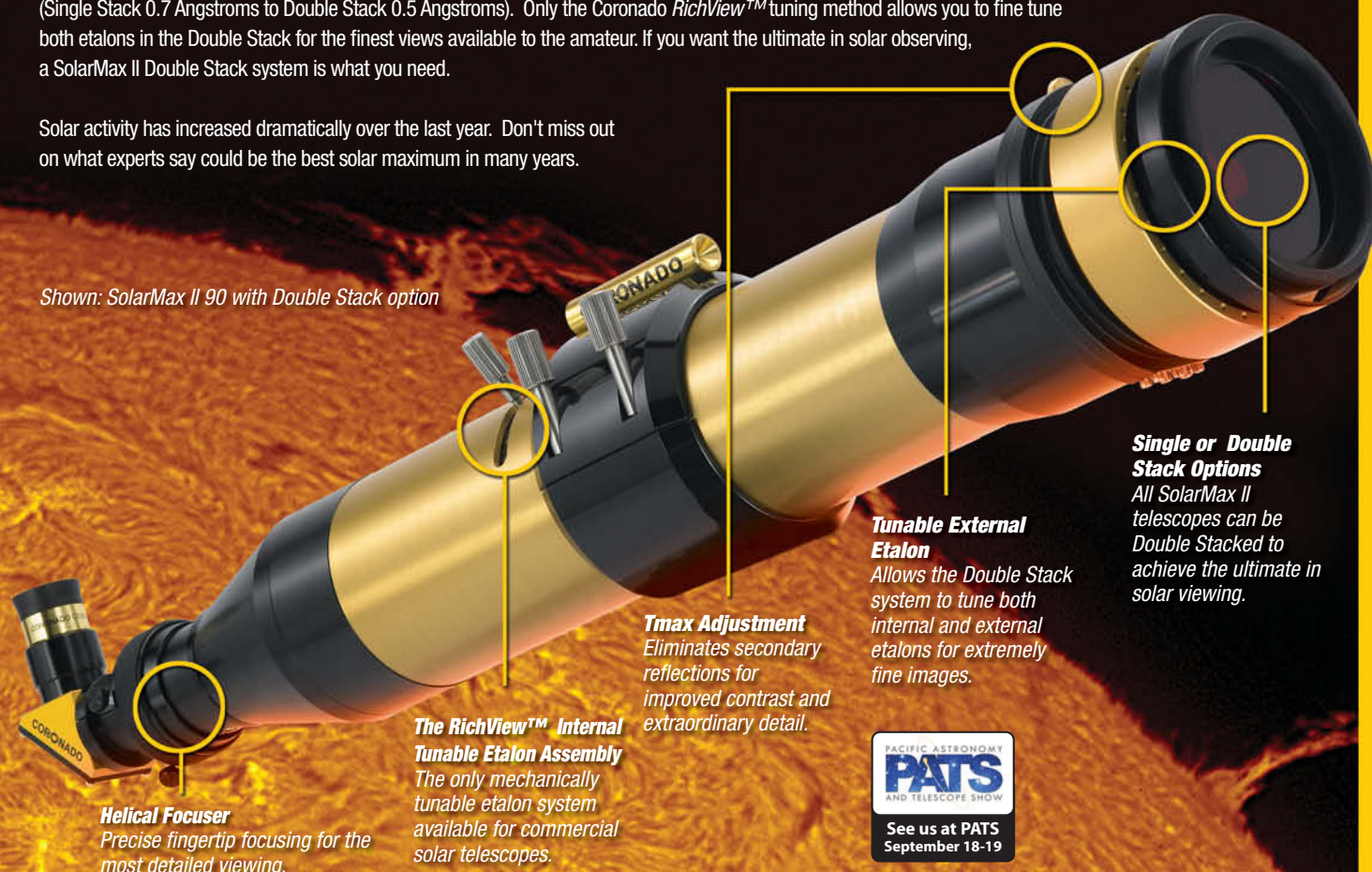
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Rosetta Visits the Biggest Asteroid Yet

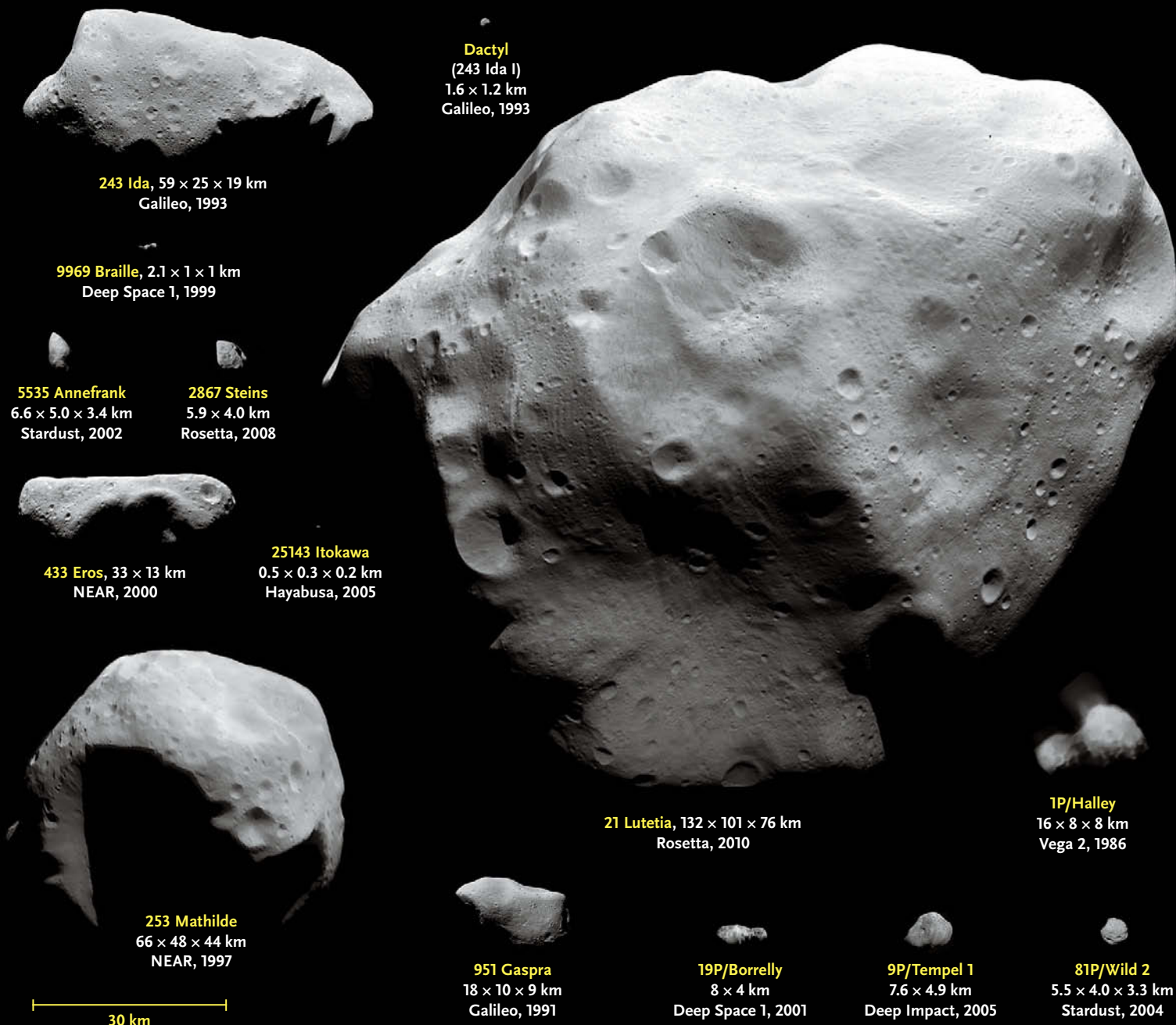
The European Space Agency's Rosetta spacecraft, launched in 2004 to land on Comet 67P/Churyumov-Gerasimenko in 2014, flew past the asteroid 21 Lutetia on July 10th along its looping way. Lutetia is 82 miles (132 km) across at its widest, making it by far the largest asteroid yet imaged up close — as shown to scale

below in the complete collection of small bodies imaged by spacecraft.

Lutetia's composition also sets it apart. It has long been known as an M-type asteroid, as classified by the spectrum of the sunlight reflected from its surface. The "M" stands for metal — and indeed, Lutetia's gravitational pull on the spacecraft revealed that its average density is about 5.5 grams per cubic centimeter,

nearly twice that of ordinary rock. Nevertheless, Lutetia shows the same cratered surface, smooth hills, soft grooves, and scattered boulders we've come to expect on asteroids generally.

This was Rosetta's second asteroid flyby. The first was of 4-mile-wide 2867 Steins on September 5, 2008. Nothing else is near Rosetta's path until it arrives at Churyumov-Gerasimenko in May 2014.



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The fresh-looking Gebel Kamil crater is about 184 feet across and 50 feet deep, though nearly filled with sand.

New Trove of Iron Meteorites

The Landsat satellite made detailed imagery of Earth's surface accessible to anyone in the 1970s, and ever since, meteorite prospectors have pored over such photos hoping to identify new impact craters. Most "discoveries" prove false, but real ones still occasionally turn up.

In February 2009, Italian geologist Vincenzo De Michele used Google Earth to spot a small, suspicious-looking depression in southern Egypt that showed a spray pattern of debris. A year later a field expedition found that the 180-foot (55-meter) Gebel Kamil crater is indeed an impact site, probably no more than about 5,000 years old. And the area is littered with thousands of nickel-iron meteorites.

When the object hit, it probably weighed roughly 10 tons and was about 4 feet (1.3 m) across. It may have lost three times that much mass as it streaked through the atmosphere. The expedition collected 5,178 fragments totaling 1.7 tons, but many more surely await discovery.



The largest known piece from the Gebel Kamil meteorite field, found 750 feet north of the crater, weighs 183 pounds (83 kg). The characteristic dimples on its exterior, called *regmaglypts*, were caused by uneven ablation as the iron meteorite streaked through the atmosphere.

Strange Twists and Ridges in Saturn's Rings

Future space historians will recall three great epochs of discovery concerning Saturn's rings.

The first was their telescopic discovery in the 1600s. In the second, circa 1980, Voyager 1 found that the rings are not a single smooth sheet but thousands of thin lines and ribbons, beautiful and strange in their collective organization. In the third, circa 2005–10, the Cassini orbiter found the ring details to be even more beautiful and strange — and unexpectedly dynamic.

For instance, the rings contain thousands of twists of icy rubble called "propellers" for their distinctive shape. These are apparently caused by tiny embedded moonlets with just enough mass to disturb the sideways flows of particles slowly moving by them. The flows move in opposite directions just to the inside and outside of a moonlet's orbit. Cornell researcher Matthew Tiscareno concludes that the embedded moonlets have to be at least 1,000 feet (300 m) across to make themselves felt this way.

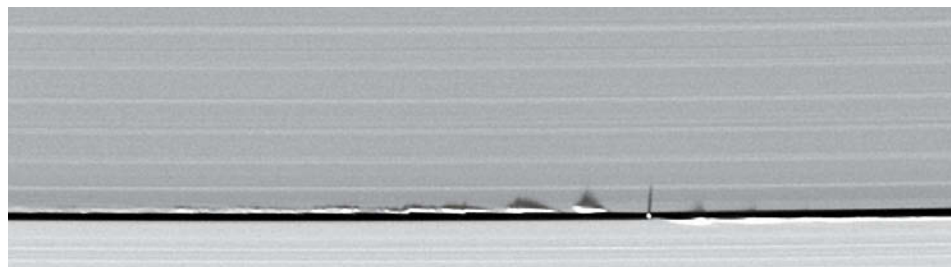
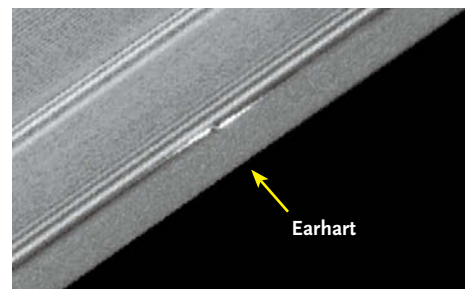
Until recently, the propellers were thought to be ephemeral. But Tiscareno and others have described a family of relatively large ones, some of them more than 100 miles long, that Cassini has tracked for up to 4 years. These structures lie in the small, 2,000-mile-wide band between the Encke Gap and the A ring's outer edge. Tiscareno has given 11 of the propellers nicknames that honor early aviators.

At least one of them, Blériot, moves unexpectedly. It sometimes precedes

or lags its expected orbital position by hundreds of miles. Either the responsible moonlet is being swayed by some unidentified resonance with another, larger moon, or it's being physically bumped and jostled as it circles Saturn.

In principle, propellers shouldn't last forever. Their central moonlets should be tidally interacting with the rings in a way that gradually shifts the moonlets outward. Apparently that's what happened to Atlas, the flying-saucer-shaped moonlet that skirts the A ring's outer edge. "The fact that we do not see consistent outward migration in Blériot's orbit suggests that a different mechanism must be operating in that case," observes Tiscareno.

The presence of so many moonlets in the rings suggests that the ring system was not born in the gas-and-dust cloud that birthed Saturn itself, but more likely formed from the breakup of a long-ago satellite — either through tidal disruption or an outright collision — the size and mass of Mimas, about 250 miles (400 km) across. Ring specialists still can't agree whether this happened billions of years ago or in the geologically recent past, perhaps within the last 100 million years.



About 5 miles (8 km) across, the tiny moonlet Daphnis is large enough to clear a gap in Saturn's A ring (the Keeler Gap) and raise ridges of disturbed ring material a mile (1½ km) high.

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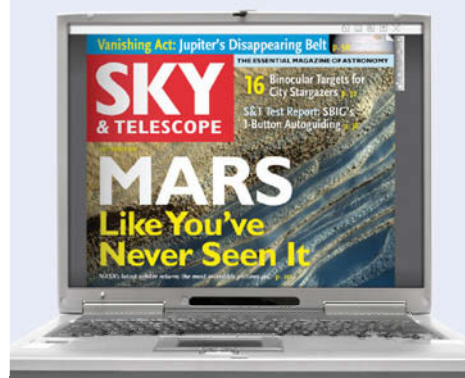
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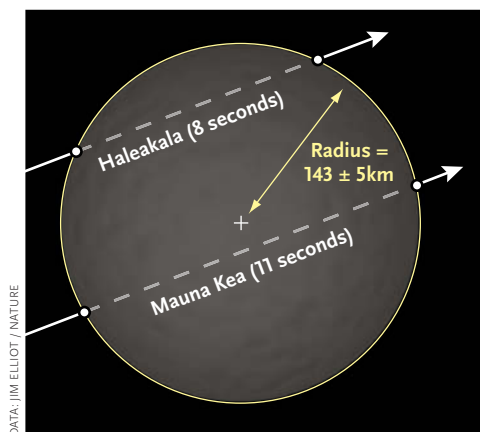
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Brief blackouts of a background star, as seen from two separated locations, were enough to show that Kuiper Belt Object 55636 is surprisingly small — assuming that its profile is round.

First KBO Occultation Gives a Strange Result

Only 20 years ago, the Kuiper Belt was just a theorists' concept of icy objects beyond Pluto. Now more than 1,100 are known — and Pluto is considered one of them.

But they're awfully far and faint, and what we know about their most basic properties, such as size and surface reflectivity, is often guesswork.

A precise way to measure the size of a small solar-system body is to time its occultation of a star. Amateurs now do this for main-belt asteroids every few days. But not one Kuiper Belt object (KBO) yielded up its size this way until last October 9th.

Success didn't come easily. KBOs are so far away that the locations of their narrow occultation paths can't be predicted to better than a few thousand miles. Nevertheless, with help from 10 amateurs, James Elliott (MIT) set up 18 stations from the west coasts of the U.S. and Mexico to Australia and New Zealand to try to record the occultation of a 13th-magnitude star by a 20th-magnitude KBO known only as 55636.

This object was discovered in 2002. By guessing that it had a dark surface like many outer-solar-system bodies, astronomers assumed it was quite big: roughly 600 miles (1,000 km) across, the size of the largest main-belt asteroid, 1 Ceres.

On the big night most observers were, as expected, either clouded out or saw that no occultation happened from their

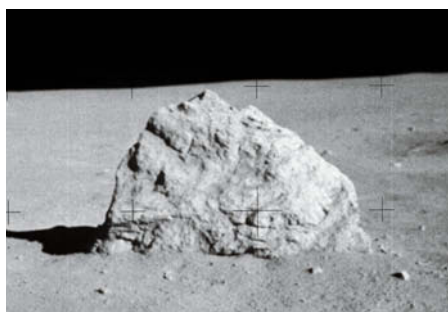
vantage points. But the numbers paid off; two stations in Hawaii got lucky. Their timings of the star's disappearance, for 8 and 11 seconds, sets the diameter of KBO 55636 at a mere 177 miles (286 km) if it's assumed to be roughly round. That means its surface is not dark gray-black but must be brilliant white, at least 80% reflective, to shine as bright as magnitude 20.

"This is a surprising result," says occultation specialist Bruno Sicardy (Paris Observatory). There's no good explanation for what would make it so bright. Astronomers may need to revise their thinking about "space weathering," the Kuiper Belt's evolution, or both.

The Moon: Damp from Day One

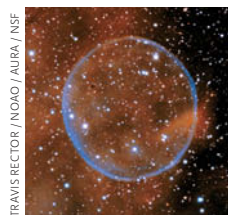
The latest on Moon water is that, in addition to ice deposits buried in shadowed polar craters and water molecules stuck to the sunlit surface, traces also exist in rocks from deep underground.

Researchers led by Francis McCubbin (Carnegie Institution of Washington) have announced that using new microanalysis techniques, they found water (in the form of its ion hydroxyl, OH) in tiny mineral grains brought back by the Apollo 14 mission. The "steaming gun" is the calcium-rich mineral apatite, which incorporates an OH radical into its crystals. Some of the microscopic specimens contain 1% water or more, suggesting that water-laced lunar magma was ubiquitous in the Moon's early history — and that the Moon as a whole may contain water at an abundance of 5 parts per million or more. Previous estimates were orders of magnitude lower.



Secrets in stones: An Apollo 14 astronaut photographed this boulder during a moonwalk in 1971.

Soap Bubble Nebula Is Real



The weirdly round object recently discovered by amateur astronomer Dave Jurasevich (July issue cover story) is indeed a new planetary nebula,

spectroscopy confirms. Using the 3-meter Lick Observatory reflector, "we were able to conclusively detect the OIII and H-alpha emission lines" from gas in the object's rim, write Richard Rudy (Aero-space Corporation) and collaborators.

A Very Wide Eye

Astronomers are celebrating the long-delayed debut of the most powerful survey telescope yet. Pan-STARRS 1, the first of four 1.8-meter telescopes planned, is now fully operational on Haleakala in Hawaii.

The Pan-STARRS telescope feeds a huge, 3° field to the largest digital camera ever built, with 1,400 megapixels. Exposures of 30 to 60 seconds record



The PanStarrs 1 telescope at sunrise.

everything to 24th magnitude. The wide field and short exposures mean that Pan-STARRS can record about 20% of the sky visible from Hawaii each night.

The survey is producing a torrent of moving and changing objects to check out, and astronomers plan a dozen key projects in particular — from cataloging 5 billion stars and 500 million galaxies, to discovering an anticipated 20,000 Kuiper Belt objects, some likely bigger than Pluto and Eris. Pan-STARRS's prime goal is to catalog potentially hazardous near-Earth objects as small as 100 meters. ♦



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NASA / TOM TSCHIDA

IMAGINE TAKING A PICTURE out the window of a 747 jet airplane in flight. Now imagine turning the camera upward in mild turbulence for some high-precision astrophotography with a telescope the size of a minivan. On May 25th, astronomers did just that, looking through a 13-foot square hole cut in the aircraft's fuselage.

NASA's Stratospheric Observatory For Infrared Astronomy (SOFIA), a 747SP aircraft modified to carry a 2.5-meter telescope, has successfully completed its early test flights and achieved first light, demonstrating that the telescope and one of its infrared cameras work together as

expected. Astronomers are looking forward to the release of the first scientific results in the months ahead.

Initial scientific investigations will focus on the center of our Milky Way Galaxy and on the massive star-forming regions such as those in Orion. The \$800-million observatory (\$2.9 billion over 20 years of operation) will fly at altitudes up to 45,000 feet (13,700 meters) using high-precision imaging and spectroscopic instruments to enable observations that are impossible from the ground along with experimental capabilities that are unavailable on current or planned space telescopes.

Detailing the Infrared Universe

Putting a telescope in an airplane and flying to dry altitudes — above 99.9% of the infrared-absorbing water vapor in Earth's atmosphere — is hardly a novel concept. Many years of development culminated in 1970 with the highly successful Kuiper Airborne Observatory (KAO, named for Gerard Kuiper), a C-141 military transport plane with a 36-inch (91-cm) telescope. After 25 years and thousands of new observations — among them discoveries of Neptune's ring system, Pluto's thin atmosphere, and direct evidence of a black hole in the center of our galaxy — NASA retired the KAO in order to re-allocate its funding to the development of the much larger SOFIA.

SOFIA is designed to probe our origins, providing new observations ranging from the solar system to distant galaxies, helping astronomers answer several major astrophysical questions. For example, decades of imaging and spectroscopy of newborn stars and their disks have revealed jets of material squirting from the poles (April issue, page 20). But we still don't know the precise



NASA / TOM TSCHIDA

SOFIA AT NIGHT In preparation for the first-light flight, the 2.5-meter telescope peers out of the 747's rear fuselage during nighttime operations testing at the Dryden Aircraft Operations Facility in Palmdale, California.

dynamical and chemical nature of these systems, nor do we fully understand their role in star formation. SOFIA will show us details such as whether the jet material follows a linear or spiraling trajectory, enabling us to distinguish between different star-formation models.

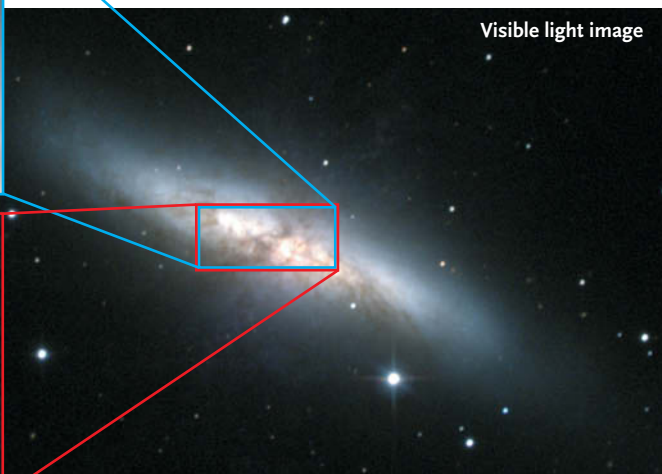
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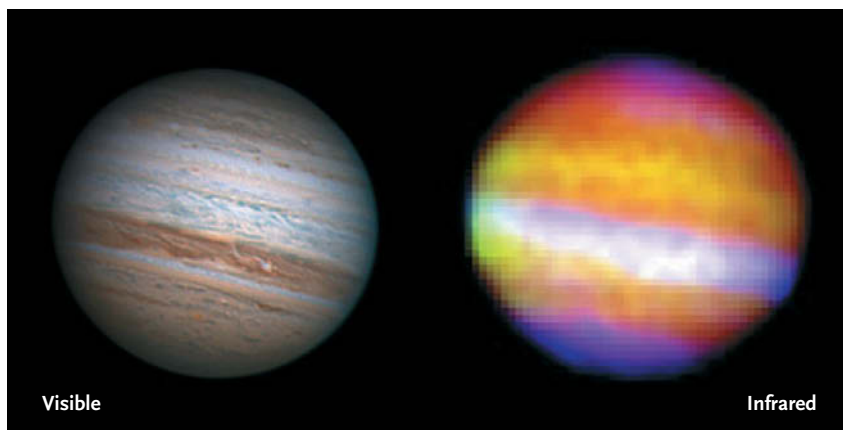
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LEFT: ANTHONY WESLEY; RIGHT: NASA / SOFIA / USRA / FORCAST SCIENCE TEAM

FIRST-LIGHT IMAGES On its May 25–26, 2010 flight, SOFIA's telescope saw first light from the air. Above: SOFIA's FORCAST camera peered deep into the central region of the galaxy M82, a realm bursting with star formation and yet completely obscured by interstellar dust in visible light. Left: These images compare the same side of Jupiter as imaged in visible light by Australian amateur astronomer Anthony Wesley and in infrared light as captured by FORCAST. The white stripe in the SOFIA image is a region of relatively transparent clouds, allowing a peek into Jupiter's warm interior.

astronomers will improve upon the spectacular infrared images from NASA's Spitzer Space Telescope. SOFIA cameras will produce detailed images of newborn stars, images that isolate wavelengths of light that we cannot observe from the ground or with existing space telescopes. Astronomers will combine these images with spectra to measure the motion and composition of star-forming regions. We'll see disks of protoplanetary material orbiting young stars, details in the clouds of gas and dust that form stars, outflows of material ejected from stars nearing their deaths, star-formation regions in distant galaxies, and galaxies in even more distant clusters.

SOFIA's spectrographs will enable precise measurements of the abundances, temperatures, densities, and motions of atoms and molecules, as well as minerals in the form of dust particles and larger bodies. Such measurements will allow astronomers to investigate several big questions: What are the physical characteristics of our galaxy's central black hole? How do the cores of interstellar clouds fragment and collapse into stars and their protoplanetary disks? How do newborn massive stars emerge from bubbles of gas within giant interstellar clouds?

Closer to home, SOFIA astronomers will study the composition and structure of Mars's and Venus's atmospheres, the upper atmospheres and moons of the gas giants, along with Kuiper Belt objects, asteroids, and comets. Over its 20-year lifespan, SOFIA's combination

of broad spectral coverage and high spatial and spectral resolution will provide unique capabilities and continuity with existing and future infrared observatories.

Benefits of Airplane Astronomy

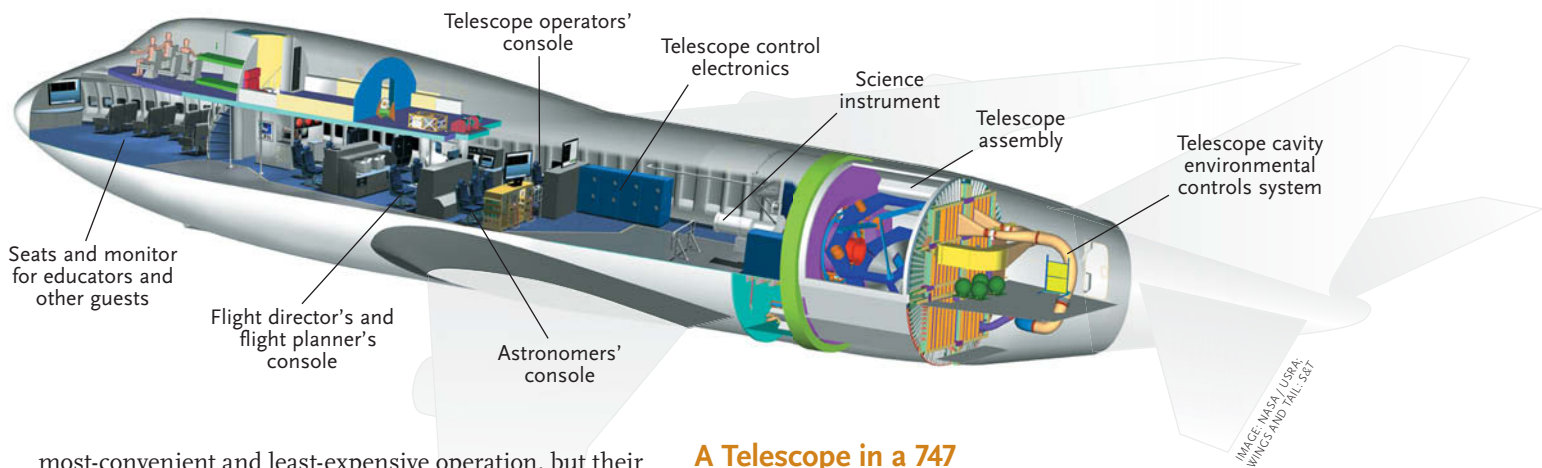
SOFIA enables these observations by covering wavelengths that extend all the way from visible light to submillimeter (very-high-frequency radio) waves, much broader than any current or planned observatory. The 747 accommodates significantly larger and heavier payloads than space telescopes, allowing instruments with higher spectral resolution. Though much less sensitive to faint infrared light than space telescopes because of its warmer temperature, SOFIA will deliver unprecedented precision in the chemical analysis of astronomical sources. SOFIA will help us probe the formation and evolution of bodies as small as asteroids and comets and as large as galaxies and galaxy clusters.

Space telescopes benefit from the lack of atmospheric distortion and light absorption, and their cold environments substantially improve infrared sensitivity. Despite its relatively small aperture (0.85 meter), Spitzer is much more sensitive in the infrared than the Keck 10-meter reflectors, even though these giant telescopes look through the most transparent atmospheric windows under Mauna Kea's best weather conditions. Ground-based telescopes offer the largest apertures and the

SOFIA's Trials and Tribulations

Due to a variety of unforeseen challenges, such as technical and management problems, and bankruptcies of key corporate partners, SOFIA took nearly a decade longer to develop and cost about three times the amount that was originally anticipated.

- **1995:** SOFIA's predecessor, the Kuiper Airborne Observatory, is retired.
- **1997:** USRA's contract for the development of SOFIA begins. NASA purchases the 747SP *Clipper Lindbergh* from United Airlines and flies it to the L-3 Communications plant in Waco, Texas, for modifications. Projected observatory development cost: \$250 million over five years.
- **2001–2004:** Three telescope-door subcontractors go out of business in succession; the aircraft operations contractor (United Airlines) goes through bankruptcy reorganization and decides not to continue with SOFIA.
- **2003–4:** The telescope is transported from Germany to the U.S., installed in the aircraft, and used for the first observations (from the ground) to test optics and tracking.
- **2006:** February: NASA announces \$0 for SOFIA in the budget. July: NASA announces restoration of SOFIA funding. September: NASA announces that SOFIA program management will be split, with overall management and flight testing at NASA/Dryden, and science mission management at NASA/Ames.
- **2007:** April: The observatory makes its first test flight. May: SOFIA flies from Texas to NASA/Dryden on its fourth flight. June: SOFIA is rededicated as the *Clipper Lindbergh* by Erik Lindbergh.
- **2008:** Summer: The telescope primary mirror is removed from the aircraft, aluminized, and re-installed. November–December: Celestial observations re-
- commence from the ground with fully reflective optics.
- **2009:** December: First open-door test flights are successful; detailed preparations begin for first-light flights.
- **2010:** April: USRA and NASA announce the first call for observing proposals from the general astronomical community. May 25–26: Telescope characterization tests and the first-light flight are successful. October: The "Early Science" astronomy program is scheduled to begin.
- **2014:** SOFIA is expected to reach its full operating capability of about 100 science flights per year. Actual observatory development cost is \$1.0 billion over 17 years of research, development, and testing.
- **2014–2034:** SOFIA will be in full operation. Operating costs, in inflated dollars, are expected to average about \$90 million per year for the 20-year mission.



most-convenient and least-expensive operation, but their warm optics glow in the infrared, and Earth's water-laden troposphere soaks up and obscures most of the infrared radiation from space.

SOFIA retains the convenience and flexibility of ground-based observing, allowing upgrades to the telescope and instruments to take advantage of the latest technology, but with the mobility to access virtually any location on Earth for eclipses, occultations, and comet observations. Just as the KAO aided technology development for Spitzer, SOFIA will also serve as a test platform for space-based instrument prototypes and techniques and will be a hands-on educational and training facility for future generations of teachers and scientists.

A Telescope in a 747

SOFIA engineers and scientists faced many technical challenges in designing and operating a telescope in an undulating and vibrating aircraft, but they also had to solve some basic mechanical and aerodynamic puzzles too. Flying a large aircraft with a 13-foot square hole in its fuselage creates mechanical stresses and turbulent airflow that interferes with the control surfaces in the tail section, compromising airworthiness and safety. The telescope cavity must be open to the outside environment since no single window material is transparent at all infrared wavelengths. Though the telescope works best outside in the cold, astronomers prefer working in a pressurized and heated cabin.

SOFIA OVER SIERRAS NASA's airborne observatory flies over California's Sierra Nevada during an April 14, 2010 test flight. The gaping hole in the fuselage exposes the 17-ton telescope. Top speed is about 500 miles (800 km) per hour.





FLIGHT PATH On its first-light flight on May 25–26, 2010, SOFIA covered about 3,800 miles. Astronomers conduct their observations during individual segments of the flight, called flight legs, along which the telescope pointing system can emulate equatorial tracking to follow an object in the celestial sphere. Most of the first-light flight legs enabled observations of bright stars for tests of the telescope control and optical systems. Two of the legs enabled observations of M82 and Jupiter.

The telescope guiding system must fix the telescope on the chosen sky position while the entire assembly experiences air turbulence and jet-engine vibrations. To minimize buffeting by turbulence, the telescope and instruments are suspended at opposite ends of a tubular arm, creating a 34,000-pound (15,400-kg) dumbbell balanced at

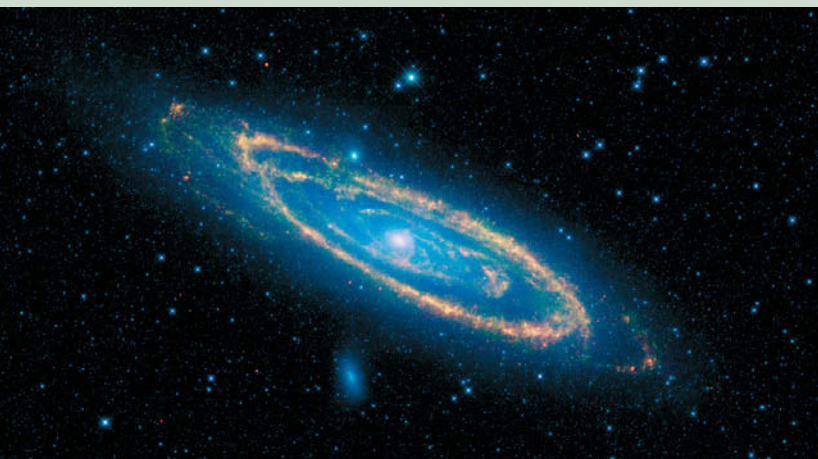
a pressure bulkhead on a 3-foot-diameter spherical bearing that floats on a thin layer of pressurized oil. The telescope assembly's inertia, assisted by air springs, dampens the large-scale motion of mild turbulence. The control system then uses gyroscopes and data from a high-speed camera to instruct magnetic torquing motors on how to counteract smaller telescope motions. Once engineers have tested and characterized in-flight telescope vibration, a computer system will measure the telescope's movement, predict its next deviation from the astronomical target, and correct the telescope control system before the motion disturbs observations.

SOFIA avoids condensation on the optics by closing and sealing the telescope compartment and back-filling it

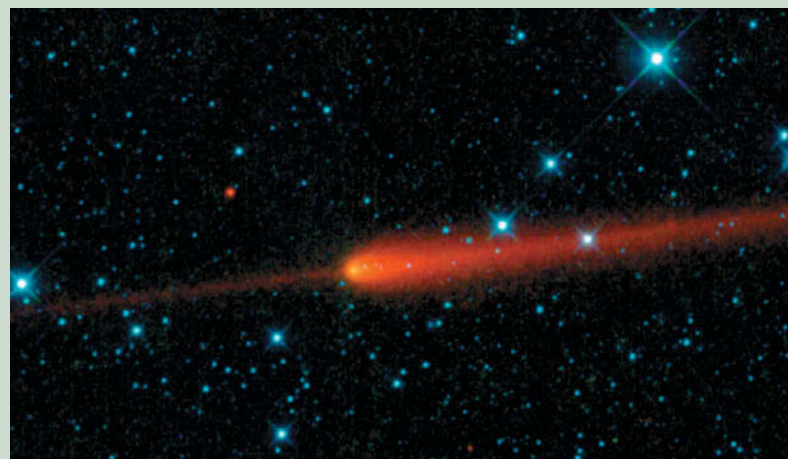
WISE Chugs Along

As SOFIA gears up for its science mission, NASA's Wide-Field Infrared Survey Explorer (WISE) satellite has completed its mapping of the entire infrared sky with a 16-inch telescope. The WISE team expects the cryogen — which keeps the scope cool enough for infrared observations — to run out around November 11th, but it could last a month longer. "We should cover at least half the sky twice, and perhaps 80% twice," reports project scientist Peter Eisenhardt (NASA/JPL).

WISE has taken more than 1 million images and cataloged more than 500 million infrared sources, including more than 12,000 new asteroids, 11 new comets, and a number of previously unknown brown dwarfs and ultraluminous infrared galaxies. SOFIA's cameras have a much smaller field of view than those on WISE, but SOFIA will study many of these objects in much greater detail. SOFIA will also enable spectral analysis of many of the objects identified by WISE and by Europe's Herschel Space Observatory. — *Robert Naeye*



NASA / JPL-CALTECH / WISE TEAM (3)



Left: WISE imaged the Andromeda Galaxy (M31) at four infrared wavelengths. Blue regions are rich in older stars while yellow and red areas show dust heated by massive young stars. Unlike the Milky Way, most of Andromeda's star formation is concentrated in a "ring of fire" that is clearly evident here. **Right:** WISE also catches objects close to home, such as Comet 65P/Gunn. The main gas and dust tail veers off to the right from the bright nucleus. The fainter streak to the left consists of dust particles previously shed by the comet.

with nitrogen gas when the aircraft is below 36,000 feet. The telescope cavity door must not interfere with the airflow along the fuselage to the aircraft rudder and stabilizers. SOFIA engineers designed the telescope cavity door using scale models and a wind tunnel at NASA's Ames Research Center in northern California.

International Partnership

German scientists and engineers contributed the entire SOFIA telescope and mount assembly, as well as two of the nine scientific instruments. Optical engineers at SCHOTT AG in Mainz, Germany cast the primary mirror, and the French optics company SAGEM-REOSC then lightened the mirror by milling a hollow honeycomb structure in its rear surface. SAGEM-REOSC also ground and polished the mirror's reflective surface figure. CSEM in Switzerland designed and built the silicon-carbide secondary-mirror assembly. The DLR (German Aerospace Center) contracted with two German firms (Kayser-Threde in Munich and MAN Technologie AG in Mainz and Augsburg) to develop the lightweight polymer composite telescope assembly.

SOFIA'S PREDECESSORS

Scientists at Los Alamos and Sandia National Laboratories used a Convair 990 aircraft to observe a solar eclipse in 1966. In the 1960s NASA flew several airborne observatories, including a 30-cm (12-inch) telescope mounted in a Learjet. In 1970 most infrared astronomical observations transferred to the Kuiper Airborne Observatory (KAO, pictured here), a C-141 military transport plane with a 36-inch telescope. In 1995 NASA retired the KAO and re-allocated its funding to SOFIA development.



NASA / JAMES RESEARCH CENTER

The aircraft development was based in the United States. L-3 Communications in Waco, Texas, completely refurbished the commercial 747. The process involved stripping the plane almost to its airframe, a complete overhaul of all aircraft systems, cutting the telescope hole



WISE is well suited for wide shots of star-forming regions in our galaxy. This section of the Seagull Nebula (IC 2177) covers an area nearly 7 times the width of the full Moon in an area straddling the border of Monoceros and Canis Major. The cloud is about 3,800 light-years away in the Orion Spur, the same partial spiral arm that is home to our solar system. The star cluster near the seagull's "eye" is NGC 2327; the stars are about 1.5 million years old. The hottest and brightest stars cause the "eye" to glow in infrared light.

in the fuselage, installing the telescope and cavity-door assemblies, rewiring the aircraft, altering the avionics, and reinforcing the outer skin on the fuselage's aft section to support the telescope's weight. Engineers and personnel at NASA's Dryden Aircraft Operations Facility in southern California completed final alterations and flight tests, and SOFIA engineers have worked with the Federal Aviation Administration and NASA to test the observatory's airworthiness and safety.

Observing on SOFIA

The aircraft cabin has airline seats with computer workstations so scientists can work comfortably on data acquisition and analysis. The researchers will fly on the observatory and control their observations in cooperation



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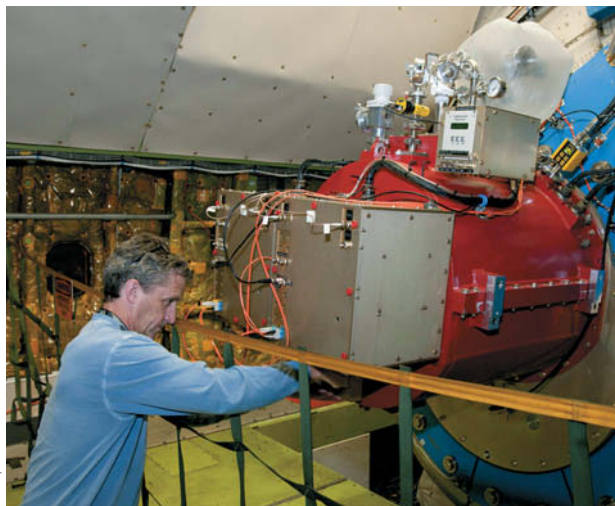
PHOTO: SHERI ENGLUND

To learn more about SOFIA, visit SkyandTelescope.com/SOFIA to listen to a podcast interview with author Luke Keller.

with SOFIA telescope operators and flight planners. Typical flights will last 8 hours, with about 6 hours spent at cruising altitude gathering science data.

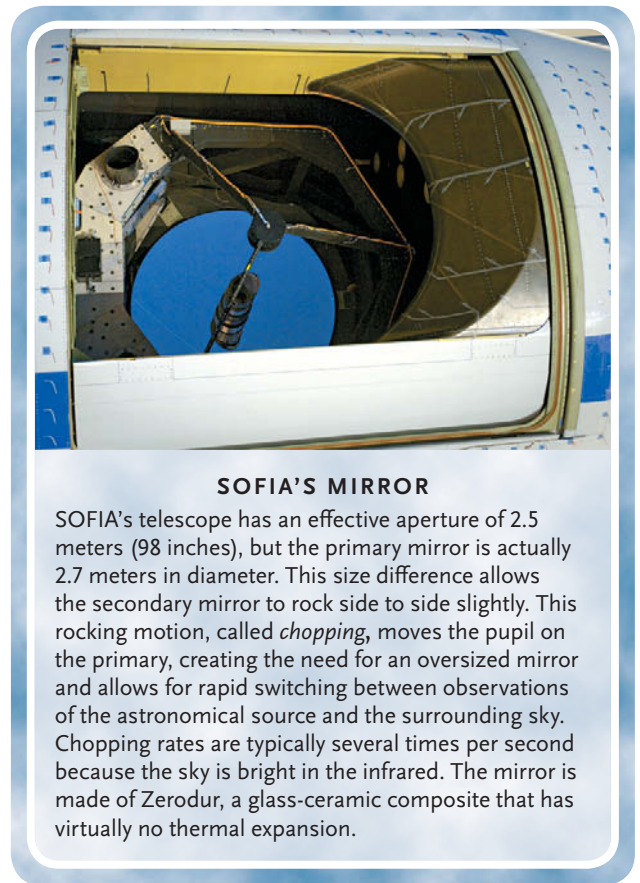
Each telescope pointing requires a unique flight path, called a leg. Flight legs must add up end-to-end so that the airplane returns to its starting point while maximizing in-flight observing time on astronomical targets.

SOFIA's current home is Palmdale Field, located near Edwards Air Force Base in southern California. The observatory will fly round trips from Palmdale to observe targets in the northern sky. Eventually, SOFIA will fly out of Christchurch, New Zealand, for part of the year to access the southern sky. With prior approval, SOFIA can operate from any airport in the world that can accommo-



NASA / TOM TSCHIDA

FORCAST Cornell University mechanical engineer **Chuck Henderson** makes adjustments to the 1,290-pound (585-kilogram) FORCAST camera.



NASA / TOM TSCHIDA

SOFIA'S MIRROR

SOFIA's telescope has an effective aperture of 2.5 meters (98 inches), but the primary mirror is actually 2.7 meters in diameter. This size difference allows the secondary mirror to rock side to side slightly. This rocking motion, called *chopping*, moves the pupil on the primary, creating the need for an oversized mirror and allows for rapid switching between observations of the astronomical source and the surrounding sky. Chopping rates are typically several times per second because the sky is bright in the infrared. The mirror is made of Zerodur, a glass-ceramic composite that has virtually no thermal expansion.

date a 747. When SOFIA reaches its full operating capability in 2014, we expect about 100 science flights per year.

Over the next 20 years SOFIA will allow astronomers to nail down many details in our understanding of origins and evolutionary processes in the universe by enabling high-resolution spectroscopy and by filling in spectral gaps left unobserved as other missions come and go. Many of these advances will be due to the fact that new risky technologies and techniques will be tried first on SOFIA before they are implemented on more complicated and volume-limited space telescopes. SOFIA is the long-awaited link between ground- and space-based infrared observatories. ♦

*Ithaca College physicist **Luke Keller** is a coinvestigator on SOFIA's FORCAST instrument. He led both the optical design and testing of the camera, and he also led the development of the image-processing and data-analysis software. His research interests include observations of newly forming planetary systems.*

*SOFIA research scientist **Jürgen Wolf**, a veteran of airborne astronomy with the Kuiper Airborne Observatory, is working to optimize SOFIA's target acquisition and tracking cameras and the telescope's pointing stability. His research interests include observations of transiting exoplanets.*

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The Hunt for Super-Earths

SARA SEAGER

Astronomers are finding and studying worlds just a little larger than ours.

For thousands of years people have wondered if we are alone. Modern astronomers pose the question in a slightly different way, a way that can be answered quantitatively, in stages, in the near future: Are there planets like Earth? Are they common? Do any of them have signs of life? The hunt for life-sustaining exoplanets is accelerating as



astronomers are uncovering dozens to hundreds of super-Earths.

A SUPER-EARTH Artist Don Dixon depicts a hypothetical super-Earth as seen from low orbit.

Nobody really knows what such a planet would look like if we could see one close up, but we can be certain that such planets will display an astonishing diversity resulting from their varying compositions, masses, and distances from their host stars.

What's a Super-Earth?

Super-Earths are unofficially defined as planets with masses between about 1 and 10 Earth masses. The term is largely reserved for planets that are rocky in nature rather than for planets that have icy interiors or significant gas envelopes. Astronomers refer to the latter as exo-Neptunes. Because super-Earths and exo-Neptunes may be continuous and have an overlapping mass range, they are often discussed together.

Super-Earths are fascinating because they have no solar-system counterparts, because they represent our nearest-term hope for finding habitable planets, and because they should display a huge diversity of properties. The wide and almost continuous spread of giant exoplanet masses and orbits illustrates the random nature of planet formation and migration; this trend surely extends to super-Earths as well. Indeed, even though about two dozen are known so far, their range of masses and orbits supports this notion. Current detection methods are biased toward finding close-in super-Earths, so there's undoubtedly a huge population waiting to be discovered.

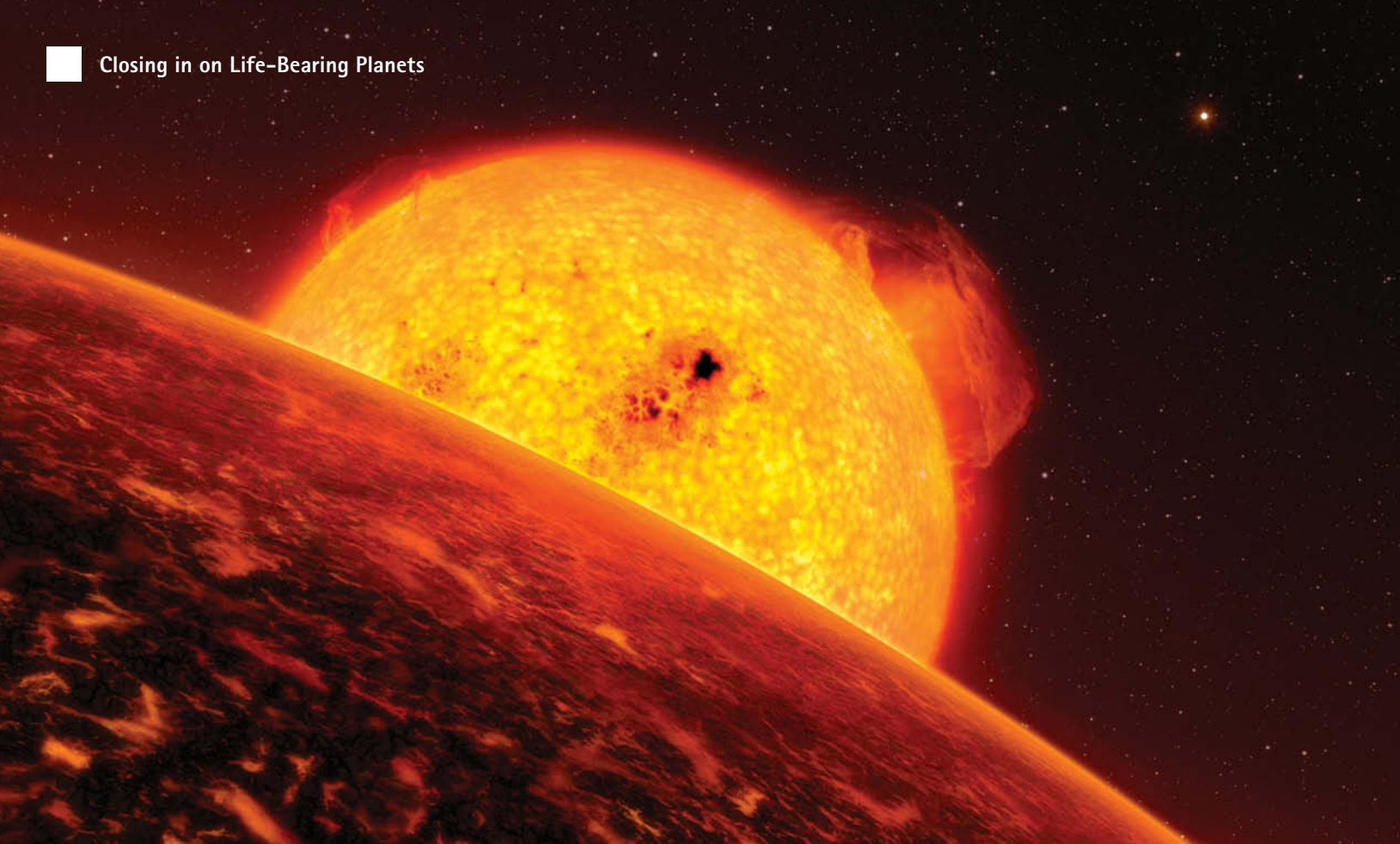
Because super-Earths have low masses and small sizes (less than 3 Earth radii), they are much more challenging to discover than giant exoplanets. But at the same time, super-Earths are easier to find than Earth-mass or Earth-size planets, especially if they orbit stars much smaller than our Sun. Super-Earths are exciting because they have the requisite solid (or in some cases liquid) surface necessary to support life as we know it. The hunt is on for super-Earths in a star's habitable zone, the region around a star with the right temperatures for surface water.

Description of a Super-Earth

Let's take a virtual trip to a hypothetical super-Earth orbiting in the habitable zone of a small *M* star (a red dwarf). A small star emits less energy than our Sun, bringing the habitable zone much closer in. A super-Earth would thus orbit its red-dwarf host at a distance of approximately 2



Illustration by Don Dixon / Cosmographica



ESO / LUIS CALÇADA

million miles, much closer than the Earth–Sun 93-million-mile separation. The alien sun would loom far larger than the Sun appears in our sky, and it would hover in the same place at all times. If you're an astronomer, you could stay on the far side, where the sky is always dark.

The permanent day and night side results from the planet's proximity to its star. The star's powerful gravity would eventually force the nearby planet into a tidally-locked state, where the planet shows the same face to the star at all times, just like the Moon does to Earth. Your birthday would occur frequently — about once every 10 Earth days. In addition, a super-Earth would have a higher surface gravity than our world, making it very difficult to stand up straight or do work. Michael Jordan would not be dunking basketballs on this planet!

FIND A SUPER-EARTH

Amateur astronomers equipped with modest backyard telescopes and modern CCD cameras, and who are experienced in high-precision photometry measurements, could, in principle, discover a super-Earth transiting a relatively bright red dwarf. Speaking of his team's discovery of the transiting super-Earth Gliese 1214b, MEarth team leader David Charbonneau says, "Since we found the super-Earth using a small ground-based telescope, this means that anyone else with a similar telescope and a good CCD camera can detect it too. Students around the world can now study this super-Earth!"

PLANET FROM HELL As one can easily tell from this artist's rendition, Corot-7b is about the last planet any spacefarer would want to visit. Orbiting only 1.6 million miles (0.017 a.u.) from its K0-star host, the 5-Earth-mass world is searing hot, and probably consists almost entirely of rock and metals. Recent models strongly suggest that Corot-7b is volcanically active, meaning its geology is probably more like Io than like Earth.

On second thought, visiting this super-Earth might not be such a great idea. You'd need to wear powerful sunscreen all the time if you're on the dayside, and you might suffer mutations induced by powerful radiation bursts from the star. Young red dwarfs can be very active, producing harmful ultraviolet radiation and huge flares that would constantly bathe the planet's surface, disabling electronics and destroying biological cells.

Some astronomers think searching for life on this kind of planet is a good example of breaking free from an "Earth-centric" biased view, while others think it's more of a case of someone looking under a streetlight for lost keys because he or she can't see anywhere else on a dark night. But observers will never be inhibited by theoretical limitations.

Most super-Earths should orbit much farther from their host star than our virtual example. And although no super-Earths are strictly known to be orbiting in their host star's habitable zone, one candidate is under consideration. Gliese 581d is a bit far from its red-dwarf host

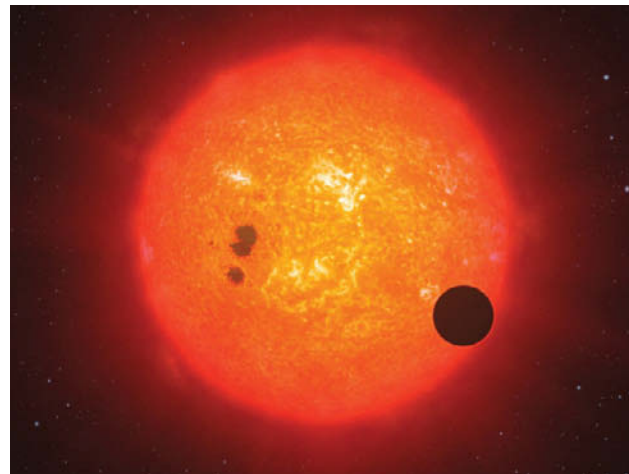
(0.22 a.u.) to be conventionally considered the right temperature, but this 7- to 10-Earth-mass world might have a thick atmosphere with a concomitant massive greenhouse effect to warm the surface.

Transiting Super-Earths

To determine whether a planet is predominantly rocky like our solar system's terrestrial planets instead of primarily made of hydrogen and helium like the giant planets, we need to measure its radius and mass. Together these yield a planet's average density, which can be used to infer the range of possibilities for a planet's interior bulk composition. Mass measurements come from the well-established radial-velocity (wobble) method. The only way astronomers can measure exoplanet sizes is from the light curves of transiting planets, those that pass in front of their star as seen from Earth. Transiting planets are thus today's most valuable commodity in exoplanet research. Two transiting super-Earths are currently known, though neither one orbits within its host star's habitable zone.

Discovered by the French Corot satellite, Corot-7b is an exotic "planet from hell" because of its high temperature — well over 2000 K (3,100°F; see *S&T*: May 2009, page 30). Its surface should be hot enough to melt lead and rock, forming lava lakes on its dayside. The intense tempera-

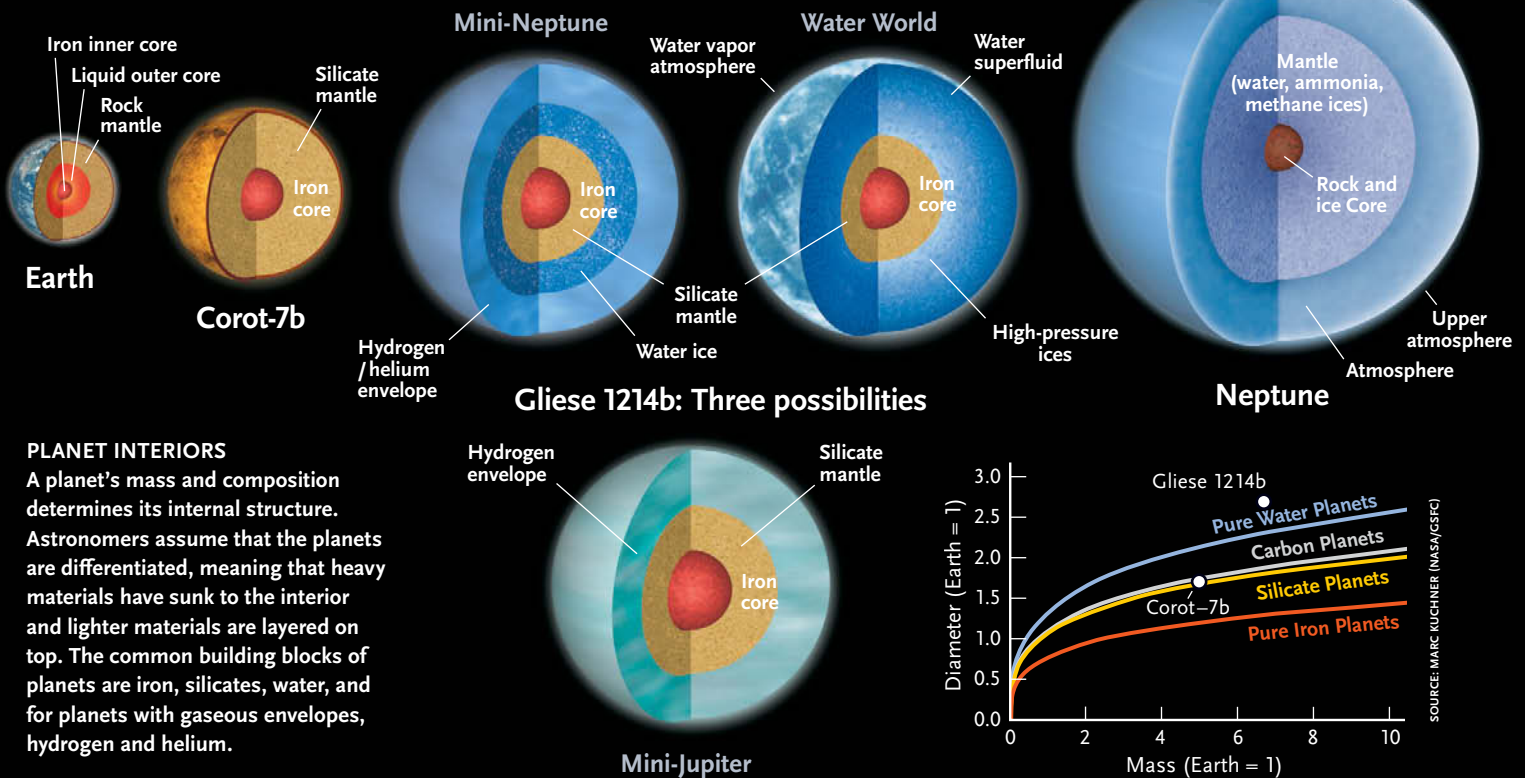
NEARLY HABITABLE The super-Earth Gliese 1214b orbits about 1.3 million miles (0.014 a.u.) from its red-dwarf host star, which probably makes its estimated 400°F temperature too hot to support life. The planet orbits its star every 38 hours. Even though Gliese 1214b orbits closer to its star than does Corot-7b, Gliese 1214 is much cooler and dimmer than Corot-7b's host star. Whereas Corot-7b orbits once every 20.5 hours, Gliese 1214b takes about 38 hours to complete an orbit. Astronomers can determine the diameter of a planet by measuring how much of the host star's light that it blocks when it passes in front, an event known as a transit.



ESO / LUIS CALÇADA

S&T: GREGG DINDERMAN

Planetary Interiors





SMALL SCOPES, BIG DISCOVERY The eight robotically controlled 16-inch Ritchey-Chrétien telescopes of the MEarth project keep an eye on about 2,000 nearby red dwarfs (spectral type *M*) to see if they have transiting planets. The telescopes are situated at the Fred L. Whipple Observatory on Mount Hopkins, Arizona. MEarth has already discovered the super-Earth Gliese 1214b, and is almost certain to discover more transiting exoplanets. Some of these worlds might be well suited for follow-up studies by NASA's James Webb Space Telescope, which could reveal the presence of atmospheric gases indicating life.

ture comes from its proximity to its host star, just over 4 stellar radii away. The atmosphere is too hot for clouds and precipitation to consist of water. Instead, clouds should be composed of high-temperature solid materials such as very small rock and iron particles, and rain would be made of liquid rock and iron.

With a mass of 5 Earths and a radius of 1.7 Earths, Corot-7b's average density is about 5.6 grams per cubic centimeter. This is about the same density as Earth, telling us that the planet is primarily rock and metal. The planet's surface gravity is almost twice as high as Earth's, so it should have less-pronounced surface features.

Curiously, astronomers have evidence for a second planet (and possibly a third) in the Corot-7 system. A gravitational tug-of-war between the two planets could lead to extremely active volcanism on Corot-7b. We might

someday be able to detect spewed-out gases such as sodium and sulfur. All in all, Corot-7b should be viewed as a super-Io: a hot, dry, volcanically active planet.

Discovered by the MEarth team (led by David Charbonneau of the Harvard-Smithsonian Center for Astrophysics), Gliese 1214b is the other known transiting super-Earth. It orbits a red dwarf at a distance of only 1.3 million miles (0.014 a.u.). Too hot for water clouds and too cold for the high-temperature clouds expected on Corot-7b, Gliese 1214b could have a bluish hue if it has no clouds, because starlight will be scattered to make a blue sky like Earth's. If so, the star and planet would make a striking red-blue pair.

Gliese 1214b contains about 6.6 Earth masses and is about 2.7 Earth radii, giving it a mean density of about 1.9 g/cm³. Its relatively low density makes the interior composition trickier to determine than Corot-7b's, highlighting one of the roadblocks in our attempts to understand what exoplanets are made of.

To understand the challenge, imagine you're given two boxes that you can't open. The boxes have identical volume and mass. Inside the box are three different materials: gas, ice, and a rock/iron mix. Can you tell whether or not the boxes have the same mass fractions of each material? No. With three or more materials it's impossible to determine how much of each material is in each box. Based on Gliese 1214b's mass, radius, and density, we cannot tell how much of each of the major planetary building blocks (hydrogen and helium gas, water, rock, and iron) are present.

One interesting possibility is that Gliese 1214b is made mostly of water in the form of high-pressure ice deep in the interior. The atmosphere would consist mostly of water vapor. Sandwiched in between the atmosphere and interior would be a layer of a very unusual material, a layer of water superfluid. Not quite a gas, not quite a liquid, superfluids don't exist naturally on Earth except at a few hydrothermal vents on the deep seafloor. Gliese 1214b is a relatively hot planet, with an external temperature of about 400 to 550 K. While some astronomers are still hopeful that Gliese 1214b might have liquid water at its surface, most models show the planet is too hot.

Earth-Size Moons

It's exciting to think of the possibility of a large, life-sustaining moon orbiting a giant exoplanet. Many giant exoplanets are known to orbit in or near their star's habitable zone. There's no question that giant planets could have one or more moons, but right now we can only detect moons of about an Earth mass or

greater (*S&T*: July 2009, page 30). The movie *Avatar* featured life on a moon orbiting a giant planet in Alpha Centauri's habitable zone. *Avatar* is about 10 years behind the times, though, because radial-velocity observations have now ruled out the presence of giant planets around Alpha Centauri A or B.

An intriguing possibility is that one or more moons orbit the giant planet Corot-9b. In a Mercury-like orbit, Corot-9b is the first known transiting planet with a large enough semi-major axis to have a significant area for a moon to exist in a stable orbit. For planets that pass too close to their host stars, even

for only a short time during the closest approach, moons could be stripped away by the host star's gravity. Astronomers are planning to use NASA's Spitzer Space Telescope to search for an Earth-size moon around Corot-9b. The subsurface of a Corot-9b moon could potentially be habitable.

— S. S.

SPACECRAFT SENTINELS Corot and Kepler are on the lookout for transiting exoplanets. Corot (*near right*) has already discovered one super-Earth (Corot-7b). In just one year, Kepler (*far right*) has bagged hundreds of planet candidates, some of which will turn out to be super-Earths, with perhaps hundreds more in the years to follow. Most of the planets that Corot and Kepler will discover will be too distant and faint for effective follow-up studies.

Outlook

The discovery and characterization of super-Earths is such a new field of research that it has raised more questions than answers. We'd like to know how common super-Earths are, the range of their interiors and atmosphere compositions, and the most burning question, if we will be able to identify any biosignature gases.

The frequency of super-Earths remains unknown. The radial-velocity results suggest that up to 30% of Sun-like stars have a super-Earth or exo-Neptune with a period of two months or less. Early results from NASA's Kepler mission hint that less than 1% of Sun-like stars may have super-Earths with periods of about a month or less.

In the solar system there is a definite relationship between the relative abundances of rock-ice-gas and planet mass: small planets (less than 1 Earth mass) are rocky, the intermediate planets Uranus and Neptune (15 to 17 Earth masses) are icy, and the giant planets Jupiter and Saturn are predominantly composed of hydrogen and helium. How super-Earths fit in could help us further understand their formation. Are super-Earths failed gas giants like smaller versions of Uranus and Neptune? Or are they overgrown Earths? Some, such as carbon planets, may even have more exotic compositions.

Super-Earth atmospheres are the windows into biosignature gases. Are the atmospheres predominantly carbon dioxide (like Venus) or nitrogen (like Earth)? Are they possibly enriched in hydrogen gas if the planets are massive or cold enough? Here we run into theoretical challenges. Unlike the giant planets, which retain all of the gases with which they were born, Earths and super-Earths will probably experience vigorous atmospheric evolution. Lightweight gases such as hydrogen eventually escape from smaller planets, but for more-massive planets, gas-surface and gas-ocean reactions can significantly alter the atmospheric composition.

Detailed super-Earth atmosphere observations will have to wait until the launch of NASA's James Webb Space Telescope around 2014. Astronomers hope to observe transiting super-Earths with JWST in the same way they have studied transiting hot Jupiters with Hubble and Spitzer. For even the most favorable targets, 100 or more hours of telescope time per planet atmosphere will likely be needed. This is akin to a Hubble Deep-Field observation for each exoplanet.

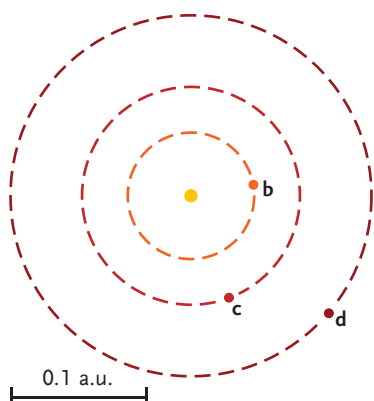
A lot of telescope time is required simply because the planets and their atmospheres are small compared to the



Known Super-Earths Around Solar-Type Stars

Planet	Mass (Earth=1)	Semi-major Axis (a.u.)	Discovery Year	Discovery Method
Gliese 581e	≥1.9	0.03	2009	RV
Gliese 581c	≥5.4	0.07	2007	RV
Gliese 581d	≥7.1	0.22	2007	RV
HD 40307b	≥4.2	0.047	2008	RV
HD 40307c	≥6.8	0.081	2008	RV
HD 40307d	≥9.1	0.134	2008	RV
Corot-7b	5	0.017	2009	Transit
Corot-7c	~8	0.046	2009	RV
MOA-2007-BLG-192-L	~3	~0.6	2008	GML
HD 156668b	≥4.2	0.05	2010	RV
61 Virginis b	≥5.1	0.05	2009	RV
OGLE-05-390L	~5.4	~2.1	2005	GML
HD 215497b	≥5.4	~0.05	2009	RV
Gliese 667C b	≥5.7	~0.05	2009	RV
Gliese 433b	≥6.0	~0.06	2009	RV
Gliese 1214b	6.6	0.014	2009	Transit
Gliese 876d	≥6.7	0.021	2005	RV
55 Cancri e	≥7.6	0.038	2004	RV
HD 1461b	≥7.6	0.06	2009	RV
HD 181433b	≥7.6	0.08	2008	RV
HD 285968b	≥8.4	0.066	2007	RV
HD 7924b	≥9.2	0.057	2009	RV

*Notes: This list does not include planets orbiting pulsars. For most of these planets, only the minimum mass is known. Some of these planets might be more massive than the 10-Earth-mass upper limit defined for super-Earths. Only two of the planets have known radii: Corot-7b (1.7 Earths) and Gliese 1214b (2.7 Earths). Main source: <http://exoplanet.eu>
RV = radial velocity GML = gravitational microlensing



SUPER-EARTH SYSTEM HD 40307 is orbited by three super-Earths, all much closer to the host star than Mercury is to the Sun. All three planets are too close to the star to have surface water.

S&T: LEAH TISCIONE

SYSTEMS WITH THREE SUPER-EARTHS

The K2 star HD 40307 in Pictor has a triple-planetary system with super-Earths that have minimum masses of 4, 7, and 9 Earth masses. They orbit the host star in a tightly packed configuration ranging from 0.05 to 0.13 astronomical unit. Inward migration must have brought the planets close together and so near to the host star. The red dwarf Gliese 581 in Libra has four known planets, three of which are roughly in the super-Earth mass range.

Mercury

star; to acquire a strong enough signal from the planet's atmosphere, the signal from dozens of transits will have to be added together. Although we'll be interested to learn what molecules occur in super-Earth atmospheres, our primary interest is water vapor to signal the presence of liquid-water oceans, and oxygen or another biosignature gas at high strength.

The Search for Super-Earths

Astronomers are currently working feverishly to increase the pool of super-Earths to study with JWST. MEarth uses an array of eight 16-inch automated telescopes in Arizona

to monitor 2,000 nearby red dwarfs. It can find planets as small as about 2 Earth radii. The space telescopes Spitzer and MOST are observing known super-Earths discovered by radial velocity to see if any of them transit their stars.

Meanwhile, Kepler and Corot continue to find transiting planets, and they will undoubtedly turn up many new super-Earths (see last month's issue, page 12). Although most of Kepler's super-Earths will be orbiting stars too faint (magnitude 12 to 16) for atmosphere follow up, JWST will be able to measure precise planetary radii.

New missions being planned to follow Kepler will yield an outstanding pool of candidates for atmosphere follow up. MIT is leading a design for the Transiting Exoplanet Survey Satellite (TESS) to search 2 million stars for super-Earths in two-month orbits. ESA's PLATO spacecraft is under study; it would identify Earths and super-Earths orbiting bright Sun-like stars (magnitude 4 to 11).

Super-Earths are no exception to the two exoplanet golden rules. First, the best in exoplanet research is yet to come. Second, in exoplanets, almost anything is possible within the laws of physics and chemistry. We're at the tip of the iceberg in terms of super-Earth discovery and characterization. ♦

Sara Seager is a professor of planetary science and physics at MIT. Her research focuses on theoretical models of atmospheres, interiors, and biosignatures for all kinds of exoplanets.



Download a **FREE BONUS PODCAST**



To learn more about super-Earths and exoplanets, visit SkyandTelescope.com/superearths to listen to a podcast interview with author Sara Seager.

SOURCE: NASA / GODDARD SPACE FLIGHT CENTER

Naked-Eye Exoplanet Host Stars

More than 470 exoplanets have been found to date, and we've put together a list of 20 naked-eye stars that host them. Point out some of these at your next star party, and wave hello — who knows, someone may be waving back.

Magnitude-1 Pollux has at least one planet, a hot Jupiter. Gamma Leonis (Algieba), the magnitude-2 star at the base of Leo's neck, has at least one planet, possibly two. Epsilon Tauri, the magnitude-3.5 star at the tip of the Hyades "V" opposite Aldebaran, has a planet. Gamma Cephei, the magnitude-3.2 star at the peak of the Cepheus house asterism, is actually a close binary, and Gamma Cephei A has at least one planet.

Magnitude-4.1 Upsilon Andromedae sports at least 3 planets, and one of them orbits in the star's habitable zone. Magnitude-3.3 Iota Draconis has a planet in a highly elongated orbit; Tau Bootis has a hot Jupiter. Just next door, 70 Virginis (magnitude 5) hosts a heavier version of Jupiter.

A bit more of a challenge in bright skies, 51 Pegasi at magnitude 5.5 and HR 8799 (also in Pegasus) at magnitude 6 both have planets; 51 Peg b was the first discovered around a Sun-like star, and the three planets orbiting HR 8799 have been directly imaged. At 6th magnitude, 55 Cancri may be a binocular object in light-polluted skies, but is well worth hunting down. This star hosts a

system of at least five planets, one of which orbits within the habitable zone.

The internet is awash with further information on these and other exoplanetary systems. The Planetary Society (www.planetary.org/exoplanets/list.php) is a good place to start, with comprehensive listings, finder charts, and illustrations. To see our list of 20 exoplanet host stars that are magnitude 6 or brighter, along with information about the planets themselves, visit SkyandTelescope.com/exoplanethosts.

Michael Deneen and Bill Waller are members of the Gloucester Area Astronomy Club, in Gloucester, Massachusetts.

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Astro-Tech Ritchey-Chrétiens, refractors, and Imaging Newtonians put serious imaging capabilities on your current mount at very affordable prices. Want proof? Just look at the image below. It was taken using a \$449

Astro-Tech AT8IN Imaging Newtonian like the one to the right.

And Celestron EdgeHD and Meade Advanced Coma-Free telescopes put superb flat-field optics on complete go-to mounts that just ache to take pictures of the heavens.

The golden age of astrophotography is here and very affordable. Are you ready to join in?

here's a \$449 example . . .



AT8IN image of the Horsehead and Flame nebulae in HaRGB by astronomy hobbyist David Rosenthal (<http://pbase.com/djrlx90>).



Astro-Tech AT8IN,
8" f/4 Newtonian,
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The new **Celestron NexGuide stand-alone** CCD autoguider takes the work out of guiding your DSLR astrophotos. It doesn't need a computer to operate in the field and runs off flashlight batteries. It plugs into your mount's autoguider port, automatically calibrates itself, and sets the guiding parameters all on its own. Who said guiding was hard?

\$240 a megapixel.

Take your choice of monochrome or single-shot color. The price is the same for either of the **SBIG ST-8300** 8.3 megapixel CCD cameras. They are two of the best bargains ever from SBIG, the leader in CCD imaging.



Little scope, huge field.

The 65mm **Astro-Tech AT-65EDQ quadruplet** f/6 apo refractor has two ED lenses and a built-in field flattener. It captured all of the Lagoon and Trifid in the single flat field image to the right.

\$549



AT65EDQ image by Jason Blaschka.



\$1995

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A lot of scopes have coma, the optical flaw that turns stars into seagulls at the edges of the field. **Meade LX200-ACF** catadioptric scopes don't. They have Advanced Coma-Free (ACF) optics that make your stars look like stars across the entire field. You get the coma-free performance of a costly Ritchey-Chrétien telescope, but at only a fraction of an R-C's price.

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Meade LX200-ACF: 8", \$2599; 10", \$3599; 12", \$4499; 14", \$6999; 16", \$14,999 to \$16,299.

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Megapixel Imaging for Less:

SBIG's ST-8300M CCD Camera

Don't be fooled by the price; this camera is built for serious deep-sky imaging.



SBIG's ST-8300M CCD Camera

U.S. price: \$1,995

Santa Barbara Instrument Group
147-A Castilian Dr., Santa Barbara, CA 93117
805-571-7244; www.sbig.com

OVER THE YEARS, many of the products I've tested have held surprises. SBIG's new ST-8300M CCD camera was not one of them. And that alone speaks volumes, since the bar had been set very high for this product from the moment its carefully guarded development was announced last October.

There were good reasons that expectations ran so high for this camera. Foremost is the company itself; SBIG has remained solidly focused on the astronomy community since it arguably launched the amateur CCD revolution more than 20 years ago with the introduction of its ST-4

autoguider/imager. Then there's the new camera's 8.3-megapixel KAF-8300 chip, which has generated more interest among amateur astronomers than any other CCD in recent memory. Unveiled with the lowest price of any similarly featured camera, the ST-8300M understandably drew considerable interest from the get-go.

Amateur astronomers have had an especially positive response to the KAF-8300 chip since Kodak introduced it several years ago. It's a full-frame CCD with a 3326×2504 array of 5.4-micron-square pixels. The active imaging area measures a very respectable 18 by 14 millimeters, and the chip has antiblooming protection, which helps prevent unsightly streaks from appearing on bright objects in the image. The CCD is also very sensitive, with a quantum

Except for the FW5-8300 Filter Wheel, everything seen here is included with SBIG's ST-8300M CCD camera. The camera body and filter wheel have standard female T-thread mounts.

ALL PHOTOS BY THE AUTHOR; ASTRONOMICAL IMAGE PROCESSING BY SEAN WALKER

efficiency that peaks at almost 60% in the middle of the visual spectrum and is close to 50% at the astronomically important deep-red wavelength of hydrogen-alpha light.

Equally interesting are the chip's small pixels, which make the CCD attractive to astrophotographers imaging with today's popular short-focus refractors and camera lenses. To achieve the often-recommended scale of 2 arcseconds per pixel for deep-sky work, the KAF-8300 requires an effective focal length of only 560 mm. Furthermore, at that focal length the chip covers a generous 1.8°-by-1.4° field of view. For optimum imaging at longer focal lengths, you can bin the ST-8300M's CCD 2×2 or 3×3 to create pixels that are effectively 10.8 or 16.2 microns square, respectively.

SBIG did not cut any obvious corners when creating this camera. The only feature lacking on the ST-8300M compared to SBIG's more-advanced imaging cameras is the company's patented internal autoguiding that uses a second, off-axis CCD mounted next to the imaging chip. Then too, guiding is no longer the prerequisite it once was for producing quality deep-sky images. Telescope drives have improved markedly in the past decade, and many of today's excellent astrophotos are made by stacking multiple 1-minute exposures, which can typically be made without guiding.

The ST-8300M is very compact, measuring just 4 by 5

WHAT WE LIKE:

Full-featured CCD camera at a remarkable price

Compact, lightweight, and well made

WHAT WE DON'T LIKE:

Presently, a limited selection of "non-standard" 36-mm-diameter filters

by 2 inches (10 by 13 by 5 cm) and weighing 29 ounces (0.8 kg). The optional 5-position filter wheel (\$695) adds 17 ounces, increases the cross section to 5 by 7 inches, and makes the camera 1 inch thicker, but the distance to the chip is still small enough to allow using the camera with standard lenses made for 35-mm cameras. To that end the ST-

8300M has a 1/4-20 "tripod" socket machined into its body, and SBIG already has optional adapters (\$165) for Nikon and Canon FD lenses. The only caveat regarding the filter wheel is its use of "non-standard" 36-mm-diameter filters. Fortunately, three of the major players making filters for astronomical imaging — Astrodon, Baader, and Custom Scientific — offer this size.

The ST-8300M requires a single 12-volt DC power source capable of delivering 3 amps, and the camera comes with a "universal" adapter that runs on 100-to-240-volts AC. The only other cable needed is for the USB 2.0 connection between the camera and your computer. Because I already had USB 2.0 cabling snaked through my telescope mount, my setup also involved a small USB

The ST-8300M's wide-field performance and impressive sensitivity to deep-red hydrogen-alpha light are apparent in this 2°-wide view of the North America Nebula's "Gulf of Mexico." The 2-hour exposure through a Baader 7-nanometer H-alpha filter was taken with a William Optics FLT-98 apo refractor working at f/5.1.



hub and a total of about 30 feet of cable, which worked flawlessly. The filter wheel's electrical connects are to the camera body, thus eliminating the need for additional power and communication cables dangling from the camera. To use the ST-8300M as an autoguider, there's an ST-4 compatible port on the body.

For image acquisition and processing, the ST-8300 ships with SBIG's *CCDOPS* version 5 as well as Software Bisque's *CCDSOFT* version 5, both of which I've used in the past. My testing also included *MaxIm D/L 5.0*, since the program was already loaded on the 8-year-old Windows XP laptop used exclusively for image acquisition in my backyard observatory. My colleague Sean Walker and I calibrated and processed the images using a variety of computers and programs. The only downside to running the camera with a laptop bordering on dinosaur status was that my image downloads were about 33% slower than specified by SBIG, with full-resolution frames requiring about 12 seconds to transfer from the camera to the computer instead of the 8 seconds claimed by the company.

I used the camera last April, May, and June, at a time when the evening sky is dominated by relatively small galaxies. It wasn't until the end that I could image targets showcasing the camera's wide-field potential with the William Optics FLT-98 apo refractor I was using (see the Quick



One of the few deep-sky targets in the Northern Hemisphere's spring sky to benefit from wide-field imaging is this well-known trio of galaxies in eastern Leo. Clockwise from top, they are NGC 3628, M65, and M66.



Look review on the facing page).

The ST-8300M's regulated, single-stage thermoelectric cooler never failed to hold the CCD's temperature at least 38°C below ambient air temperature. On nights when a slight breeze kept the air stirred up in my roll-off roof observatory, I could achieve a temperature drop of 40°C. Regardless, like many modern CCD chips, the KAF-8300M has particularly good thermal characteristics, typically generating a dark current of only 0.2 electron per pixel per second when cooled to just 0°C. This low thermal signal is very desirable for a deep-sky camera, especially one used with narrowband filters that allow only a small amount of light to reach the chip.

Despite its low price, the ST-8300M is a no-compromise CCD camera that delivers image quality consistent with SBIG's line of high-end cameras. And like so many other products in today's digital world (think computers and smartphones), the ST-8300M is proof that decreasing prices do not mean less performance.

Senior editor *Dennis di Cicco* is amazed that it's been 20 years since he reviewed SBIG's ST-4 in the September 1990 issue.

Above: Using the same setup as for the North America Nebula, the author captured this view of the western half of the Veil Nebula. It was made from 30-minute exposures through red, green, and blue filters. North is at left.

Below: This author's setup for all the astronomical images in this review included an Astro-Physics Mach1 mount and home-made guidescope.



Quick Look

William Optics FLT-98 f/6.3 Apo Refractor

U.S. price: \$2,395

Worldwide dealer list available online
at www.williamoptics.com



THE TIMING WAS PERFECT. I was just beginning my tests of SBIG's ST-8300M CCD camera when I spotted the William Optics FLT-98 f/6.3 apo refractor at the Northeast Astronomy Forum last April. The scope's 618-mm focal length is an excellent match for the camera's 5.4-micron pixels, producing an image scale of 1.8 arcseconds per pixel. Equally attractive for astrophotography is the FLT-98's built-in digital focusing scale (called the Digital Display Gauge, or DDG for short) and \$269 optional Adjustable Flatteners Reducer IV (AFR-IV). The AFR-IV has a 0.8 $\times$ magnification factor, and while it's made for several William Optic refractors, with the FLT-98 it yields an effective focal length of 500 mm and an image scale of 2.2 arcseconds per pixel on the ST-8300M. A loan was quickly arranged for this review.

Visually, the FLT-98's air-spaced triplet objective, made with extra-low dispersion

Above: Weighing 13 pounds (5.9 kg) and measuring just 20 inches (51 cm) with the dewcap retracted, the William Optics FLT-98 comes with this exceptionally heavy-duty carrying case.

Right: The author quickly took a liking to the FLT-98's built-in digital readout for the position of the focuser's drawtube.

(ED) glass, delivers the bright, crisp, color-free star images that we've all come to expect from modern apochromatic refractors. But with photography being my main interest, I didn't linger at the eyepiece.

In addition to delivering excellent star images across the ST-8300M's CCD, the field flattener has a unique feature, making it especially useful with astronomical CCD cameras. For the best optical performance, the spacing between any field flattener and the camera's focal plane must be critically set. All the flatteners I've used in the past have been made with the 55-mm back focus dictated by the T standard established for 35-mm cameras. That's great if you shoot with DSLRs, but there's no industry standard for the back focus of astronomical CCD cameras. Getting the proper spacing for these cameras usually means cobbling adapters and a lot of trial-and-error experimenting.

The position of the AFR-IV's two-element lens can be varied within the body of the flattener by more than 20 mm with a simple twist of an external ring. It was thus a simple matter of screwing the flattener onto the ST-8300M's filter wheel and shooting a couple of short test exposures at different lens positions to zero-in on the optimum spacing. What a joy it was to nail the proper setting without endless tinkering with adapters and spacers.

The field illumination with the AFR-IV is notably uniform across the ST-8300M's chip, and I really only needed to use flat-field images for calibration when there were image artifacts due to dust on the camera's filters and/or CCD window.

It's probably a carryover from years of doing "old-fashion" astrophotography with film and manual guiding, but I like being outside with a telescope while shooting pictures. So I've never considered it a burden to manually focus my cameras even in this age of sophisticated autofocus gizmos.

Nevertheless, I immediately took a real liking to the DDG. It displays the position of the focuser's draw tube to an accuracy of 0.01 mm. This is a bit of overkill, and even with a deft touch on the scope's

fine-focus knob, it's challenging to set a position this accurately. But achieving an accuracy of 0.05 mm is a breeze, and that was certainly accurate enough for my setup and observing conditions. I've never used a manual system that was faster to focus than the DDG. It's great.

The DDG is powered by a small, internal 12-volt battery, and its large digits are very easy to read. The display has red backlighting controlled by a separate on/off button. The battery lasts a long time, especially if, unlike me, you remember to turn off the backlighting when you're done using it!

The FLT-98's focuser is a modified-Crayford design with ball bearings encasing a moving stainless-steel rail on the drawtube. The manufacturer doesn't specify its load capacity. While I had no flexure problems during 10-minute exposures with the 4.1-pound load of the AFR-IV and ST-8300M, heavier cameras might present problems for setups involving a guidescope (focuser flexure is rarely a problem with off-axis guiding).

Overall, this imaging setup was extremely nice. I only wish I could have used it to advantage on the big, splashy targets that become available in my late-summer and autumn evening skies. ♦

— D. di C.

WHAT WE LIKE:

Excellent apo performance
Built-in digital focusing scale

WHAT WE DON'T LIKE:

Focuser may flex under heavy loads

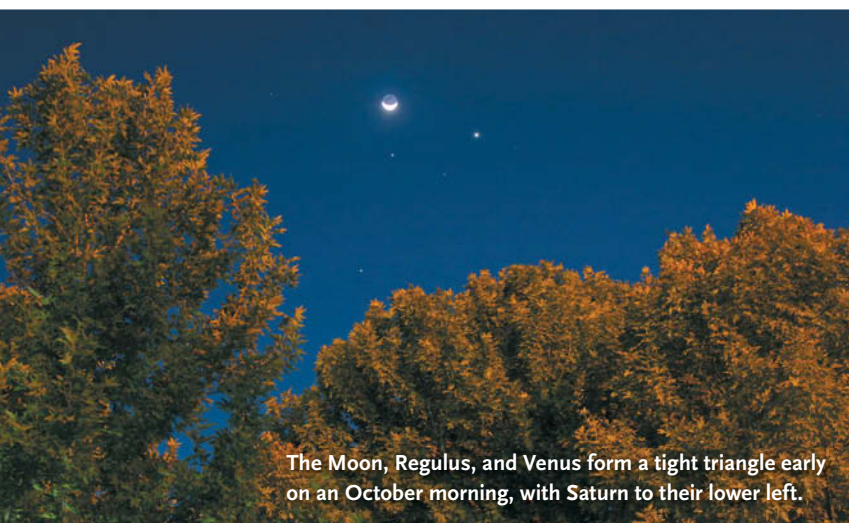




Joys of an Autumn Night

October stargazing is splendid in many different ways.

IT'S EASY TO LIKE Autumn days. Sunny but temperate afternoons, fresh air and blue skies. Colored leaves on trees and falling gently to the ground. Flocks of migrating birds, the harvest from the fields. But what's to like about autumn nights? A great number of things.



The Moon, Regulus, and Venus form a tight triangle early on an October morning, with Saturn to their lower left.

BABAK TAPRESHI / TWAN

Nights keep getting longer. If you're a stargazer, you are starved for more hours of starry darkness after summer's short nights. Autumn brings them — longer and longer nights until winter begins.

Autumn's first hours of the night build the suspense for the mid-evening and late-night arrival of the brilliant constellations of winter. Okay, it may seem like cheating to give autumn credit for the splendors of winter stars. But there's a lot to be said for anticipation and the thrill of arrival. Each step in the arrival of the winter constellations on an autumn night whets the appetite for the next. First we see Capella and the Pleiades, then the Hyades and Aldebaran, then mighty Orion and his vertical-when-rising Belt. After that we see Procyon, the Little Dog Star. And the impossible-to-top final act is the Big Dog Star, Sirius, the brightest nighttime star of all.

Crystal-clear skies. Weather records prove that over much of North America, nights in September and October average fewer clouds, less haze, and lower humidity than at any other time of year.

Big galaxies and star clusters. The two large spiral galaxies that are nearest in space to ours are Messier 31 in Andromeda and Messier 33 in Triangulum. NGC 253 in Sculptor is another splendid and relatively close spiral.

The big Pleiades and huge Hyades star clusters are in the early-winter constellation Taurus, but they rise high fairly early on autumn evenings. And Perseus, usually considered an autumn constellation, has the giant Alpha Persei Cluster and the Double Cluster. All of these are glorious not only in binoculars and telescopes but also to the naked eye in dark skies. Other big autumn clusters include M34 in Perseus and NGC 752 in Andromeda.

Unlike in other seasons, the brightest autumn constellations come at us from one direction. At other times of year, bright stars rise simultaneously in the northeast, east, and southeast. But the three *concentratedly* bright constellations of autumn — Cassiopeia, Andromeda, and Perseus — ascend as a compact group in the northeast sky.

Variable stars. Autumn evenings offer prototypes of the three most important classes of variables. These stars are Delta (δ) Cephei, which gives Cepheid variables their name, the eclipsing binary Algol in Perseus, and Mira (a long-period variable) in Cetus. Mira should come to the peak of its roughly 332-day-long period this month.

Star lore. Autumn evenings present us with the two largest groups of lore-related constellations. One group comes from the Perseus myth: Perseus, Andromeda, Cassiopeia, Cepheus, and Pegasus. Adjacent to them are the water constellations: Capricornus the Sea-Goat, Aquarius the Water-Bearer, Piscis Austrinus the Southern Fish, and Pisces the Fishes. Cetus the Whale is a member of both groups, and Delphinus the Dolphin and the River Eridanus are outliers.

The contrast of bright and dim. The state of the sky portrayed on the all-sky map on page 44, when Capricornus is highest in the south, can be called the Capricornus Hour. At this time, the bright stars of Lyra, Cygnus, Aquila, and Sagittarius are adornments on the Milky Way band that runs like a sash of honor across the sky. To either side of the sash, dim constellations and empty sky stand in delightful contrast. ♦

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



MOON PHASES

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

PLANET VISIBILITY

	◀ SUNSET	MIDNIGHT	SUNRISE ▶	
Mercury	Visible September 12 through October 5			E
Venus	SW	Visible through October 12		
Mars	SW	Visible through October 20		
Jupiter	E	S	W	
Saturn	Visible starting October 15			E
PLANET VISIBILITY SHOWN FOR LATITUDE 40° NORTH AT MID-MONTH.				

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

IMAGE BY BABAK TAFRESHI / TWAN

NEPAL'S HIGH HIMALAYA shine from the light of the setting Moon around midnight in late November 2009. The Beehive Cluster (M44) is rising over the right-hand shoulder of 22,349-foot Ama Dablam, which is often cited as one of the most beautiful mountains in the world.

October 2010

- 3 **EVENING:** The eclipsing binary star Algol is at its minimum brightness, magnitude 3.4 instead of its usual 2.2, for a couple of hours centered at 10:28 p.m. EDT (7:28 p.m. PDT). See page 59 for Algol's full October schedule.
- 4 **PREDAWN AND DAWN:** Regulus is about 6° lower left of the waning crescent Moon (for North America), as shown on page 48.
- 6–20 **PREDAWN:** The zodiacal light is visible in the eastern sky 120 to 80 minutes before sunrise from Northern Hemisphere locations far from artificial light pollution. Look for a huge, tall pyramid of light slanting to the right through Regulus and the Beehive Cluster.
- 6 **DAWN:** A very thin crescent Moon is visible about 8° above the eastern horizon a half hour before sunrise. Mercury may also be visible extremely low in the sky to the left of the Moon. Bring binoculars.
- 6 **EVENING:** Algol reaches minimum at 7:17 p.m. EDT.
- 7 **NEW MOON** (2:44 p.m. EDT).
- 9 **BRIGHT EVENING TWILIGHT:** Use binoculars starting shortly after sunset to search for Venus, the waxing crescent Moon, and Mars just above the southwestern horizon, as shown on page 48.
- 10, 11 **DUSK:** the Moon is lower right of Antares on the 10th and upper left of Antares on the 11th.
- 14 **FIRST-QUARTER MOON** (5:27 p.m. EDT).
- 19 **EVENING:** Jupiter is about 6° below the Moon.
- 22 **FULL MOON** (9:37 p.m. EDT).
- 23–24 **NIGHT:** Algol reaches minimum at 9:10 p.m. PDT on the 23rd, which is 12:10 a.m. EDT on the morning of the 24th.
- 23 **EVENING AND NIGHT:** The shadows of both Europa and Ganymede fall on Jupiter from 9:40 to 11:04 p.m. EDT (6:40 to 8:04 p.m. PDT). And Algol is at minimum light by the time the double shadow transit ends.
- 25 **EARLY DAWN:** The Pleiades are 1° or 2° upper right of the Moon (for North America), as shown on page 49.
- 26 **EVENING:** Algol reaches minimum at 8:58 p.m. EDT.
- 29 **VENUS** is at inferior conjunction, 6° south of the Sun. Its hair-thin crescent is more than 1' long — a fine spectacle for careful telescopic observers in the Southern Hemisphere. From the Northern Hemisphere, Venus is beneath the Sun and visible only during broad daylight, making it difficult and dangerous to observe.
- 30 **LAST-QUARTER MOON** (8:46 a.m. EDT).
- 30–31 **NIGHT:** The shadows of both Europa and Ganymede fall on Jupiter from 9:16 to 11:59 p.m. PDT on the 30th, which is 12:16 to 2:59 a.m. EDT on the 31st.



Using the Map

WHEN

Late August	Midnight *
Early September	11 p.m.*
Late September	10 p.m.*
Early October	9 p.m.*
Late October	Dusk

*Daylight-saving time

HOW

Go outside within an hour or so of a time listed above. Hold the map out in front of you and turn it around so the yellow label for the direction you're facing (such as west or northeast) is at the bottom, right-side up. The curved edge is the horizon, and the stars above it on the map now match the stars in front of you in the sky. The map's center is the zenith, the point overhead.

Example: Rotate the map a little so that "Facing West" is at the bottom. Three-quarters of the way from there to the map's center is the brilliant star Vega. Go out, face west, and look three-quarters of the way up the sky. There's Vega!

Note: The map is plotted for 40° north latitude (for example, Denver, New York, Madrid). If you're far south of there, stars in the southern part of the sky will be higher and stars in the north lower. Far north of 40° the reverse is true. Jupiter is positioned for mid-October.

You can customize a sky chart for any location, date, and time of night at SkyandTelescope.com/skychart.

Binocular Highlight: Sagitta's Messier

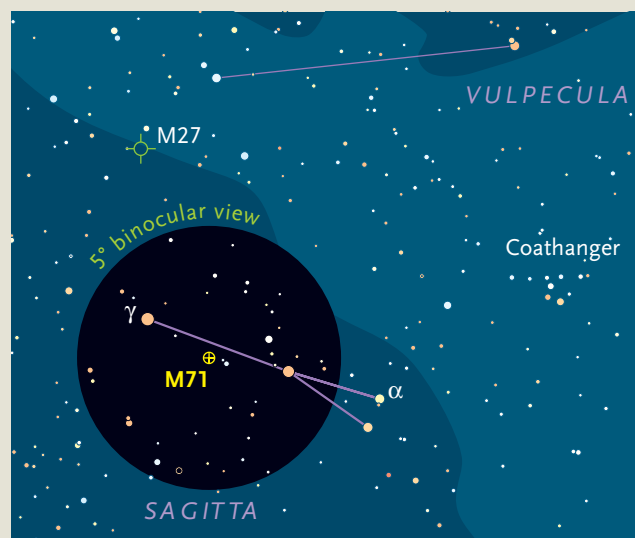
LITTLE SAGITTA THE ARROW is one of my favourite constellations. I like that its compact size makes it a nifty binocular target — all the stick-figure Arrow's main stars are contained in the field of view of my 10×50s. Sagitta is also a good jumping-off place for showpiece planetary nebula M27 and the nifty Coathanger asterism, though both objects actually reside in neighboring Vulpecula. But Sagitta does have one prize of its own: **M71**.

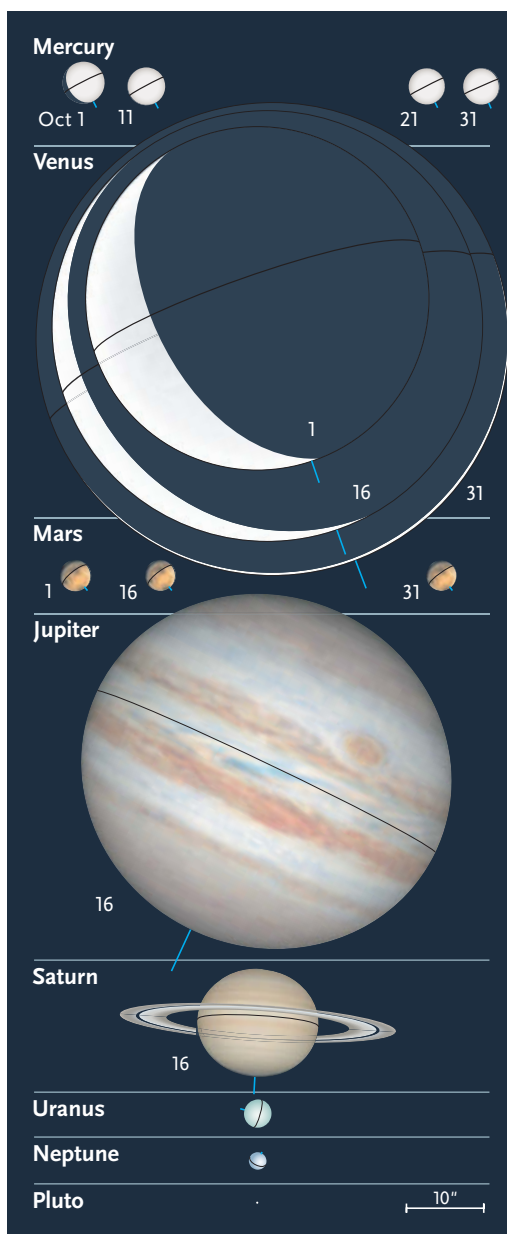
The true nature of M71 was a mystery until recently. Astronomers knew it was either a very rich open cluster, or an unusually loose globular, but were initially unsure which. Today it's confidently classified as a globular cluster, albeit one that's situated only 13,000 light-years distant.

Tucked away just south of the Arrow's shaft, M71's location is easy to pin down. But seeing the cluster itself can take a little effort, especially if your skies are compromised by light pollution. From my reasonably dark backyard, I'm able to find M71 with 10×30 image-stabilized binoculars, though it's easier to snag in 10×50s. The cluster is large enough to be obviously nonstellar and is nearly uniformly bright across its diameter. Indeed, it looks a bit like a fainter version of nearby M27.

My 15×45 image-stabilized binos pull in a 10th-magnitude star sitting just outside M71's northeastern fringe, giving the globular a slightly asymmetrical appearance. However, unsurprisingly, even my 15×70s fail to resolve any cluster members. Just west of M71, though, there's a trio of equally spaced stars whose brightness diminishes from southwest to northeast. The stars are magnitudes 6.2, 7.7, and 8.3, and the juxtaposition with the cluster produces a striking field. ♦

— Gary Seronik



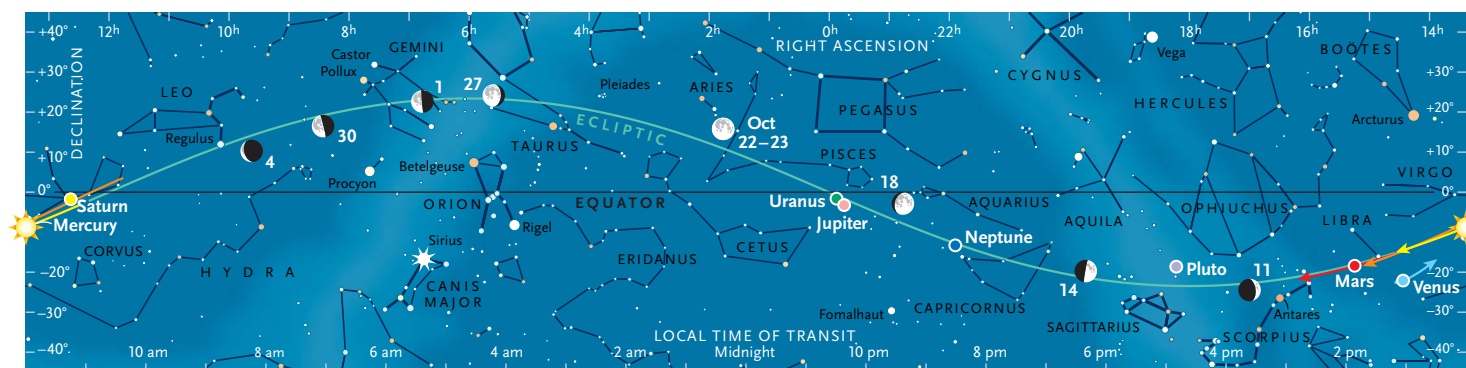


Sun and Planets, October 2010

	October	Right Ascension	Declination	Elongation	Magnitude	Diameter	Illumination	Distance
Sun	1	12 ^h 27.8 ^m	−3° 00′	—	−26.8	31′ 57″	—	1.001
	31	14 ^h 19.8 ^m	−13° 57′	—	−26.8	32′ 13″	—	0.993
Mercury	1	11 ^h 45.4 ^m	+3° 38′	12° Mo	−1.1	5.5″	88%	1.232
	11	12 ^h 50.0 ^m	−3° 47′	5° Mo	−1.4	4.9″	99%	1.376
	21	13 ^h 52.4 ^m	−11° 04′	3° Ev	−1.3	4.7″	100%	1.430
	31	14 ^h 53.7 ^m	−17° 17′	9° Ev	−0.7	4.7″	97%	1.420
Venus	1	14 ^h 30.0 ^m	−21° 43′	35° Ev	−4.8	44.5″	19%	0.375
	11	14 ^h 32.5 ^m	−22° 38′	26° Ev	−4.6	52.1″	10%	0.320
	21	14 ^h 20.5 ^m	−21° 29′	14° Ev	−4.3	58.9″	3%	0.283
	31	13 ^h 59.7 ^m	−18° 10′	6° Mo	—	1′ 01.4″	1%	0.272
Mars	1	14 ^h 32.8 ^m	−15° 17′	33° Ev	+1.5	4.1″	97%	2.257
	16	15 ^h 14.4 ^m	−18° 27′	29° Ev	+1.5	4.1″	97%	2.297
	31	15 ^h 58.3 ^m	−21° 04′	25° Ev	+1.4	4.0″	98%	2.327
Jupiter	1	23 ^h 51.4 ^m	−2° 40′	169° Ev	−2.9	49.7″	100%	3.969
	31	23 ^h 40.1 ^m	−3° 49′	137° Ev	−2.8	47.1″	100%	4.185
Saturn	1	12 ^h 31.3 ^m	−1° 01′	2° Ev	+0.9	15.7″	100%	10.558
	31	12 ^h 44.7 ^m	−2° 25′	26° Mo	+0.9	15.9″	100%	10.448
Uranus	16	23 ^h 52.1 ^m	−1° 42′	155° Ev	+5.7	3.7″	100%	19.183
Neptune	16	21 ^h 53.3 ^m	−13° 21′	124° Ev	+7.9	2.3″	100%	29.454
Pluto	16	18 ^h 12.2 ^m	−18° 41′	71° Ev	+14.1	0.1″	100%	32.232

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

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



The Sun and planets are positioned for mid-October; the colored arrows show the motion of each during the month. The Moon is plotted for evening dates in the Americas when it's waxing (right side illuminated) or full, and for morning dates when it's waning (left side). "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.

Jupiter's Moons

Oct 1

2

EAST

WEST

3

4

5

Europa

6

7

8

9

10

11

Callisto

12

13

14

15

16

17

Ganymede

18

19

20

21

22

23

24

Io

25

26

27

28

29

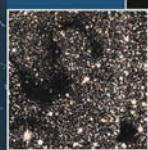
30

31

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.

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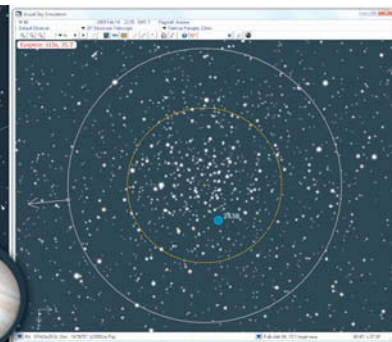


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Jupiter Rides High

The great gas giant is ideally placed for telescopes in October.

VENUS AND MARS slip quietly down into the Sun's afterglow in early October. The only other planet visible in the evening is Jupiter — a grand sight, still nearly at its brightest and biggest, and visible virtually all night long.

At dawn, Mercury is lost from view early in the month. But it's replaced by Saturn, which appears higher every morning.

DUSK AND SOON AFTER

Venus enters its beautiful crescent phase for telescope users every time it nears the end of one of its months-long evening apparitions. But this season it's making

its lowest, poorest possible exit from the evening sky (as seen from mid-northern latitudes).

As October starts, Venus is technically near its maximum possible brightness at magnitude -4.8 , but it appears much dimmer because it's low in bright evening twilight. Venus sets just an hour after the Sun — and even that setting time is deceptive. The planet takes a shallow-angled path down to the horizon at mid-northern latitudes, so it's *very* low each evening. By October 9th, when a thin Moon floats a few degrees upper left of Venus, the planet is barely above the horizon in very bright twilight 20 minutes after sunset, as shown below.

That same evening, **Mars** stands about 6° above the nail-paring-thin Moon. But you may have to wait until more like 45 minutes after sunset to glimpse the $+1.5$ -magnitude world. (Binoculars will help greatly.) Later in the month, Mars disappears in the sunset glow. Mars is racing eastward relative to

the stellar background, so it doesn't reach conjunction with the Sun until February 4, 2011. It won't be a naked-eye object again until late next spring.

In contrast, Venus has rounded the near side of its orbit relative to Earth, so it's rushing fast toward inferior conjunction with the Sun on October 29th. It disappears from naked-eye view in mid-October, then shoots up gloriously into the dawn sky in early November (for mid-northern latitudes).

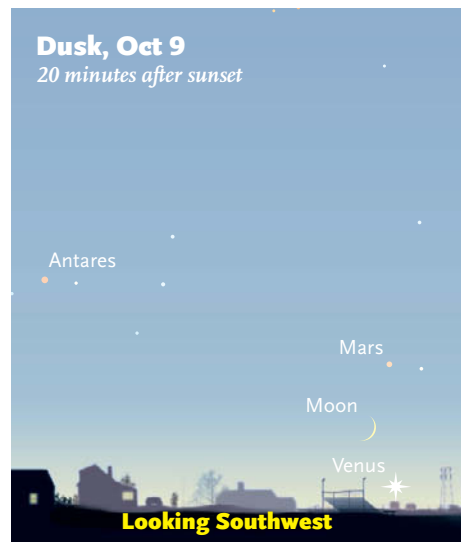
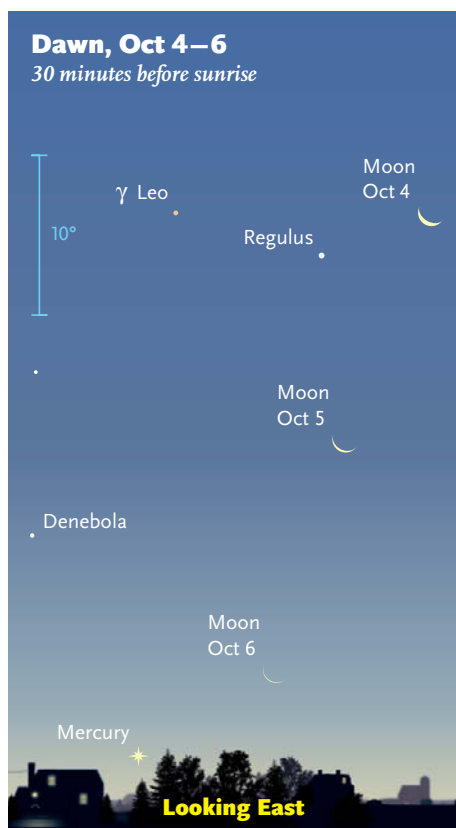
Neptune, at the Capricornus-Aquarius border, is fairly high in the south shortly after dark. Use the charts on page 56 of last month's issue, or at SkyandTelescope.com/UranusNeptune, to locate the two outermost giant planets.

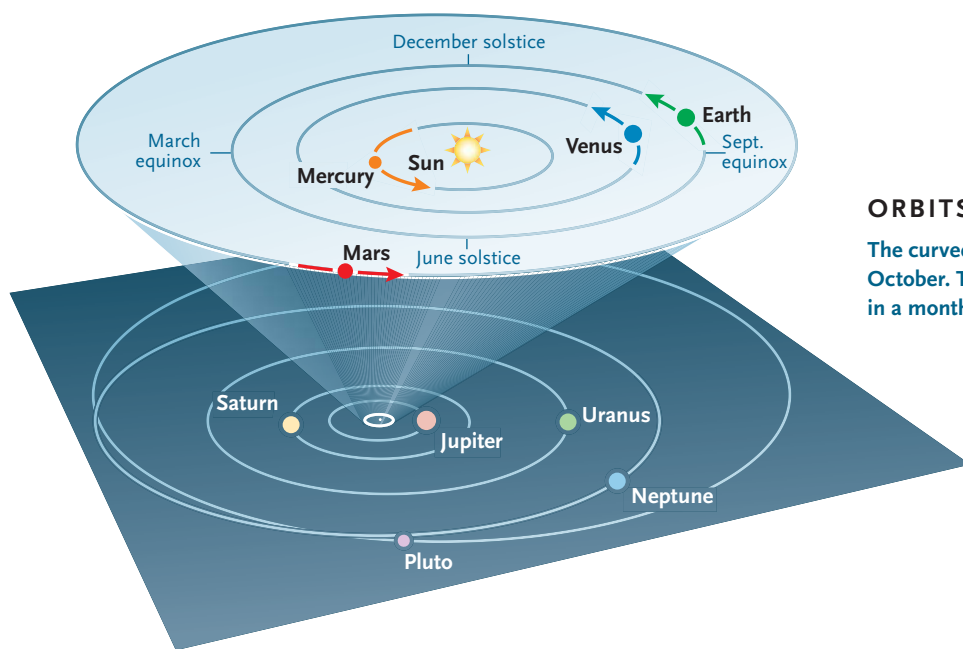
Pluto, in Sagittarius, is about to disappear into the glow of sunset. But you can still seek it just after the sky becomes dark during the first week of October using the charts at SkyandTelescope.com/Pluto.

DUSK TO ALMOST DAWN

Jupiter shines low in the east in evening twilight, climbing higher each week. After dark the king of planets dominates the sky almost all night long, blazing at magnitude -2.9 . Jupiter retrogrades (moves westward relative to the starry background) in October, crossing from Pisces into Aquarius.

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





ORBITS OF THE PLANETS

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

Jupiter transits the meridian (reaching its highest due south) in late evening, so that's the best time for telescopic observations of the rich feast of features in its clouds. Jupiter's disk shrinks slightly during October, from 50" to 47", but that's still bigger than the planet *ever* appears during many years. Jupiter sets during morning twilight in early October and around 4 a.m. daylight-saving time at month's end.

Uranus was at opposition on the same day as Jupiter back on September 21st, and the two were considerably less than 1° apart then. Like Jupiter, Uranus spends October retrograding, but much more slowly. Jupiter pulls to 2° from Uranus by October 9th and 3° by the 25th.

DAWN

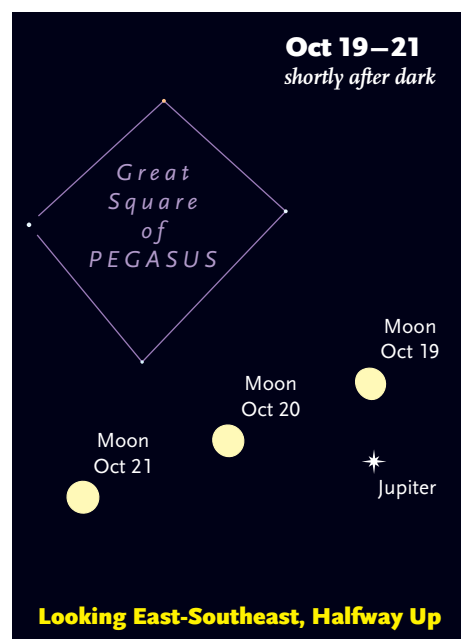
Mercury had a fine morning apparition in mid- to late September, and it still rises an hour before the Sun as October begins. But this smallest and fastest of planets appears lower in the dawn each day, and it's lost from view after the first week of October. Mercury reaches superior conjunction with the Sun on October 17th. It will have a low apparition in the evening sky in late November and early December.

Saturn makes opposite progress — into the dawn sky and higher each morning after its conjunction with the

Sun on October 1st. Saturn passes only ½° north of brighter Mercury on the American morning of October 8th, but the pair is very low in bright dawn then; you'll need a very clear eastern horizon and optical aid to see the planets.

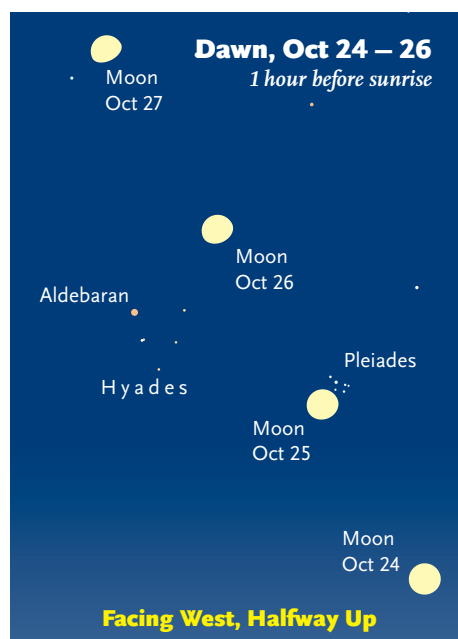
After that, Saturn rapidly climbs higher in the dawn each week. It's within 1° of fainter Gamma Virginis (Porrima) from October 15th to 28th.

Though Saturn is now on the far side of Earth's orbit from us, and its globe appears a bit small (less than 16" wide), its rings are now opening up beautifully.



MOON PASSAGES

The **Moon** is a waning crescent to the upper right of Regulus at dawn on October 4th. A very thin waxing lunar crescent is upper left of Venus on October 9th, but the two set while the sky is still quite bright. Use binoculars to look for them barely above the southwestern horizon about 20 minutes after sunset, as shown on the facing page. On October 19th the waxing gibbous Moon shines above Jupiter in the east at nightfall. The waning gibbous Moon is very near the Pleiades before dawn on October 25th; use binoculars or a telescope to pick up the brightest stars of this cluster. ♦



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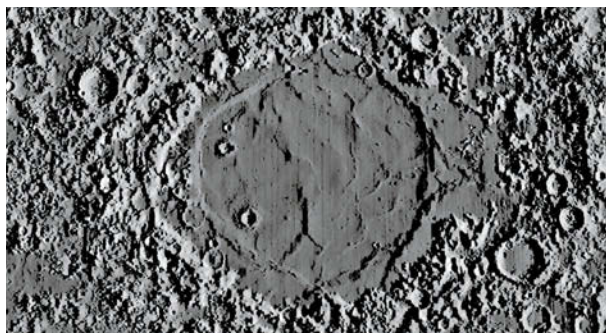


Unmasking Mare Ridges

Digital terrain maps shed new light on these enigmatic features.

MARE RIDGES ARE narrow elongated swells seen within all lunar maria. Because ridges have gentle slopes and are typically only a few hundred meters high, they can only be seen when illuminated from a shallow angle. While that's fine for observing certain ridges, such as the Serpentine Ridge along the eastern shore of **Mare Serenitatis**, ridges farther west aren't visible at the same time. Simple geometry deprives us of seeing these far-reaching features in their entirety, and it hinders our ability to understand them.

Fortunately, technology now makes it possible to appreciate a mare's entire system of ridges in one image. New Zealand amateur Maurice Collins has constructed accurate images of the lunar surface using the computer program *Lunar Terminator Visualization Tool* (<http://ltvt.wikispaces.com/LTVT>) combined with the new Digital Elevation Model from NASA's Lunar Reconnaissance Orbiter. Maurice's image shown below depicts all of Mare Serenitatis with a constant Sun angle of $\frac{1}{2}^\circ$, revealing the ridge patterns across the entire mare. Like other circular maria, Mare Serenitatis occurs within an impact basin whose most prominent rim is the contact between the



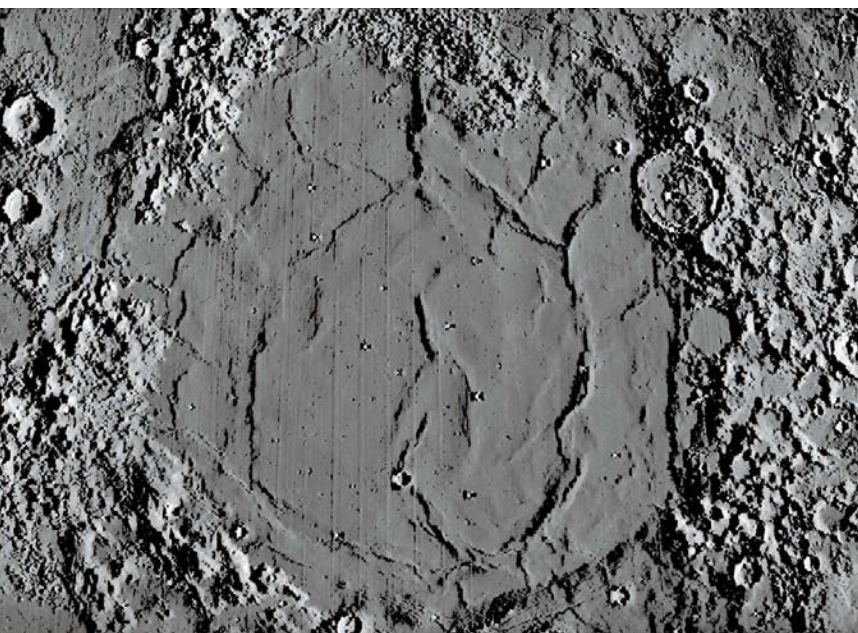
MAURICE COLLINS (2)

A nearly circular fault within Mare Crisium is revealed when visualizing the Moon with a constant solar illumination of $\frac{1}{2}^\circ$.

mare and surrounding rugged terrain. Inside that 670-kilometer-wide (416-mile) rim is another rim, about 400 km in diameter, consisting entirely of a roughly circular pattern of mare ridges. Maurice's image reveals that ridge ring, and also other less-continuous ridges that are both concentric and radial, as well as a ridge system that cuts across the middle of the mare floor. It's fair to say that this view reveals complexities of the ridge system that exceed our current ability to fully understand.

Another circular mare with a somewhat simpler ridge pattern is **Mare Crisium**. Here a nearly continuous ridge defines an inner ring roughly 360 km in diameter. The shadows from the east side ridge, and the brightness of the ridge on the west, indicate that the mare within the ring is lower than the surroundings. Altimeter measurements obtained from Apollo 15 indicate the mare drops about 200 meters on the inner side of the ridge ring, so it must be a fault. Much like Serenitatis, other short ridges within Crisium don't follow any discernible pattern; scientists don't yet know how to interpret them.

Mare Tranquillitatis is another roughly circular mare that's generally thought to fill an impact basin so



Until recently, mare ridges were very difficult features to observe and interpret in their entirety. The newly released Digital Elevation Model recorded by NASA's Lunar Reconnaissance Orbiter allows us to see the entire Moon under a constant angle of illumination. This topographical map of Mare Serenitatis reveals the entire network of concentric and radial mare ridges, offering new insights into the origins of these shallow features.

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Highlighted feature	Size (miles)	Description
A Mare Crisium	375 × 345 miles	Flooded basin
B Mare Serenitatis	416 miles	Flooded basin
C Mare Tranquillitatis	542 miles	Flooded basin

Phases	
Last quarter	October 1, 3:52 UT
New Moon	October 7, 18:44 UT
First quarter	October 14, 21:27 UT
Full Moon	October 23, 1:37 UT
Last quarter	October 30, 12:46 UT

Distances	
Perigee	October 6, 13h UT 223,354 miles diam. 33' 35"
Apogee	October 18, 18h UT 251,921 miles diam. 29' 21"

Librations	
Röntgen (crater)	October 3
Jansky (crater)	October 14
Malapert (crater)	October 20
Rook Mountains	October 27

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

ancient that very little of its rim survives today. However, examining the pattern of mare ridges on another of Maurice's simulations provides surprisingly little support for the ancient basin hypothesis. There's no single circular ring of mare ridges, but a massive rise cuts diagonally across the mare, with well-known islands of older lavas cropping out along the ridge.

Because Tranquillitatis is nearly twice

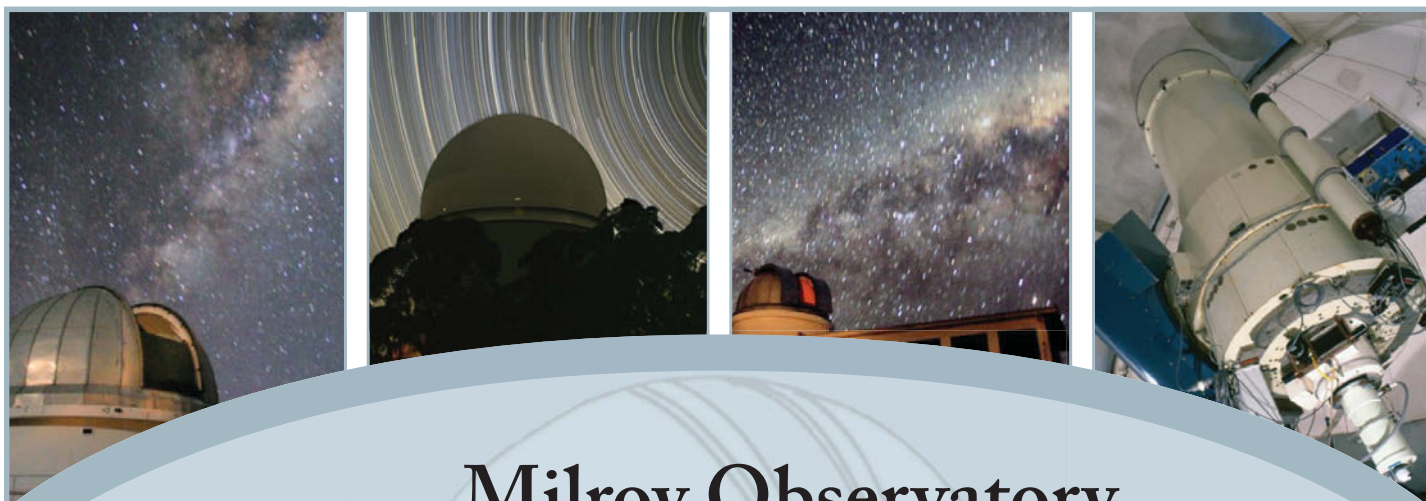
as wide in the east-west direction as in the north-south, it's unlikely to be a single circular basin. Unlike other mare-filled basins, topographical data shows that Tranquillitatis is not a significant depression, although its western half is deeper than its eastern side. The abundance of mare lavas at Tranquillitatis demonstrates that there must have been crust-cutting fractures that allowed magma to rise up from the lunar mantle. Whether or not Mare Tranquillitatis is underlain by an impact basin — or maybe two — is uncertain. The ridges don't provide any compelling clues.

Examining these synthetic lunar images demonstrates that the elusive mare ridges we observe telescopically are much more complex than our current understanding. Some circular mare ridges definitely mark inner rings of basins, but many others refuse to relinquish the secrets of their origins. ♦



Viewing Mare Tranquillitatis with a constant solar illumination of ½° provides little evidence for its presumed impact origin.

Visit contributing editor Charles Wood's website lpod.wikispaces.com for a daily lunar fix.



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▼ **PREMIUM RITCHEY** Deep Sky Instruments recently unveiled its new RC-14C (\$15,495), a 14¼-inch Ritchey-Chrétien reflector. This f/7 astrograph features Pyrex optics hand-figured by renowned telescope maker Paul Jones and is encased in a carbon-fiber tube to virtually eliminate focus drift throughout the night. Together with its integrated field-flattener, the RC-14C produces a 2-inch (52mm) image circle, which covers today's large-format cameras. Its computer-controlled electronic secondary focuser is fully ASCOM compliant and additionally includes manual controls. The telescope comes with tube rings and integrated Losmandy D-style dovetail plates.

Deep Sky Instruments

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

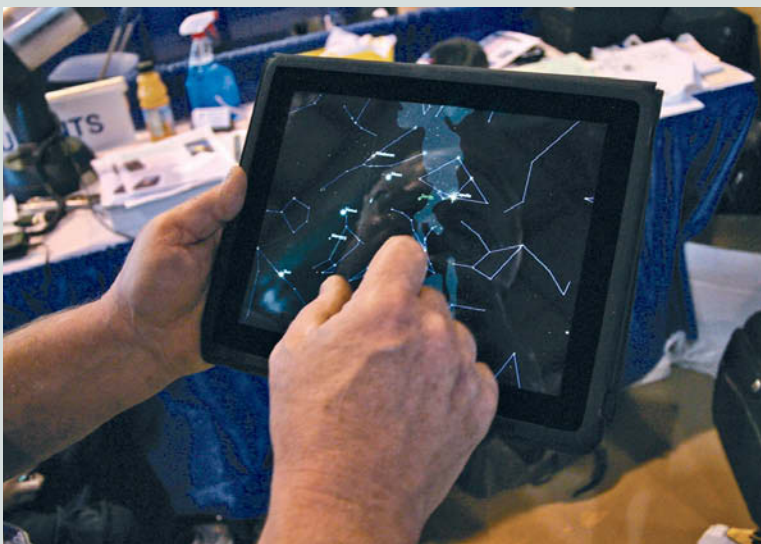
▼ **SOLARMAX UPDATE** Meade is upgrading its Coronado series of hydrogen-alpha (H- α) solar telescopes. The SolarMax II 60 (2.3-inch aperture) and SolarMax II 90 (3.5-inch) dedicated H- α telescopes (\$1,299 and \$3,599, respectively) feature a 0.7-angstrom passband internal Etalon filters with patented RichView tuners, allowing you to zero in on the most interesting details visible on the Sun, including prominences, filaments, and complex active regions. Both scopes can be fitted with an optional external Etalon filter, narrowing the bandpass to below 0.5 angstrom, increasing image contrast and detail. Each SolarMax II 60 comes with a clamshell tube ring, Sol Ranger Sun finder, and a Cemax 1¼-inch eyepiece. The SolarMax II 90 also includes two additional Cemax eyepieces.

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▲ **IPAD PLANETARIUM** Carina Mobile (formerly Carina Software) updates its popular *SkyVoyager* planetarium app version 1.6.2 (\$14.99) to support the Apple iPad, as well as to add new features. In addition to all the previous features such as its 300,000-star database, the complete Messier, NGC, and IC catalogs, and "real view" compass features, *SkyVoyager* now utilizes the full resolution of the large iPad screen. Users can activate the improved night-vision mode to preserve their dark adaptation while operating a telescope. An optional expansion pack (\$4.99) adds 2½ million stars down to 12th magnitude from the Tycho-2 catalog, as well as more than 300 images of popular deep-sky objects to enhance the look of the app. *SkyVoyager* also supports WiFi telescope control with the additional purchase of a WiFi-to-serial adapter. See Carina Mobile's website for a complete list of features.



Encounters with Comet Hartley 2

A binocular comet crosses the sky in October, then a spacecraft meets it in November.

NO SOONER DID we lose sight of the little comet of the June dawn, C/2009 R1 (McNaught), than another visitor was positioning itself for easier viewing in October. Periodic Comet 103P/Hartley 2 will be high in the evening sky when at its best, glowing at perhaps 5th magnitude. It should be dimly visible to the unaided eye from very dark locations, and visible in binoculars or a telescope from most other places in the Northern Hemisphere.

Hartley 2's expected brightness results from how closely it will pass Earth: by just 0.12 astronomical unit (11 million miles; 18 million km) on October 20th. This will be its closest approach since its 1986 discovery and one of the closest approaches by any comet in the last few centuries.

A New Orbit

How could a naked-eye short-period comet go undiscovered until just 24 years ago?

The story began when Malcolm Hartley detected a tiny, 17th- or 18th-magnitude

smudge on a photographic plate taken March 16, 1986, during a sky survey by the 1.2-meter U.K. Schmidt Telescope at Siding Spring, Australia. More position measurements revealed it to be a short-period comet orbiting the Sun about every 6 years. It was the second periodic comet discovered solely by Hartley.

Running Hartley 2's path backward revealed that it fell into its current orbit only recently. Calculations by astronomers including Kazuo Kinoshita in Japan showed that three close encounters with Jupiter (0.33 a.u. in 1982, 0.09 a.u. in 1971, and 0.23 a.u. in 1947) had shifted the comet's orbit closer to the Sun. Prior to those encounters Hartley 2 never came closer than 2 a.u. from the Sun, leaving it beyond visual detection.

Hartley 2's next return came in 1991, when it brightened in September to 8th magnitude. It did so again at its following return in December 1997. The 2004 apparition was a poor one, with the comet

remaining relatively far from Earth.

Now it's arriving front and center for its best showing yet.

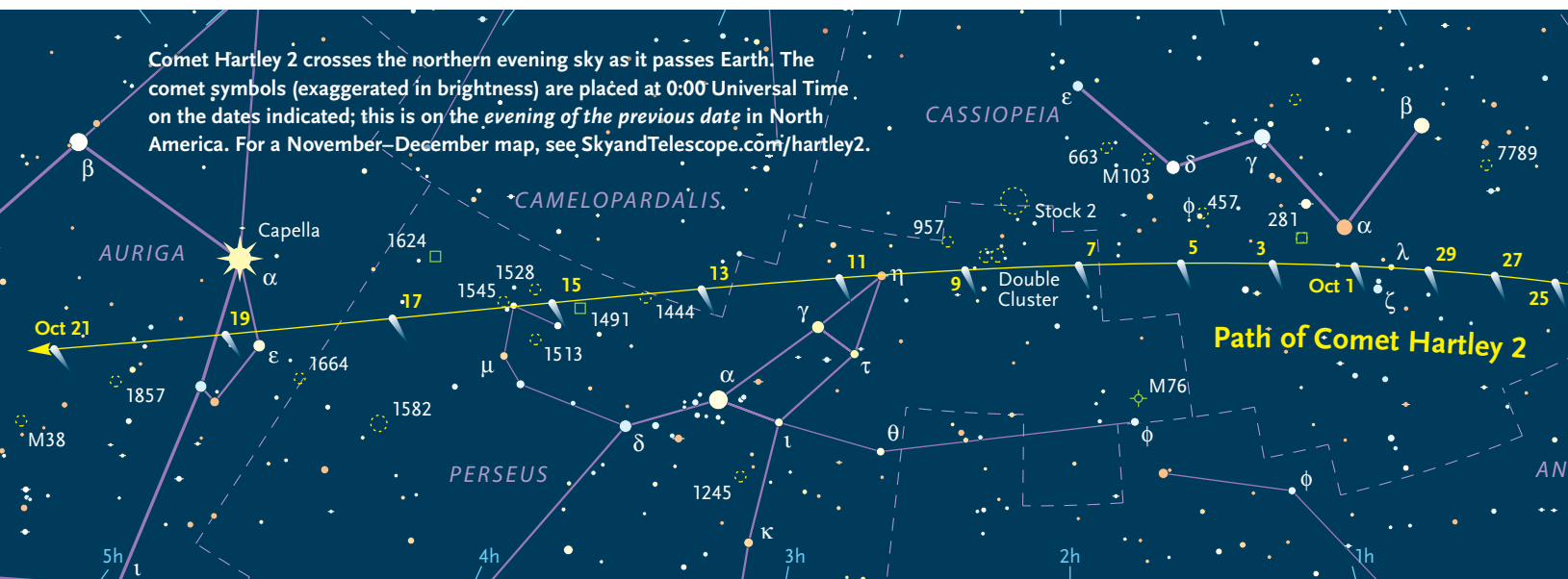
Comet Timetable

When this issue begins reaching subscribers in late August, Hartley 2 should be 10th magnitude and moving northeast through Pegasus, already positioned high for mid-northern observers after nightfall.

By September 1st, Hartley 2 moves north into Lacerta, where it spends a few days at about 9th magnitude before crossing into northern Andromeda. On the night of September 8–9, at new Moon, the comet is less than 1° from 3.6-magnitude Omicron (o) Andromedae. By now it should be 8th or 9th magnitude.

The waxing Moon will brighten the evening sky from about September 15th to 26th. On the 22nd, Hartley 2 should be 7th or 8th magnitude and within a few degrees of Lambda (λ) Andromedae.

October 1st finds the comet passing



1.5° south of Alpha (α) Cassiopeiae, high in the northeast during now-moonless evenings. It will be perhaps 6th magnitude and should remain at least this bright for the next nine weeks. But it's important to note that, with the comet now just 0.18 a.u. from Earth and closing, its light is no longer concentrated into a small dot but is more spread out. So even if you can sight a 6th-magnitude star with your unaided eyes, Hartley 2 will be tougher.

On the American night of October 7th, when the comet should be 5th or 6th magnitude, it will be creeping less than 1° south of the Double Cluster in Perseus. The clusters are magnitudes 4.3 and 4.4. This will make for a wonderful wide-field sight and a great astrophoto opportunity — particularly since it's again new Moon!

Perigee, Perihelion, and Departure

Hartley 2's closest approach to Earth comes on October 20th, at a distance of 0.121 a.u. That's only 0.02 a.u. farther than the great comet Hyakutake came 14 years ago in 1996. (Of course Hyakutake was intrinsically many times larger and brighter; they'll look totally different.) On October 20th, Hartley 2 will be passing just south of Capella and will perhaps be at its peak predicted brightness of magnitude 5. But the Moon will be bright waxing gibbous, and then full on the 22nd.

By the end of October, the comet is



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Cenkner, August A. Jr., B.A., B.S., M.S., Ph.D.

Hubble Space Telescope Identifies Dark Energy,

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waiting until later in the night to climb high into good view. Perihelion comes on the 28th, when Hartley 2 is 1.06 a.u. from the Sun and — still around 5th magnitude — in Gemini. But that morning, the nearly last-quarter Moon is just a few degrees away from it.

Moonless viewing times return around November 1st. But now, with the comet moving away from both the Sun and Earth, it fades by about a magnitude every two weeks. In November it's a midnight-or-later object heading south across Gemini, Monoceros, and into Puppis. It ends

November in Puppis at 7th magnitude east of Sirius. By the end of December it fades to 10th magnitude, closer to Sirius. It won't return again until 2017.

Australian S&T editor **Greg Bryant** fondly recalls his first sighting of Hartley 2 in 1991.

Comet Flyby November 4th!

Amateur astronomers aren't the only people looking forward to an encounter with Comet Hartley 2. NASA has redirected its Deep Impact spacecraft (above), which spectacularly imaged the nucleus of Comet 9P/Tempel 1 in July 2005, to fly past Hartley 2 on November 4th. The probe will take pictures and other data from as close as 600 miles (1,000 km).

Deep Impact's post-2005 mission has been named EPOXI, a contraction of "Extrasolar Planet Observation and Characterization" and "Deep Impact Extended Investigation." No projectile will be launched toward the comet nucleus this time; the probe used up its one shot on Tempel 1.

Originally, Deep Impact's second target was supposed to be Comet 85P/Boethin. But once the mission was under way, Boethin vanished; it apparently broke up completely. Hartley 2 was the backup plan.

Hartley 2's nucleus is thought to be small, probably just 1 km wide; compare that to the four previously imaged comet nuclei shown in News Notes. But astronomers think that Hartley 2 may spew gas and dust from 100% of its surface, not just isolated vents, around its times of perihelion. Because Hartley 2 is smaller but more active than Tempel 1, scientists are keen to explore the similarities and differences between these two short-period comets.

As the date approaches, check SkyandTelescope.com/hartley2 for updates — and for how you may be able to watch the encounter live.



NASA / JPL-CALTECH

Phenomena of Jupiter's Moons, October 2010

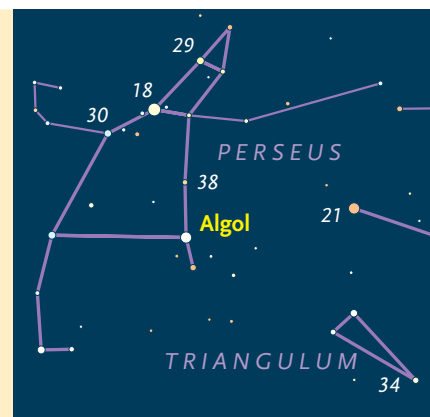
Oct. 1	1:46 II.Ec.R 2:08 I.Oc.D 4:37 I.Ec.R 23:18 I.Tr.I 23:34 I.Sh.I	3:17 I.Tr.E 3:45 I.Sh.E 14:10 III.Tr.I 16:01 III.Sh.I 17:04 III.Tr.E 19:02 III.Sh.E	20:03 III.Sh.I 20:25 III.Tr.E 21:49 II.Tr.I 23:03 III.Sh.E 23:05 II.Sh.I	2:49 II.Tr.E 3:04 III.Sh.E 4:23 II.Sh.E 4:50 I.Ec.R 23:01 I.Tr.I 23:50 I.Sh.I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

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**). **Also on Jupiter:** For the Great Red Spot's transit times, see SkyandTelescope.com/redspot.

Minima of Algol

Sept.	UT	Sept.	UT	Oct.	UT	Oct.	UT
2	13:33	16	21:36	1	5:39	15	13:43
5	10:21	19	18:24	4	2:28	18	10:32
8	7:10	22	15:13	6	23:17	21	7:21
11	3:58	25	12:02	9	20:06	24	4:10
14	0:47	28	8:51	12	16:54	27	0:58

These geocentric predictions are from the heliocentric elements $\text{Min.} = \text{JD } 2452253.559 + 2.867362E$, where E is any integer. Derived by Gerry Samolyk (AAVSO), they reflect a slight lengthening in the star's period that seems to have occurred in early 2000. On the chart at right, the magnitudes of useful comparison stars are given to the nearest tenth with the decimal point omitted.



Asteroid Occultations

Would-be observers of asteroid occultations — the brief vanishing of a star when a minor planet passes in front of it — have long lists of predictions to choose from nowadays, complete with path maps, finder charts, and full information. Cruise the list for October 2010 at www.asteroidoccultation.com/2010_10_sm.htm. There, two events involving relatively bright stars stand out for North America:

On the **morning of October 14th**, an 8.8-magnitude star in Gemini will be occulted by the small asteroid 1212 Franquette for up to 5 seconds along a narrow path crossing the U.S. from southern California to South Carolina.

On the **evening of October 16th** (the 17th in Universal Time), an 8.0-magnitude star in Pisces will be occulted by the small asteroid 1273 Helma for up to 3.7 seconds along a narrow path running from Labrador through Michigan, Oklahoma, and west Texas.

The two asteroids are only about 50 and 20 miles in diameter, respectively, so their shadow paths are correspondingly narrow. That means you'll have to do some driving and/or be lucky! But even near-miss observations showing that no occultation occurred at your site are valuable and should be reported. For more information on this fascinating subcategory of amateur astronomy, see www.asteroidoccultation.com/asteroid_help.htm. ♦

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Asteroid Maven

An award-winning amateur astronomer experiences the joy of discovery by helping to reveal some of the asteroid belt's best-kept secrets.

ROBERT STEPHENS

It's 6 a.m. and the roof of my observatory is rolling shut, ending another night of automated observations. With the smell of fresh-brewed coffee in the air, my computer starts spinning through the precious images waiting on the hard drive, mining them for data. With anticipation and a few mouse clicks, the night's results are displayed and a bit of the universe is revealed.



ASTEROID AFICIONADO
Author Bob Stephens poses with his 14-inch Celestron C14 telescope at the Goat Mountain Astronomical Research Station (GMARS) in southern California. GMARS enjoys much darker skies than Stephens's home observatory near Los Angeles.

ALL PHOTOGRAPHS BY THE AUTHOR
UNLESS OTHERWISE STATED

The joy of discovery, what Thomas Huxley called the *Divine Dipsomania*, is the rush that accompanies learning something no one else has known. For decades it's been mainly the domain of professional astronomers, but now amateur astronomers are using off-the-shelf equipment and mainstream software to contribute to data collection and original research.

Working with equipment that cost about as much as a used car, I began doing research on asteroids about 10 years ago, eventually contributing to studies by professional astronomers as well as publishing my own papers. It's *Divine Dipsomania*, and it's something that other amateurs can enjoy while taking their astronomical quest in new directions, developing friends and colleagues along the way.

Like many longtime amateur astronomers, I've moved through a series of interests over the years. In the 1970s I started building telescopes because the instruments I wanted were not within reach of a poor college student. Soon I was doing astrophotography, first with off-the-shelf film, and then graduating to cold cameras packed with dry ice. Eventually I hyper-sensitized film with a mixture of



An artist portrays a binary asteroid of the type studied by author Bob Stephens.



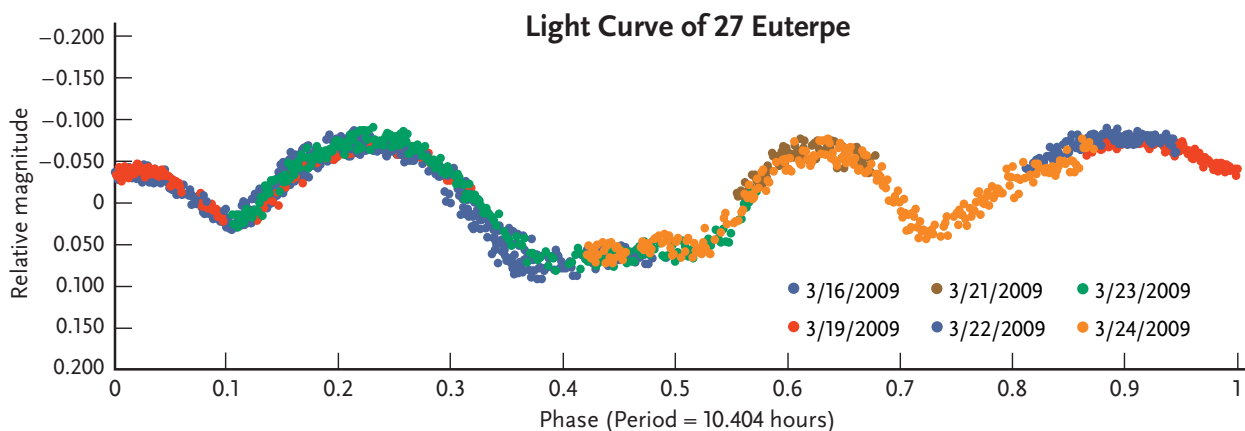
HOME OBSERVATORY Stephens's most productive observatory is built right into his house in Rancho Cucamonga, California. His Siberian huskies Boris and Natasha stand guard over a small attached building on the rear of the house, which has a roll-off roof and a 12-inch Meade RCX 400 telescope.

It was the introduction of CCD cameras that eventually rekindled my interest in contributing to astronomical science. An article about amateurs discovering asteroids piqued my interest, and that led me to a pro-am conference on asteroids at Lowell Observatory in 1999. Professional astronomer Alan Harris spoke about some of the big sky surveys that were coming on line that would likely make most of the future asteroid discoveries. But he also suggested that amateurs could do important work by measuring the brightness of asteroids. Brian Warner was one of the amateur speakers, and he talked about a software package he developed called *MPO Canopus* for doing asteroid photometry. It's not surprising that Harris and Warner soon became friends and collaborators.

hydrogen and nitrogen gases. But after years of experimenting, I felt like I was hitting the wall on astrophotography.

During my early years as an amateur I observed variable stars for the American Association of Variable Star Observers (AAVSO). Founded in 1911, the AAVSO is still going strong. My contributions, however, waned when my day-to-day life became focused on starting a business.

With a new interest in doing asteroid photometry, I attended a meeting of the Western Wing of the I.A.P.P.P., a group founded in 1980 to promote pro-am collaboration on photoelectric photometry. The group has since become the Society for Astronomical Sciences (SAS), which holds a symposium each May in Big Bear, California. In addition to variable stars, SAS members have eclectic



ASTEROID LIGHT CURVE

The irregular light curve of 27 Euterpe (pronounced you-TUR-pay) befuddled astronomers for years. Stephens was the first person to determine its rotational period: 10.404 hours. The light curve's odd shape is probably due to the asteroid having an irregular shape, with concavities that cast deep shadows at high Sun phase angles.

interests, such as studying exoplanet transits, gamma-ray bursts, meteors, and asteroids.

I have built and currently operate three observatories. Not surprisingly, the most productive one is the one 40 feet from my kitchen. Somehow the city inspector got the idea this was a sunroom, failing to notice that the roof wasn't attached to the walls. My "sunroom" holds a 12-inch Meade RCX 400 telescope, which operates more than 100 nights a year chasing asteroids. My home observatory highlights the fact that more important than arcminute pointing accuracy, perfect tracking, and 6th-magnitude skies is a scope that's permanently mounted in an observatory. It eliminates the hassle of setting up equipment, especially when there's a hint of bad weather on the way.

My other observatories each house 14-inch Schmidt-Cassegrain telescopes (from Celestron and Meade) and are located at the Riverside Astronomical Society's Goat Mountain Astronomical Research Station. This 10-acre property is currently home to 12 observatories as well as 17 observing pads, a 22-inch public telescope, two houses, and a garage. Dark-sky operations and public star parties occur there several weekends each month.

Asteroid Projects

I started doing asteroid photometry of whatever objects were conveniently placed in the sky and bright enough for my equipment. By plotting the changing brightness of an asteroid over time, one can create a light curve and determine the asteroid's rotational period. Suggested asteroids to observe are published quarterly in the *Minor Planet Bulletin*. Ten years ago there were only about 800 asteroids

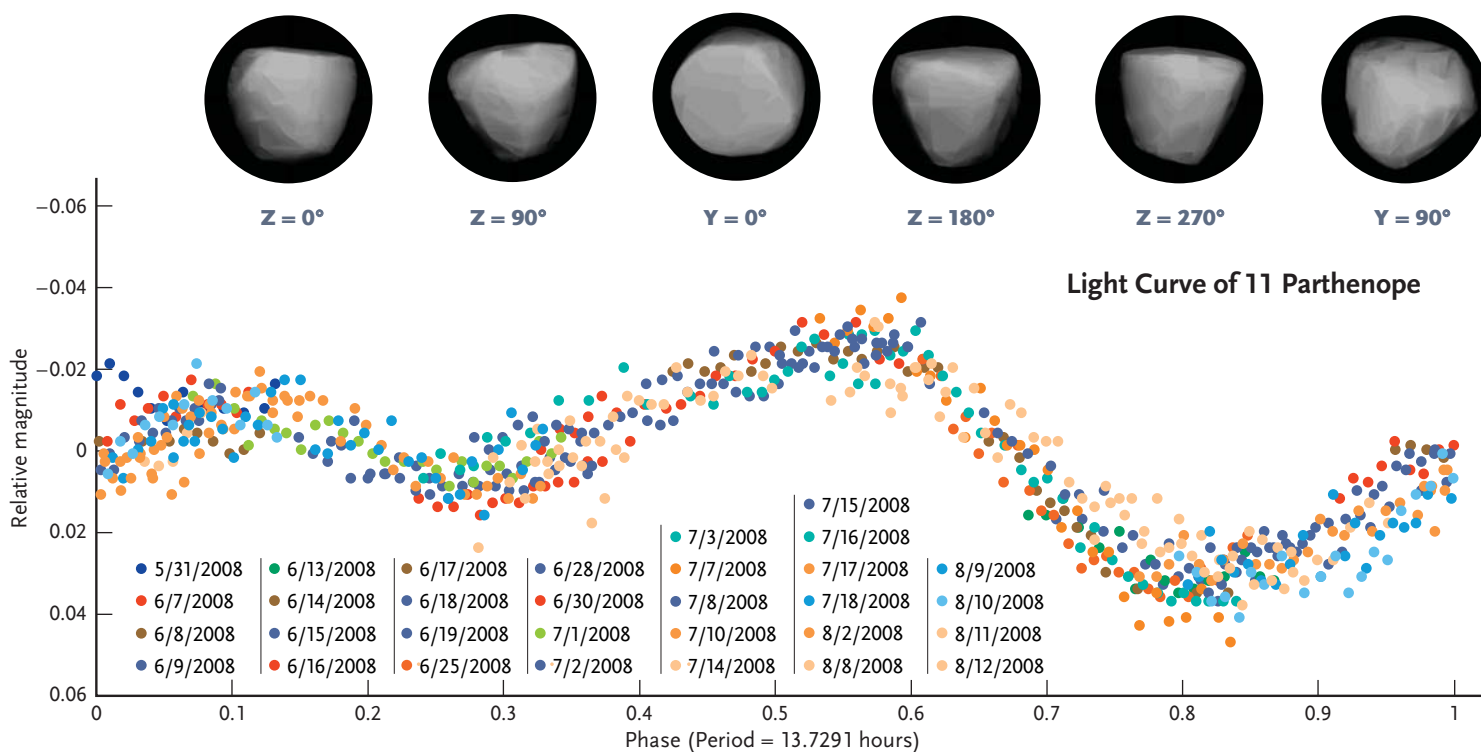
with known rotational periods. Now there are about 3,600 — most of which have been determined by amateurs.

My first attempt to create an asteroid light curve was an abysmal failure. Unknowingly, I had selected a difficult target and had acquired some poor images. Over time and through persistence, I improved my skills and started publishing results in the *Minor Planet Bulletin*. Seeing my name in a peer-reviewed scientific journal was a rush and it motivated me to take on the next project.

One of my early projects was the main-belt asteroid 27 Euterpe, which was one of the earliest-known asteroids not having a reliably determined rotational period. Harris told me it was known among professionals as "You Turkey" because its light curve defied explanation. By making extensive brightness measurements, over time I was able to extract an oddly shaped light curve with a rotational period of 10.404 hours.

There are many software packages that can do photometric measurements, but by far the most popular one for asteroid photometry is *MPO Canopus*. Nearly 90% of the light curves published in the *Minor Planet Bulletin* are generated with this software. The program makes

MYSTERY SOLVED *Bottom:* By making long-term photometry measurements, Bob Stephens and Brian Warner confirmed a previous measurement of the rotation period of asteroid 11 Parthenope: 13.7291 hours. Professionals had a difficult time with this 150-kilometer main-belt asteroid because its brightness varies by no more than 0.12 magnitude, probably due to a relatively symmetrical shape. *Below:* Warner produced this shape model from the light curve using an algorithm in the software *MPO LCInvert*.



the analysis of an asteroid's brightness fairly straightforward, automatically "tracking" the object as it moves in successive images and determining the brightness based on as many as five reference stars in the field.

With enough brightness measurements I can create a light curve, which I usually plot to show a complete rotational period. These "phased" light curves usually have two maxima and two minima, since a typical asteroid is shaped like a potato, reflecting more light from its wide sides than when viewed end on. *MPO Canopus* contains a light-curve analysis module incorporating a Fourier-analysis algorithm developed by Harris in the 1980s. While the module can show which periods are more likely, it still takes human interpretation to make judgment calls on the final outcome.

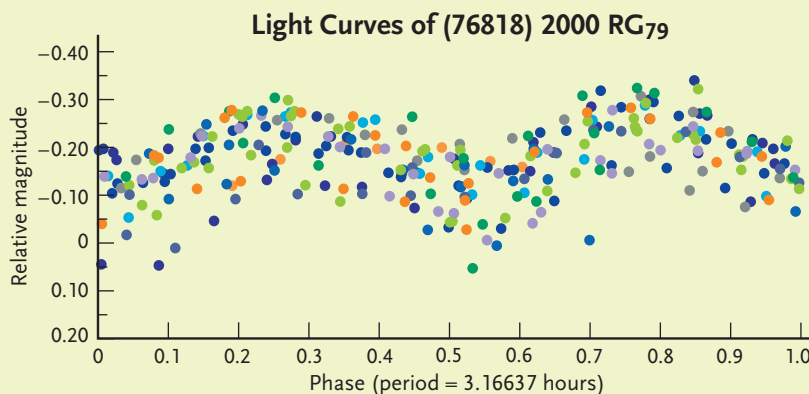
A Revolution

Surveying asteroid rotational periods has led to many important discoveries. It's not an overstatement to say that during the past decade, studying asteroid light curves has sparked a revolution in our thinking about the evolution of these small bodies. Astronomers used to think that collisions dominated asteroid evolution, but now they feel that solar radiation is the most important factor. Contributing to this realization was the discovery of the so-called "spin barrier." Asteroid light curves combined with radar and spacecraft observations have shown that most asteroids are "rubble piles" — bodies held together mostly by the mutual gravitation of many small parts. If such an asteroid rotates faster than about 2 hours, it will simply fly apart. A few asteroids are known to rotate much faster and are therefore objects held together by cohesion and forces beyond mutual gravitation.

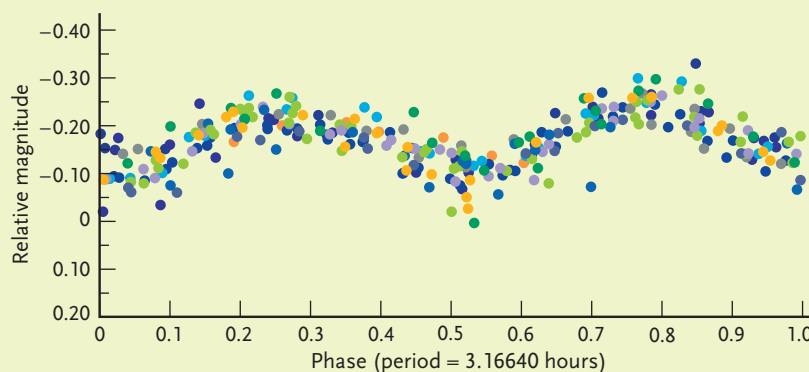
Professional astronomers recently discovered the YORP effect (standing for Yarkovsky, O'Keefe, Radzievskii, and Paddack). Solar heat radiating off the irregular surface on the "afternoon side" of small asteroids provides a tiny rotational push that causes the asteroid to spin up or spin down depending on its asymmetry. Light curves from backyard observatories are helping astronomers measure the YORP effect by checking the observed times of minimum light relative to the predicted times.

About four years ago, Czech astronomer Petr Pravec gave a presentation at the SAS Symposium on the search for binary asteroids. It inspired me to become involved with a small group of observers who have now discovered dozens of binary asteroids by observing small changes in light curves caused by eclipses and occultations between the primary body and its satellite. More small binary asteroids have been discovered with light-curve observations than by any other method, including Hubble Space Telescope observations, adaptive optics, or Earth-based radar.

BINARY ASTEROID Photometric observations by Warner and Stephens revealed the orbital period of the binary asteroid (76818) 2000 RG₇₉. The original light curve looks like a mess, with some hints of periodicity.

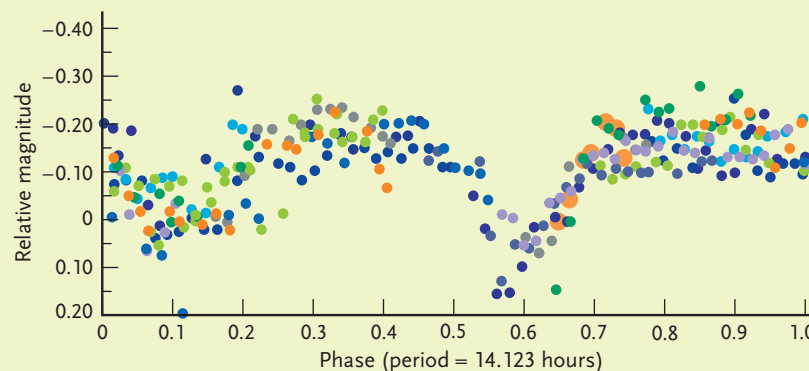


After using a Fourier analysis, Warner extracted a 3.16640-hour periodicity — the asteroid's rotation period.



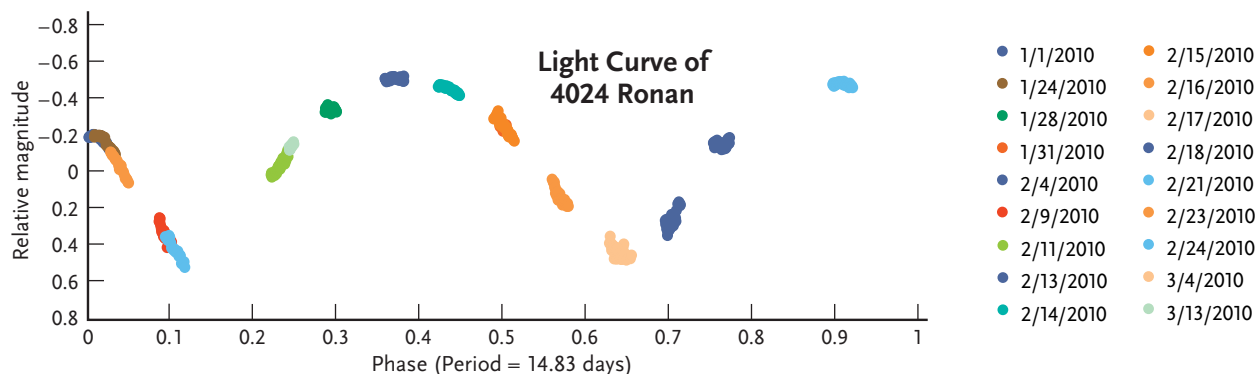
After subtracting the second light curve from the first, the telltale sign of a binary asteroid (with a 14.123-hour orbital period) becomes apparent. The shallower dip is caused by the smaller asteroid passing in front of the larger one and the deeper dip comes from the smaller asteroid passing behind its counterpart. The depth of these events shows that the larger asteroid has about three times the surface area of its satellite. The fact that the light curve is not flat between events indicates that the satellite is aspherical.

SOURCE: BRIAN WARNER



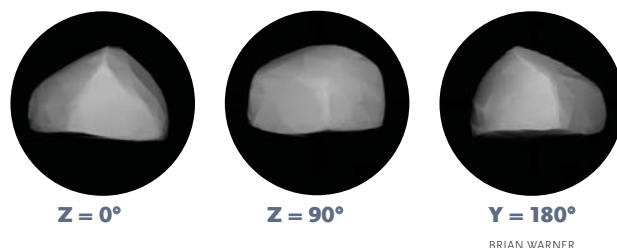
Dates of Observation

• 10/2/2008	• 10/17/2008	• 11/2/2008	• 11/22/2008	• 12/27/2008
• 10/3/2008	• 10/25/2008	• 11/7/2008	• 11/24/2008	• 12/28/2008
• 10/5/2008	• 10/27/2008	• 11/8/2008	• 11/25/2008	• 12/30/2008
• 10/7/2008	• 10/29/2008	• 11/9/2008	• 12/21/2008	• 1/3/2009



ULTRA-LONG PERIOD Above, Stephens and Warner found that asteroid 4024 Ronan has a long rotation period: about 356 hours (14.83 days). This exceptionally long period might be due to spindown from the YORP effect.

SHAPE MODEL Right, Using light curves by Warner and Stephens, Warner derived these shape models for asteroid 386 Siegena, which is about 165 kilometers across.



Studies by Pravec, Warner, and others, now suggest that the spin-up caused by the YORP effect is the dominant mechanism for the formation of small binary asteroids. As the rotation rate of a small, rubble-pile asteroid approaches the spin barrier, it sheds mass, spawning a satellite.

One of the first proofs of the YORP effect was obtained by Stephen Slivan. Using data collected at Wellesley College and contributed by myself and other amateurs, Slivan demonstrated that members of the Koronis asteroid family fall in two distinct groups, each with their own rotational rates and pole orientations. This work has led to several papers in the planetary sciences journal *Icarus* where I was listed as a coauthor. This success motivated me to take my work to a much higher level!

Slivan's analysis used a mathematical process called "light-curve inversion," which determines the pole orientation and approximate shape for an asteroid based on its light curve. Such models are often used in conjunction with radar, adaptive optics, and occultation observations to precisely determine the size, shape, and orientation parameters. *MPO LCInvert* software gives amateurs an opportunity to use light-curve data to generate their own models, nearly a dozen of which have been published in the *Minor Planet Bulletin*. This is an exciting way that amateurs can

"see" an asteroid's shape with backyard telescopes.

Another area for amateur asteroid research is following up on the light curves of long-period asteroids, those with rotational periods exceeding 24 hours. Traditionally these objects have suffered from an observing bias, since professional observatories can rarely schedule enough nights to determine an accurate light curve. And amateurs have overlooked them in favor of objects that produce a complete light curve in a single night.

Until recently it was thought that only a few long-period asteroids existed. With better statistics it's becoming apparent that about a quarter of all small asteroids have long rotational periods. The seemingly ubiquitous YORP effect may be involved in this phenomenon by spinning down some asteroids. Astronomers are still investigating why they linger so long in the doldrums of slow rotators.

I have also taken an interest in Trojan asteroids, which proceed or follow Jupiter in a somewhat stable orbit. Since they are trapped in the giant planet's Lagrangian 4 and 5 points, they may have been locked in their orbits since the "Great Migration," when the gas giants arrived at their current orbits (*S&T*: September 2007, page 22). Because Trojans are generally dark objects, they are not within easy reach of modest-sized telescopes and so have not been studied as extensively as main-belt asteroids. Many questions remain: How old are they? Are they homogeneous population(s)? How has the solar system's evolution affected them? With just a couple seasons of work, my observations have found a substantial percentage of the known rotational periods for this class of objects.

Download a FREE BONUS PODCAST



To listen to a podcast interview with author Robert Stephens, visit SkyandTelescope.com/asteroid

On the Horizon

Not everyone has the desire or temperament for scientific contributions. For those of us who do, contributing to science, even in a small way, can give a strong sense of purpose to our astronomical observations. Observing asteroids to help refine their physical properties provides that purpose as well as important clues to the evolution of our solar system.

Isaac Newton wrote in his memoir, "I do not know what I may appear to the world, but to myself I seem to have been only like a boy playing on the sea-shore, and diverting myself in now and then finding a smoother pebble or a prettier shell than ordinary, whilst the great ocean of truth lay all undiscovered before me." We may seem like we are diverting ourselves with pebbles, be they space rocks or stars in the sky, but they all contribute to the truth before us. The process ends up being an enjoyable path of self-discovery and development, resulting in our small contribution to this truth. ♦

California-based observer **Robert Stephens** won the American Astronomical Society's 2010 Chambliss Amateur Achievement Award for the research described in this article.



STAR TRAILS OVER GMARS Stephens captured this long exposure of star trails over the GMARS dark-sky site in April 2009. GMARS has 12 amateur observatories.

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M13 image taken using an 8" Meade SCT by astronomy hobbyist David Rosenthal (<http://pbase.com/djrlx90>)



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Sagitta, the Arrow

Clusters and nebulae feather this tiny constellation.

*Further up there is another Arrow shot — alone without a bow.
— Aratus, Phaenomena*

AN ARROW FROM the bow of Sagittarius, the Archer, seems to have fallen into the frothy river of the Milky Way and been borne northeast where it fetched up against Vulpecula, the Fox, as he fords the stream. In his 1910 book *Round the Year with the Stars*, Garrett P. Serviss writes that Sagitta is “interesting when viewed with an opera-glass for its row of little stars from which, as from a maypole lying horizontally, depend loops of still smaller stars looking like garlands.” Or perhaps Sagitta has just snagged some riverweed along the way.

The showpiece of Sagitta is the loosely concentrated globular cluster **Messier 71**. My husband’s 7×42 binoculars show a small faint fuzzball that lies halfway along and a little below a line connecting the markedly orange stars Delta (δ) and Gamma (γ) Sagittae (see page 45 for another binocular view). Off the western side of M71, a

line of three stars increases in brightness from southwest to northeast. The brightest, 9 Sagittae, is 6th magnitude.

Through my 130-mm (5.1-inch) refractor at 23×, M71 displays a faint 7′ halo with a dim star just south of the bright 2½′ core. The cluster is lovely at 117×. At least 20 diamond-chip stars embellish the fleecy haze, some of the brightest in an east-northeast to west-southwest line across the center. At 164× the cluster has the sparkly appearance of many stars just on the verge of resolution.

At a distance of 13,000 light-years, M71 is the third nearest globular cluster included in Charles Messier’s catalog. It’s topped only by M4 in Scorpius at 7,200 light-years and M22 in Sagittarius at 10,000 light-years.

The only other globular cluster gracing Sagitta is **Palomar 10**. It’s excruciatingly faint in my 130-mm scope at 164×, requiring averted vision and a serious investment of time to merely detect its presence. Averted vision is the practice of looking off to one side of an object to allow its light to fall on a more sensitive area of the eye’s retina. I need to find just the right “sweet spot” to see Palomar 10. The best place toward which to avert one’s gaze varies from person to person, so experiment to find your own sweet spot.

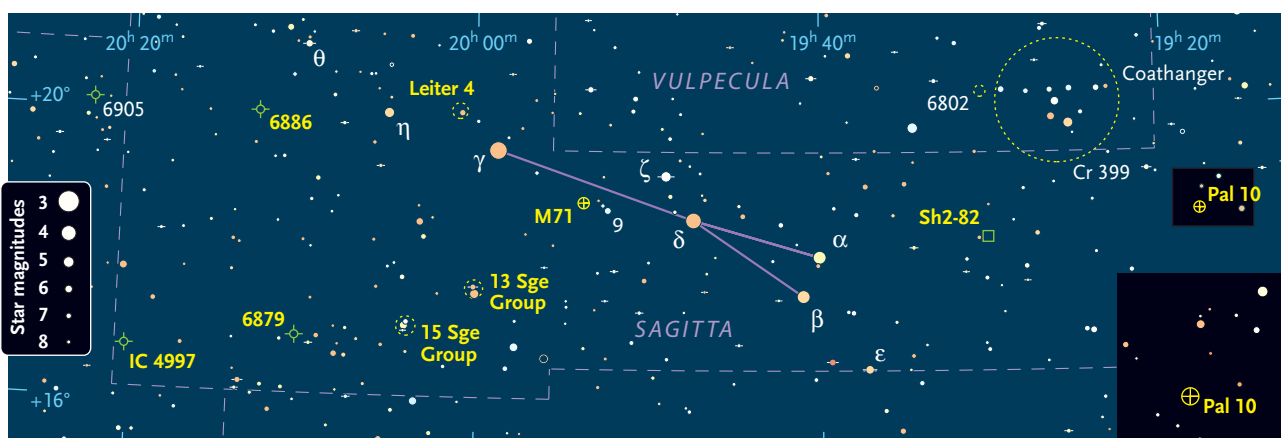
A 20′ line of five 10th-magnitude stars south of Palomar 10 helps pin down its position, and a 13th-magnitude star sits off the cluster’s northeastern edge. My quick eye-piece sketch indicates that the insubstantial glow appeared less than 1′ across. The apparent size of Palomar 10 triples through my 10-inch reflector at 187×. The cluster’s slightly grainy haze contains a few extremely faint points of light. These must be star clumps or foreground stars, since the brightest cluster members are perhaps 17th magnitude.

Despite appearances, Palomar 10 is intrinsically brighter than M71. Although it’s 6,000 light-years farther away, the added distance alone dims Palomar 10 by only 0.8 magnitude. However, the cluster is also heavily obscured. Palomar 10 suffers 5 magnitudes of extinction as its light is absorbed and scattered by intervening dust grains in space, while M71 only loses 0.8 magnitude to the same effect.

Messier 71 is very loose and easy to resolve for a globular cluster. For many years astronomers weren’t sure if it was an unusually dense open cluster or an unusually sparse globular.



JOSEF POPPEL / STEFAN BINNEWIES / RAINER SPARENBERG



Sagitta has several nice asterisms, two of them splashy and colorful. I viewed both of these bright asterisms through my 130-mm refractor at 37×.

The first is the **13 Sagittae Group**, most of whose members fan northward from its namesake star. I see a dozen stars in this 12' × 6½' group, the brightest in shades of gold and orange. The wide star pair east-south-east of 13 Sagittae is the double **H IV 100**, first noted by William Herschel in 1782. They appear gold and white in my 10-inch scope.

The second is the **15 Sagittae Group**, which covers nearly 13' and embraces pale yellow, yellow, and gold stars. The 8.7-magnitude yellow star near the southern edge has a 9.5-magnitude companion 5.4" to its south-southwest. They form the double star **Σ2622**, one of many discovered in the 19th century by Friedrich Georg Wilhelm von Struve. He described the components of this duo as *sub flava* and *sub cærulea* (yellowish and bluish). The dimmer star looks merely white to me.

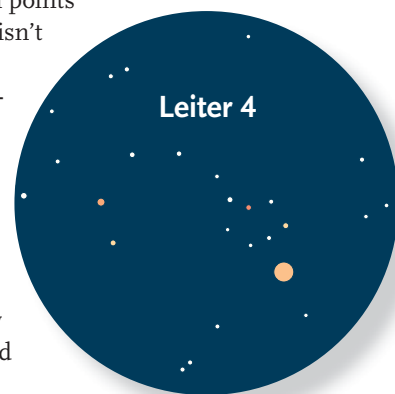
Appropriately enough, Sagitta contains the cute, arrow-shaped asterism **Leiter 4**. It shares the field with Gamma, ¾° southwest, in my 130-mm refractor at 63×. The brightest star is gold and marks the point of the arrow. Six more stars fill the arrowhead, which points south-southwest. The arrow's shaft isn't straight, but rather a 7-star arc that curves back on itself to form a semi-circle. When German amateur Frank Leiter chanced upon this asterism, he saw the semicircle and three of the arrowhead's stars as a hook in the sky. What image captures your imagination?

Sagitta harbors several planetary nebulae. The three brightest, located in eastern Sagitta, are quite small.

NGC 6886 measures about 10" × 5" and is found 1¾° east of Gamma. It marks the northeast

corner of a 1½' isosceles triangle formed with two stars of similar magnitude. The nebula is nearly stellar through my 130-mm scope at 63×, while at 117× it shows a tiny blue-green disk. In deep images, NGC 6886 resembles the planet Saturn, but even with my 15-inch reflector at high power, I can't see the ansae that elongate it southeast-northwest. Instead, the bright part of the nebula simply seems to be surrounded by a round glow. Can you spot the faint outer lobes?

NGC 6879, the faintest of the three planetaries described here, is 8" across. Look 1° east-southeast of 15 Sagittae for a colorful group of 6th- to 8th-magnitude stars outlining a 40' Christmas tree. The tree's tip points east toward



Adornments on the Arrow

Object	Type	Magnitude	Size	RA	Dec.
Messier 71	Globular cluster	8.2	7'	19 ^h 53.8 ^m	+18° 47'
Palomar 10	Globular cluster	13.2	4'	19 ^h 18.0 ^m	+18° 34'
13 Sge Group	Asterism	5.0	12' × 6.5'	20 ^h 00.0 ^m	+17° 37'
15 Sge Group	Asterism	5.3	12.5' × 10'	20 ^h 04.0 ^m	+17° 04'
Leiter 4	Asterism	6.4	7' × 5'	20 ^h 01.1 ^m	+20° 03'
NGC 6886	Planetary Nebula	11.4	10" × 5"	20 ^h 12.7 ^m	+19° 59'
NGC 6879	Planetary Nebula	12.5	8"	20 ^h 10.4 ^m	+16° 55'
IC 4997	Planetary Nebula	10.4	2.5" × 1.5"	20 ^h 20.1 ^m	+16° 44'
Sh 2-82	Bright Nebula	—	9'	19 ^h 30.4 ^m	+18° 17'

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



Above: The red glow of Sharpless 2-82 is due to hydrogen-alpha emissions and the blue is from reflected starlight. North is to the upper left. **Left:** Finnish amateur Jaakko Saloranta sketched Sharpless 2-82 as seen through his 8-inch reflector at 92× with a UHC filter.

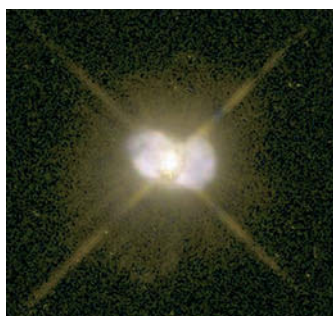
a 7.6-magnitude star, the brightest in the area. This star is the southernmost of four that make a 15′ kite flying westward. NGC 6879 is 5′ west of the kite’s top. In a rich starfield, this tiny planetary stands out as the “star” that looks slightly fuzzy and blue-gray through my 130-mm refractor at 63×. It’s still very small at 117× but reveals a brighter center. It responds well to a narrowband nebula filter and even better to an O III filter, but a hydrogen-beta filter hampers the view.

About 2° northeast of Rho (ρ) Aquilae, **IC 4997** is the smallest but brightest member of the trio. Through my 130-mm scope at 37×, IC 4997 is the second-brightest and easternmost “star” of a 2′ obtuse triangle. At 164×

this minuscule bluish nebula seems to have a brighter center. In my 15-inch scope at 247×, the planetary appears slightly elongated northeast-southwest with a stellar point at its heart. Hubble Space Telescope images of IC 4997 show two bulbous lobes crowding opposite sides of its 12.2-magnitude central star.

The nebula **Sharpless 2-82** both reflects starlight and glows with its own light. Sweep 2° west from Alpha (α) Sagittae to a ½° trapezoid of 7th- and 8th-magnitude stars with its shortest side east. The brightest part of the nebula is 6′ west of the northernmost star, which has a golden hue. Sh 2-82 is a readily visible 5′ mist through my 130-mm refractor at 63×. The 10th-magnitude star near its center supplies the energy that makes the nebula glow, and a fainter star sits 1′ east-southeast. Through my 10-inch reflector at medium to high magnification, fainter nebulosity reaches north from the eastern half of the main mass to a 10.7-magnitude star. A narrowband filter makes the bright region stand out better but erases the upstretched arm.

Sh 2-82 is sometimes called the Little Cocoon or the Little Trifid for its resemblance to IC 5146 in Cygnus and Messier 20 in Sagittarius. ♦

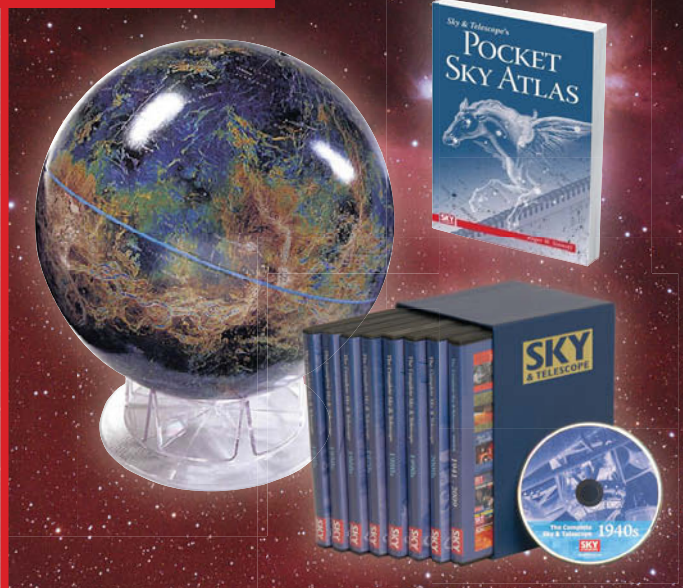


These Hubble Space Telescope images show the outer lobes of the planetary nebulae NGC 6886 (left) and IC 4997 in great detail.

Sue French welcomes questions, comments, and suggestions at scfrench@nycap.rr.com.

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Ed's Tracking Travelscope

This compact wonder might be the ultimate ultra-portable Dobsonian.

WHEN I CAST THE NET for last year's travelscope challenge (March 2009 issue, page 72), I hauled in a wonderful assortment of highly portable 8-inch Dobsonian telescopes. If nothing else, the response showed how many creative ways readers found to solve the same problem. After the most-compact scopes were described in the August 2009 issue (page 62), I continued to receive e-mails from telescope builders who had created new instruments. One of the nicest was crafted by Ohio ATM Ed Jones, who readers may recall built the Chieftspiegler telescope featured in the November 2008 issue (page 87).



Ed Jones's 10-inch travelscope fits in an airline overhead-luggage compartment, yet includes a motorized tracking platform. *Inset:* The secondary-mirror adjustment is accomplished with a clever spring-loaded tilt mechanism.

Ed upped the travelscope ante by building a 10-inch reflector with a raft of nifty features. It breaks down into a $14 \times 15\frac{1}{2} \times 9\frac{3}{4}$ -inch package weighing just 34 pounds, which qualifies it as carry-on luggage on most airlines. The scope is also remarkable for including a motorized tracking platform!

The mount has three main components. There's the motor-drive assembly and south bearing block, both of which bolt to the top of the scope's carrying case. Riding on these is the modified ground board that the scope sits on. For portability, this part folds up for storage inside the case. Only the motor block and the scope's truss poles don't fit in the case. Ed says that he gets about an hour of tracking before the platform needs to be reset.

There are two features at the tube's front end that caught my attention. One is the unusual three-vane spider assembly that supports the scope's secondary mirror. You're probably wondering, what's with all the wiggles? The wavy vanes are designed to suppress the diffraction spikes around bright objects that arise from straight-vaned spiders. There are a variety of ways to accomplish this. I often use a single curved support (December 2009 issue, page 68), but any curved vane will produce less-distinct spikes than a straight one.

The second feature I like is the novel way Ed adjusts the tilt of the secondary mirror. Look closely at the inset photograph, and you'll see what's going on. The mirror is attached to a strip of aluminum bent to a 45° angle. The section of the strip that joins to the spider hub has a small thumbscrew that tilts the mirror toward or away from the focuser. The bolt attaching the aluminum strip to the hub has an acorn nut (drilled through), which allows the assembly to rock back and forth when the thumbscrew is turned. There's a small leaf spring that loads the strip against the acorn nut. Neat.

Ed says the instrument has turned out to be a great planetary scope and that stars are perfect pinpoints — without spikes! You can read and see more about it at his website <http://home.fuse.net/eljones>. ♦

Contributing editor **Gary Seronik** has built numerous telescopes, including 8- and $12\frac{3}{4}$ -inch travelscopes featured on his website, www.garyseronik.com.

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Beneath the Shroud of Venus

With careful planning, amateurs can map the surface of our nearest neighbor.

DANIELE GASPARRI

Despite being the closest

planet to Earth, Venus remains an enigmatic world to us today. Whereas Mars, Jupiter, and Saturn captivate observers as they traverse the ecliptic each year, Venus never strays far from the Sun, and is rarely visible in a dark sky. Its surface is permanently shrouded from view by thick clouds of sulfuric acid, revealing only faint streaks to imagers using color filters. The planet is also subjected to a runaway greenhouse effect, which heats its surface to hellish temperatures exceeding 450°C (840°F).

These conditions have one little-known benefit for astronomers willing to probe deeper into Venus's thick atmosphere. When the planet is close to inferior conjunction, amateurs can capture thermal emissions from its hot surface using CCD cameras and special filters. For a brief period, we can *see* Venus's surface!

As Venus closes in on inferior conjunction this month, Southern Hemisphere planetary imagers may want to try recording the elusive thermal emissions visible on the planet's nightside. Last year Daniele Gasparri captured a series of images in his attempt to map surface features usually hidden by the planet's opaque clouds; his best result is shown at right. Compare his image to the topographic map recorded by NASA's Magellan spacecraft in the early 1990s shown to the left. Unless otherwise noted, all images are courtesy of the author.



TOPOGRAPHIC MAP COURTESY OF NASA

Recording the Light of Heat

During Venus's 2004 western elongation, Christophe Peller of France was the first amateur to image the planet's nightside thermal emissions at near-infrared wavelengths (*S&T*: September 2004, page 20). Key to his success was his use of a 16-bit CCD camera and a near-infrared filter with a transmission peak at 1,000 nanometers (1 micron). In this part of the spectrum, the planet's atmosphere becomes more transparent. Additionally, the high temperature of the planet's surface causes it to glow faintly in this spectral region. The combined effect allows these thermal emissions from the surface to escape into space.

In recent years, a number of amateurs have also captured this phenomenon, demonstrating that thermal emission from Venus's surface regularly penetrates the planet's thick cloud cover. The best images display large dark regions, whose origins were uncertain, but perhaps might be associated with known surface features.

In March 2009, Venus passed roughly $8\frac{1}{2}^\circ$ north of the Sun during its inferior conjunction. This apparition presented me with a rare opportunity to record the planet's nightside in a dark sky for an extended period from my location in rural Italy. I decided to undertake a campaign to image the planet's nightside, with the goal of recording data on consecutive nights to determine if these large dark and light regions rotated with Venus's known surface.

My equipment for this project consisted of a Celestron C9.25 Schmidt-Cassegrain telescope, an SBIG ST-7XME CCD camera, and a Schott RG1000 filter. I chose the CCD camera over the popular video cameras used by most planetary imagers today due to the ST-7XME's 16-bit images, high sensitivity, and extensive dynamic range, which allow me to record surface details with a much higher signal-to-noise ratio than is possible with 8- or 12-bit video cameras. The ST-7XME has a non-antiblooming chip that records linear data, allowing accurate calibration and analysis of the resulting pictures.

A long period of clear evening skies allowed me to record images for a full 7-day stretch, from March 12 to March 18, 2009. I collected 1,700 single frames in all, or about 240 per day, with exposures ranging from 2 to 10 seconds, depending on the brightness of the sky.

Despite the sunlit crescent being more than 20,000 times brighter than the unlit region, every frame revealed the faint glow of the planet's unlit portion. The visibility of this elusive detail was limited mainly by the sky brightness, not by the dayside glow. Unlike capturing Venusian cloud features at ultraviolet wavelengths, thermal emissions from Venus's unlit regions cannot be recorded when the Sun is above the horizon.

To avoid mistaking internal reflections within my telescope for actual surface features, I rotated the camera frequently between images, and also moved the position of the planet within the camera's field of view.

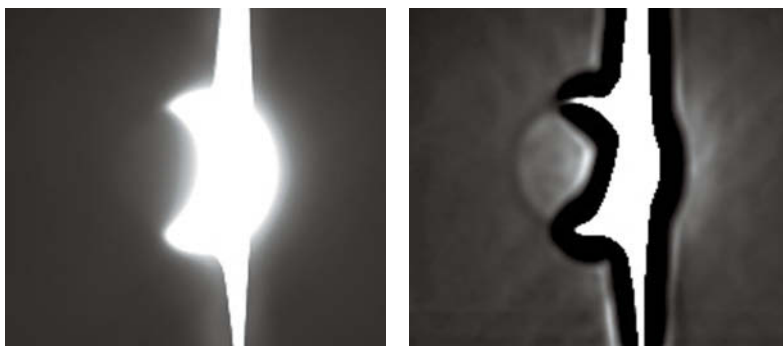


Author Daniele Gasparri poses with the Celestron C9.25 Schmidt-Cassegrain telescope he uses to image Venus.

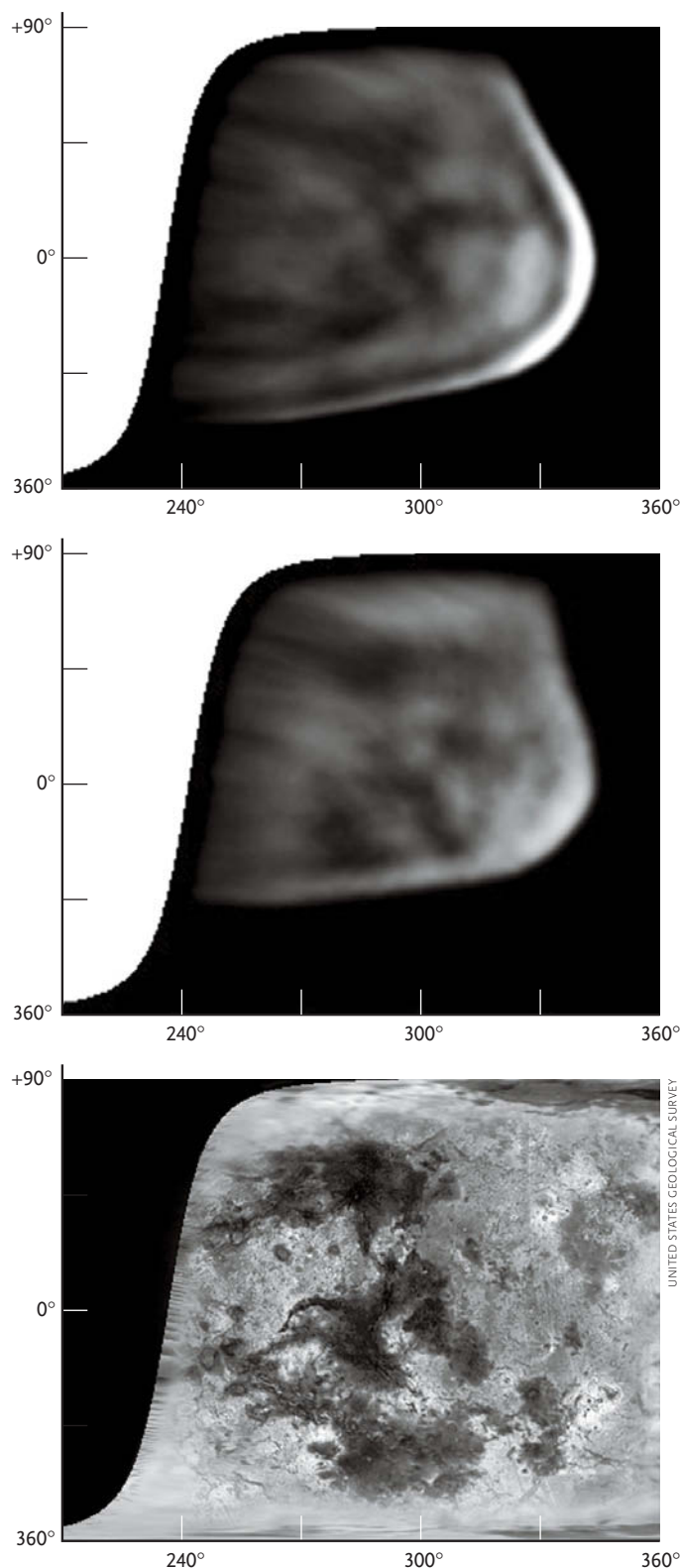
Separating Land and Sky

Once I finished the project's image-acquisition phase, I recorded a number of flat-field and dark-frame calibration images, and averaged every set to create a master calibration frame for each. These frames were crucial to the campaign's success. Because the surface details were only a few hundred counts above the background of each image, I needed to carefully map and remove hot pixels and sensitivity variations within the CCD itself. Calibration using these dark- and flat-field images accurately removed these imperfections.

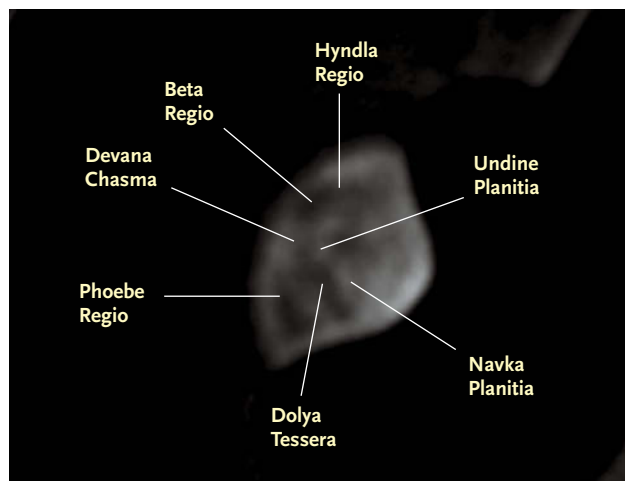
For each day's data, I created two separate images made by averaging 150 frames. I then processed these using similar steps, and monitored the results to avoid introducing artifacts. I achieved the best processing using



Using a Celestron C9.25 telescope, an SBIG ST-7XME CCD camera, and a Schott RG1000 near-infrared filter, Gasparri recorded Venus as it neared inferior conjunction. At left is the stacked result taken on March 17, 2009, which basically shows the planet's highly overexposed sunlit side. The heavily sharpened image on the right shows subtle detail on the planet's unlit (left) side.



During the period of March 12 through 18, 2009, Venus rotated roughly 7°. Because the hottest regions on Venus are located at low elevations, re-projecting the images as a cylindrical map allows direct comparison to the digital elevation map produced by NASA's Magellan spacecraft.



Highland features such as Beta Regio, Hyndla Regio, and Phoebe Regio appear darkest in Gasparri's image due to their cooler temperatures. The low-elevation regions of Devana Chasma, Undine Planitia, and Navka Planitia are bright as expected.

a combination of unsharp mask and a few dozen iterations of Lucy-Richardson deconvolution. I then averaged the two images together to create the final version for each dataset.

After this initial processing, I was pleased to see the nightside disk swarming with dark regions — areas with lower-than-average thermal emissions. In theory, these regions should correspond to mountains and highlands, which (just as on Earth) are much cooler than valleys and low-altitude plains. (Venus's temperature drops about 8°C, or 14°F, for every kilometer increase in elevation.)

Upon closer analysis of my images, I noticed two predominant kinds of details: small-scale, high-contrast spots, roughly consistent on all seven days' images, and large, low-contrast features, which varied somewhat from day to day.

At first I assumed that all the details were surface features, but I quickly remembered that the atmosphere isn't *completely* transparent as seen through my RG1000 filter. These day-to-day changes might be due to a rapidly rotating cloud system polluting my images. To better interpret my data, I first measured the rotation period of smaller spots. The result was clear: the spots were rotating as a solid body with a period of about 240 days, matching the known rotational period of Venus's surface. My next step was to find some way to remove the unexpected cloud contamination and generate a crude topographic map that I could compare with altimetry data recorded by NASA's Magellan spacecraft in the early 1990s.

Professional astronomers using specialized cameras while imaging Venus remove this residual cloud contamination by recording separate data at longer wavelengths, and then they subtract these images from the 1-micron frames. Unfortunately, my camera's silicon CCD chip is

blind to wavelengths greater than 1.1 microns, so I had to find another way to remove these clouds from my images. The solution turned out to be surprisingly simple. I created a median of the raw, stacked images taken on March 12th, 13th, and 14th. This stacking operation rejects areas of each image that don't appear consistently in each frame. Because Venus only rotates 2.4° over the course of three days, the residual cloud features disappeared in the resulting median-combined image. Voila! Doing the same to the image sets of March 16th, 17th, and 18th left me with two final images showing the similar surface features with a strong signal-to-noise ratio.

Comparison to Magellan

Based on the laser-altimetry map generated by the Magellan orbiter, I realized that surface features spanning latitudes -30° to +60°, and longitudes 250° to 330°, should be visible in my images. I generated an approximate cylindrical projection map of both my final images using the freeware *WinJUPOS* (www.grischa-hahn.homepage.t-online.de/astro/winjupos/index.htm), and then compared them to Magellan's data. It was immediately apparent that my experiment was a success — dark spots visible in my images corresponded quite well with highlands on Venus's surface, while the bright areas matched the lowlands. I had definitely captured the planet's surface!

I was able to identify the large features Beta Regio and Phoebe Regio; both appear quite dark because they're located at several kilometers elevation. Closer examination revealed the highlands of Hyndla Regio, Asteria Regio, and Dolya Tessera, with its peculiar oblong shape. In contrast, Devana Chasma, Navka Planitia, and Undine

Planitia are brighter due to their low elevations.

I was able to extract an additional data point from my images — one related to the cloud contamination at 1 micron. As I discovered how to remove this point from my data, it occurred to me that it should be possible to separate it from the surface image and display daily cloud movement.

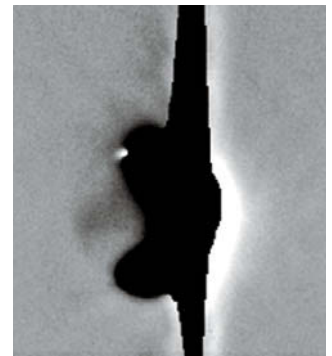
To highlight the presence of the clouds, I divided two images taken on consecutive (or close) days using pixel math. This process removed the surface details from the image, and left only the transient objects from the 24-hour period visible. If no clouds were present, or their movement was similar to that of the surface, the resulting image would have lacked any features.

The best results came from using images taken on March 16th, 17th, and 18th. In these divided images, surface details disappeared completely as expected, leaving behind large-scale features produced by differences in the planet's atmospheric transparency during those days. The resulting images displayed low-level clouds located at altitudes between 30 and 40 kilometers (19 and 25 miles).

Future Potential

Venus's nightside isn't only a curious phenomenon that we can image to prove our abilities. There's real potential for ongoing scientific research — with a sensitive camera and a dark sky, it's possible to build a global map of the surface with moderate resolution when the dayside crescent is very thin. This technique also has the potential to detect volcanic eruptions and fresh lava flows (July issue, page 20), or other large-scale changes hinted at by recent studies. Amateurs concentrating on recording thermal emissions from Venus's surface can also support current and future spacecraft, calling attention to transient events that may escape the notice of orbiters with narrow-field-of-view cameras. There's plenty of science and a good challenge for anyone to get involved. ♦

Daniele Gasparri images the Sun, Moon, and planets from his balcony in rural Italy. See more of his photos and planetary maps at www.danielegasparri.com.



By subtracting images recorded on consecutive days, suspected surface features on the unlit (left) side are cancelled out, allowing the author to isolate subtle cloud features at altitudes of roughly 30 to 40 kilometers. The sunlit (right) side remains highly overexposed.



Capturing the thermal emissions from Venus's surface requires imaging the planet very close to inferior conjunction. When the crescent is very thin, long exposures of up to 10 seconds are required in a dark sky. This allows enough signal to register on your detector at the expense of overexposing the lit crescent.



► **HYDROGEN ACTION**

Pete Lawrence

With solar activity on the upswing, bright active regions, prominences, and dark filaments are again becoming a daily occurrence.

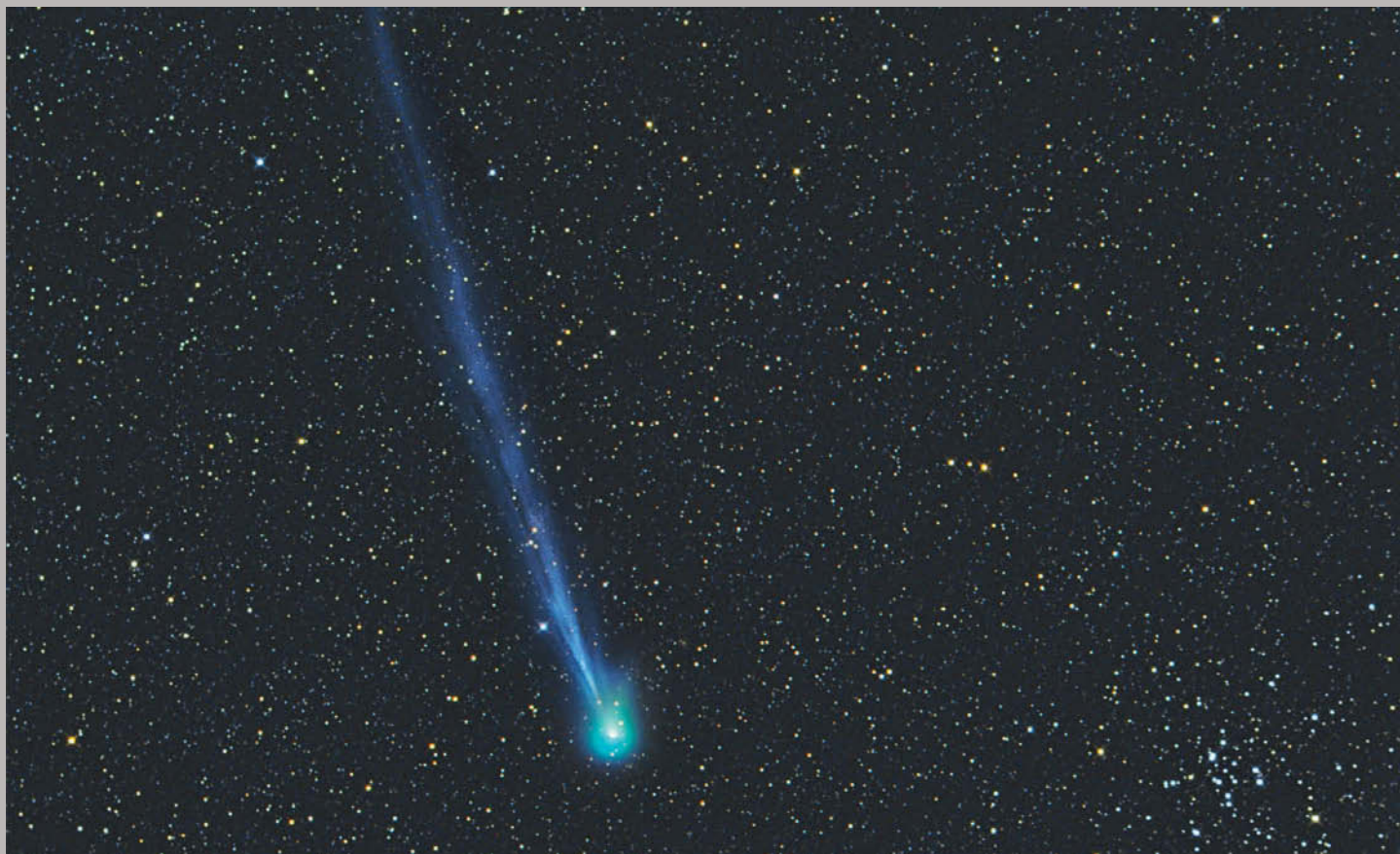
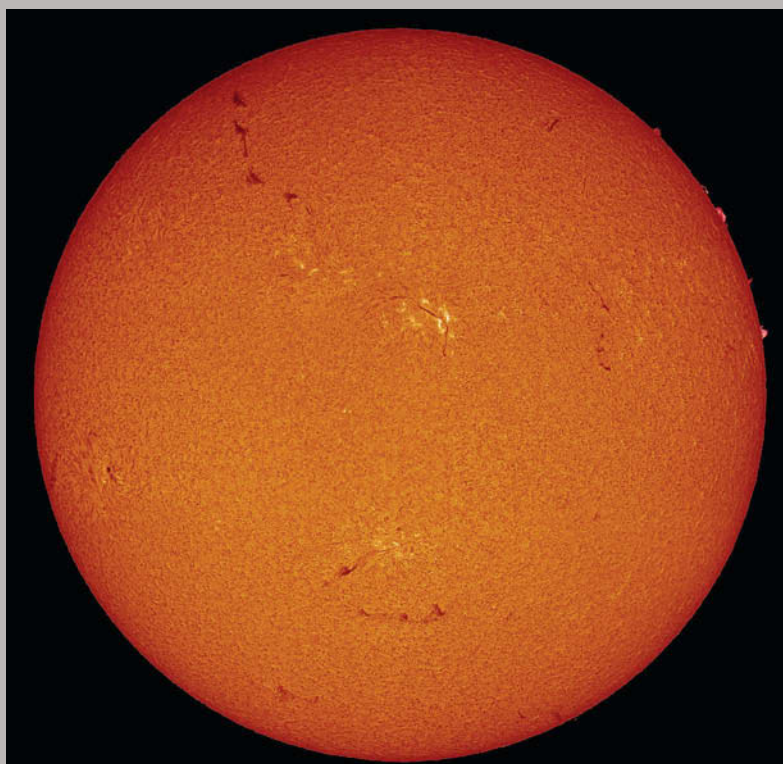
Details: Vixen FL102S refractor, Solarscope SF-70 hydrogen-alpha filter, and Lumenera SKYnyx 2-0 video camera. Mosaic of nine single frames recorded on June 28, 2010.

▼ **A WELCOME VISITOR**

Gerald Rhemann

Comet C/2009 R1 (McNaught) delighted early-morning observers in June as it brightened to naked-eye visibility and briefly sported a long, bluish ion tail.

Details: Astro Systeme Austria ASA8N-OK3 astrograph with SBIG STL-11000 CCD camera. Total exposure time was 26 minutes through color filters.



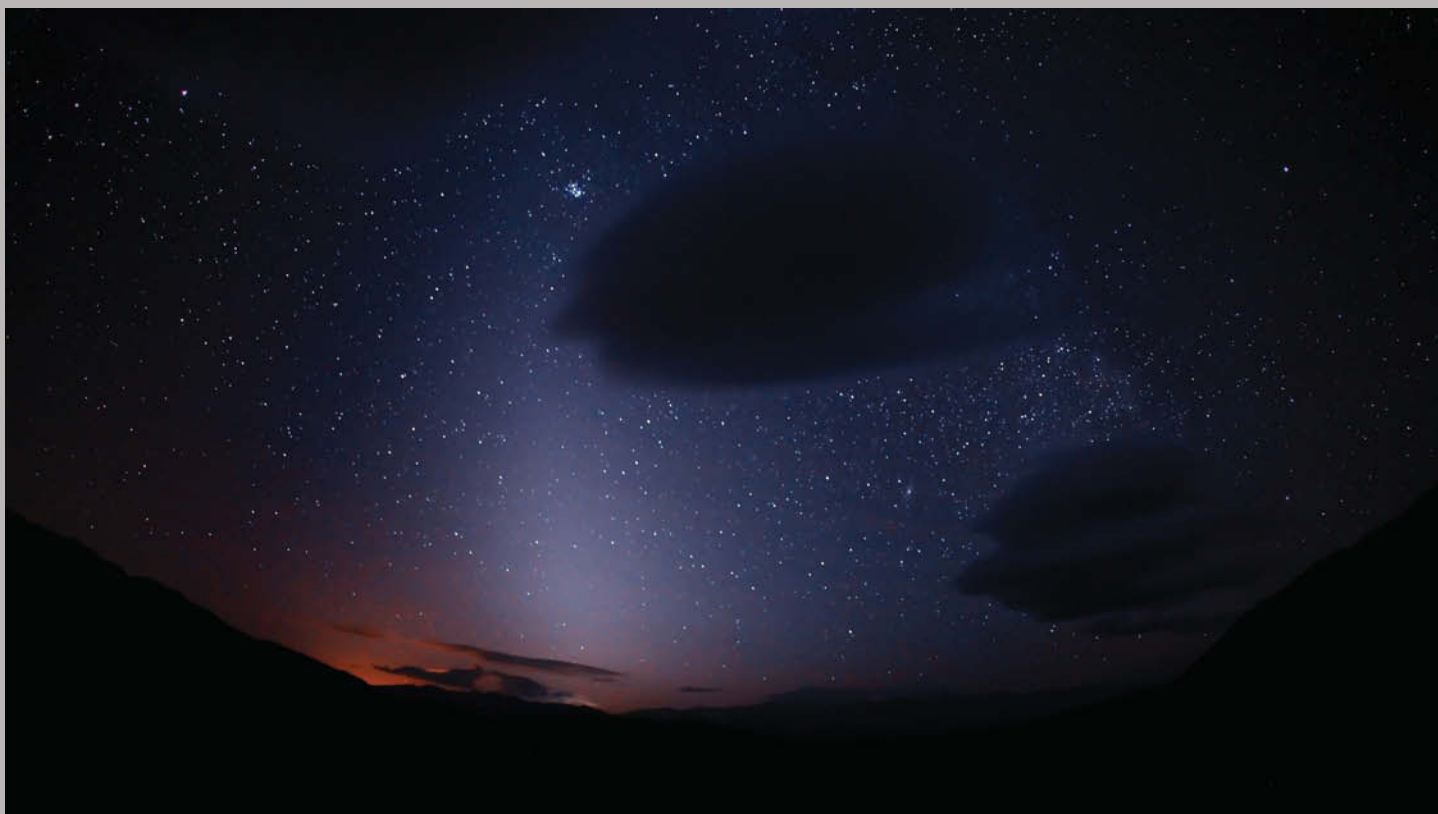


◀ YOSEMITE MOONBOW

Chunki Park

The fine spray produced by the Upper Yosemite Falls conspired with the full Moon to produce this sublime moonbow last June.

Details: Canon EOS Rebel XSi DSLR camera with 28mm lens. Exposure was 15 seconds at ISO 800.



▲ ZODIACAL NIGHT

Brian A. Morganti

This remarkable display of the zodiacal light was captured from the dark skies of Death Valley, California. Silhouettes of standing lenticular clouds frame the Pleiades at top and M31 at right.

Details: Canon EOS 5D Mark II DSLR camera with 10-to-24-mm zoom lens. Total exposure was 32 seconds at ISO 2500.

► A COLORFUL ECLIPSE

David Hough

Australian amateur David Hough captured the subtle range of colors visible on the Moon during the partial eclipse of June 26th.

Details: Meade 127ED refractor with a modified Canon EOS 40D DSLR camera. Combined exposures ranging from 2½ seconds to ¼2000 second, processed with Photomatix Pro. ♦



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Photograph courtesy of the NAIC-Arecibo Observatory, a facility of the NSF



unique contributions derived from Arecibo research and development.

Join us as we wind through the rainforest-blanketed karst terrain of Northern Puerto Rico. We'll get a sense of the massive physical scope of the Arecibo radio telescope. We'll boldly go where ordinary visitors are not permitted. NAIC scientists will update us about the radio astronomy, planetary radar discoveries, and climatology research at the observatory. From the monitoring of near-earth objects to cosmology, astrophysics, and global warming research, you'll gain insight into the vital activities at Arecibo. This optional six-hour tour includes transportation and entrance fees and costs \$175.

The Power and Progress of Radio Astronomy

Near Arecibo, Puerto Rico, the world's largest dish antenna points skyward and tunes us into the radio universe. Whether it involves probing the nearest asteroids or spotting the most distant galaxies, radio astronomy has created a crucial window into the cosmos — and it remains our most likely channel for contact with other civilizations. Join Ivan and find out how radio astronomy is moving to the next level at Arecibo and new facilities around the world. Discover a universe that is forever unseen by human eyes.

Celestial Navigation

This hands-on, six-hour class is about determining your exact position on Earth — using the celestial bodies visible in the sky as your references. This seminar will cover the tools used for celestial navigation, primarily the sextant and an accurate timepiece. The coordinate system of both the Earth and the sky will be explained as will the relationship between longitude and time. The navigator's traditional Noon Sight will be discussed and the procedures will be explained and demonstrated.

Tips and Techniques at the Telescope

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A Journey to the Center of the Milky Way

The greatest attraction of the tropical sky is not a single star or constellation but the view it affords of the center of the Milky Way. Shrouded in interstellar dust, the exotic environment at our galaxy's hidden core is only now being revealed with the power of space-based astronomy. This session puts Caribbean stargazing in perspective with a cutting-edge trip to the galactic center, where astronomers are hunting for dark matter, tracking the flight of hypervelocity stars, and peering over the event horizon of a supermassive black hole.



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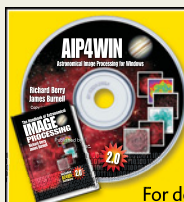
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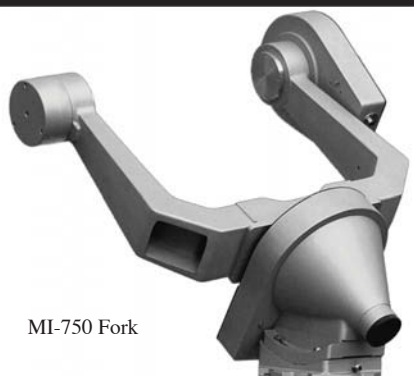


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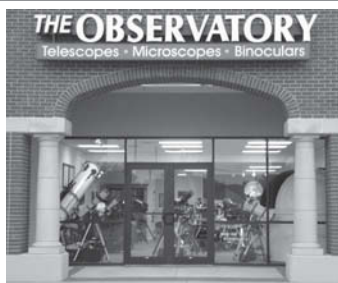
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In Space

It's easy to forget that our home planet is actually among the stars.

SPACE SHUTTLE launches are always bittersweet events for me. Like many other science-inclined American boys, I always wanted to be an astronaut when I grew up, and like so many others, that didn't happen. Instead, I grew up, earned a science degree in college, and went into teaching and writing. I got married and had two children, and the truth is that whatever childhood fancies may be, I would not trade these good things for a single trip to orbit.

Yet the desire is still there, every time I watch a launch and keep daily track of the activities of the shuttle and International Space Station astronauts as they carry out remarkable feats of engineering, science, and courage hundreds of miles above my head. Fortunately, my interest in amateur astronomy serves as a substitute for launching into the stars myself, and setting up my telescopes on dark nights gives me a personal window to the

environment the astronauts explore.

Like everyone else who has lived in the late 20th century, I heard the rhetoric about “spaceship Earth” without giving it much thought. Late one night, however, while doing some stargazing — I think I was meteor watching — the meaning of the phrase hit me. I lay back in a lawn chair, looking up at the sky above. With the surrounding trees disappearing at the edge of my vision, and my sense of gravity suspended as I lay in the cool night air, an illusion suddenly presented itself to me: I was no longer laying back, looking up at the stars, but rather pressed flat against a vertical surface, looking forward and out into the abyss of space.

“Of all the strange things that man has forgotten,” wrote my favorite author, G. K. Chesterton, “the strangest and most tragic lapse of memory is that by which he has forgotten that he is living on a star.” That night I remembered what Chesterton said, and realized that we have forgotten that Earth is actually itself a part of space, an exotic “star” whirling about a fantastic corner of the cosmos. When I’m observing I always try, and sometimes succeed, to capture that feeling again, and to perceive us as we really are: not bound to the ground with the heavens far above, but clung exhilaratingly to a spinning ball wheeling through space.

This is part of the romance of space travel: to “slip the surly bonds of Earth,” as the poet and aviator John Gillespie Magee, Jr., wrote, to be able to look out the window and see the stars go by — *to be in space*. Yet we often forget that the very ground we think of as solid beneath our feet is actually a chunk of rock hurtling through the galaxy. As individuals we do not need to launch ourselves into orbit aboard massive rockets in order to travel to space. All we need do is to look out into the space that surrounds us each night. Those who risk their lives by traveling to the stars do mankind a noble service, and it's only natural to admire their privilege. Yet, in the end, there's no real need for me to go “out there” to the stars; I'm already here among them. ♦

A graduate of the University of Notre Dame, Michael Baruzzini writes and teaches science in Colorado Springs, Colorado, where he enjoys stargazing under mountain skies.



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